Diversity of Odonata (Insecta) in lotic systems from Serra da Bodoquena, Mato Grosso do Sul State, Brazil

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ABSTRACT. Diversity of Odonata (Insecta) in lotic systems from Serra da Bodoquena, Mato Grosso do Sul State, Brazil. A systematic survey was carried out in four lotic systems from Serra da Bodoquena, the largest natural forests of the State, from August 2007 to November 2008. 548 specimens belonging to 33 species, distributed in 5 families were sampled. Libellulidae was dominant, with 13 species, followed by Gomphidae, Coenagrionidae, Protoneuridae and Calopterygidae.

KEYWORDS. Aquatic insects; Odonata community; Neotropical Region; species richness.

RESUMO. Diversidade de Odonata (Insecta) em sistemas lóticos da Serra da Bodoquena, Mato Grosso do Sul, Brasil. Um estudo sistemático foi realizado em quatro sistemas lóticos da Serra da Bodoquena, maior extensão de florestas naturais do estado, de Agosto de 2007 a Novembro de 2008. Foram coletados 548 espécimes pertencentes a 33 espécies, distribuídas em 5 famílias. Libellulidae foi dominante, com 13 espécies, seguida por Gomphidae, Coenagrionidae, Protoneuridae e Calopterygidae.

PALAVRAS-CHAVES. Insetos aquáticos; comunidade de Odonata; Região Neotropical; riqueza de espécies.

One of the biggest problems for conservation in tropical forests is the lack of information allowing the establishment of priorities and concentration of efforts on practical actions. This is largely due to low availability of faunal inventories, which limits the knowledge of the distribution and abundance of species (De Marco & Vianna 2005). Faunal surveys are necessary for conservation, ecosystem management and environmental protection, not only as representations of biodiversity but also from organisms serving as indicators of environmental conditions. Such surveys have been particularly important in relation to estimate species richness in highly diverse groups such as insects (Kremen *et al.* 1993).

In this context, Odonata have been increasing, in recent years, as a tool to assess the health of aquatic ecosystems. Odonata are widely distributed in aquatic ecosystems and spend long periods in an aquatic immature stage, thereby allowing for an evaluation of the stability of the community and the environment (Von Ellenrieder 2000; Osborn 2005). The Odonata include insects known as dragonflies or damselflies and have about 6000 species worldwide (Kalkman *et al.* 2008). In Brazil, the Odonata fauna is estimated at around 800 species (Souza *et al.* 2007), approximately 48% of all species of the Neotropical Region. Unfortunately, only 29% of Brazilian territory presents data on Odonata species richness (De Marco & Vianna 2005). Some of our knowledge comes from the state of Mato Grosso do Sul, where the known fauna of Odonata is about 150 species, with the most information from the Pantanal region (Longfield 1929; Santos 1944; Souza *et al.* 2002; Heckman 2006, 2008; Souza & Costa 2006; Pessacq & Costa 2007). However, even this state lacks faunal information from many portions.

Serra da Bodoquena is one of the priority areas for conservation in the state of Mato Grosso do Sul, concentrating the largest natural forest of this state. The region's rivers have clear waters, which facilitates the observation and the study of underwater flora and fauna. However, there are few inventories of its aquatic insects. In the region, the known fauna of Odonata is only about 80 species, with inventories primarily from the northern portion of Serra da Bodoquena (according to records from Zoology Collection of Universidade Federal do Mato Grosso do Sul (ZUFMS) and Santos 1944).

The current work presents the Odonata species composition and richness in four rivers at Serra da Bodoquena. These data enhance additional information about Odonata in the region and can support future conservation and management strategies in the area.

MATERIAL AND METHODS

Characterization of the study area. Serra da Bodoquena (21°08'02" to 20°38'26"S and 56°48'31" to 56º44'28"W) is located in the mid-southern portion of Mato Grosso do Sul

State, and extends from Miranda City to the north to Porto Murtinho City, to the south, including parts of Bodoquena, Bonito and Jardim (Ibama 2002) (Fig. 1). It is a plateau steeply sloping to the Pantanal, consisting by carbonatic rocks (Boggiani *et al.* 1998; Sallun-Filho *et al.* 2004). The region is characterized by a mountain-chain (Boggiani *et al.* 1998), with altitudes that vary between 450 and 800 m. Climate is temperate humid with hot summers and two well-defined seasons. The average annual temperature varies between 20 and 22°C and annual rainfall varies between 1300 and 1700 mm. The highest rainfall occurs during October to April, with periods of drought during May to September (PCBAP 1997). Native vegetation is formed by deciduous and semideciduous Atlantic forest, Cerrado and savanna (Furtado *et al.* 1982; Scremin-Dias *et al.* 1999). The hydrography of the region is characterized by limestone Rivers with high alkalinity and low turbidity. The region is part of the Paraguay River basin and is fed by streams such as the Salobra, Prata, Perdido, Formoso, Sucuri and Aquidaban.

The Serra da Bodoquena are located biogeographically in the central portion of a Neotropical Region called "Chaqueño" (*sensu* Morrone 2004), which includes continuous biomes (*e.g.* Caatinga, Cerrado, Chaco) to the Amazon and Atlantic forests. These biomes form a "Corridor of Savanna" between these forests and can therefore foster a heterogeneous biota comprised of both endemic taxa (of which there are relatively few in this area) as well as widespread species.

Collection sites. We sampled at four rivers in the Serra da Bodoquena: Perdido, Laudejá, Aquidaban and Salobra Rivers (Fig. 1). Two locations were sampled in each river, separated by 500 to 1000 m, with each sampling location covering about 50 m linear. Diversity in vegetation and structure among the sampling locations was designed to maximize potential Odonata species encounters.

Perdido River (21º26'59.04"S and 56º47'28.14"W – Fazenda Santa Maria do Rio Perdido – Municipality of Jardim) – This is a third-order river, a tributary of the Apa River. The points sampled consisted primarily of plant species characteristic of seasonal deciduous forest. The landscape around this forest is characterized by extensive areas of pasture. In this locality, the width of the river is about 20 m, with only marginal shading. The substrate is predominantly rocky, with coastal areas also containing sand and macrophytes (*Myriophyllum* sp.).

Laudejá River (21º07'12.62"S and 56º45'24.64"W – Fazenda Laudejá – Municipality of Bonito) – This is a fourth-order river, a tributary of the Perdido River. The sampling locations contained degraded riparian vegetation, and some area in regeneration, with late successional forest. It is surrounded by large area of pasture. One of the samples was located in an area with cattle and Cyperaceae. In this locality, the width of the river is about 15 m, with only marginal shading. The bottom substrate is predominantly sand, with little marginal vegetation. The depth varied according by season. In the rainy season (October to April), its average depth

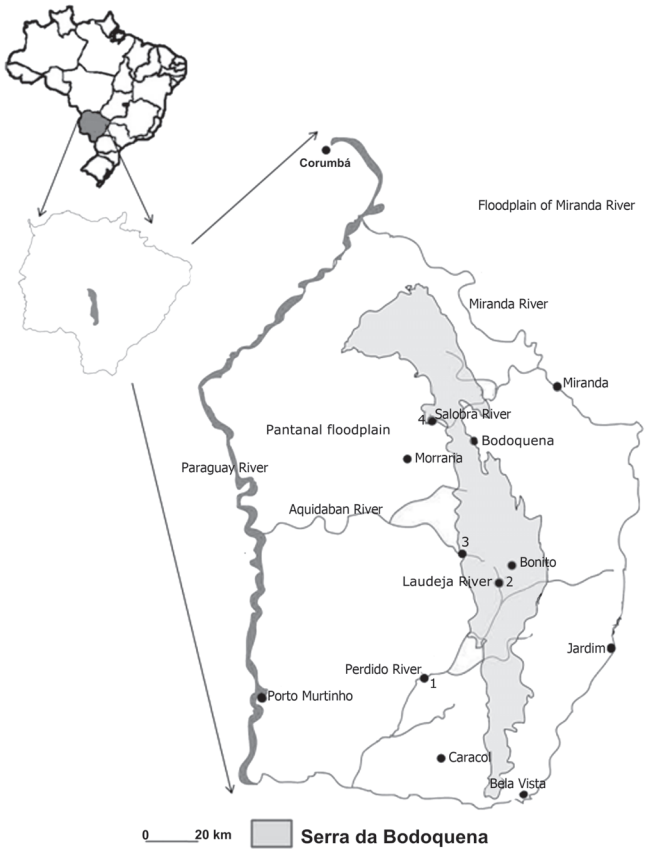

Fig. 1. Geographical location of the Serra da Bodoquena and the sampled transects: (1) Point of Perdido River, (2) Point of Laudejá River; (3) Point of Aquidaban River; (4) Point of Salobra River.

was 2.60 m. In the dry season (May-September), its depth reached the maximum of 0.80 m.

Aquidaban River (21º03'10.1"S and 56º55'36.5"W – Indian Village São João – Municipality of Porto Murtinho) – This is a third-order river, a tributary of the Paraguay River. This area was mainly composed of plant species of great size and characteristic of seasonal semi-deciduous forest and Cerrado. The surrounding landscape is characterized by forest in an advanced stage of regeneration. In this transect, the width of the river is approximately 8 m, with a great deal of shading, thereby restricting vegetational growth in the understory. The bottom substrate is composed of sand, gravel and leaf litter.

Salobra River (20º40'22.67"S and 56º44'49.46"W – settlement Canaan – Municipality of Bodoquena) – This is a third-order river, a tributary of the Miranda River. This sampling locality was quite degraded, with some areas completely without vegetation and others in early stages of regeneration. The landscape around this river is characterized by extensive areas of pasture, with some areas flooding during the rainy season, and pools and dams for cattle. The width of the river is about 15 m, with little shading, especially from trees of greater size. The bottom substrate is composed of pebbles and aquatic macrophytes attached to a sandy bottom.

Data collection. The inventory was carried out bimonthly, conducted between 30 August 2007 and 25 November 2008. For a comprehensive inventory, adult and immature species were collected. Adults were collected with entomological nets and packed live into rectangular envelopes (12 x 8 cm) of thin paper, following Lencioni's (2005) methodology. The sampling effort consisted of an active search, usually lasting between 9 and 15 hours of the day, always by the same person. The immatures were collected with a metal sieve with 30 cm diameter mesh and 5 mm openings. Immature samplings were standardized by set of 20 sieved samples. We particularly focused on collecting adults and larvae in the last instar in order to be able to determine sex. The immatures were brought alive to the laboratory to be reared to adulthood for accurate identification to species. The specimens were nominally recognized to the level of genus and species when possible. Identification of adults followed the works of Carvalho & Calil (2000), Costa *et al.* (2002), Lencioni (2005, 2006), Garrisson *et al.* (2006) and Heckman (2006, 2008), and identification of immatures followed the works of Carvalho *et al.* (2002) and Costa *et al.* (2004). The collected material is deposited in the Entomological Collection of the Museum of Biodiversity in the Universidade Federal da Grande Dourados (UFGD) and in the National Museum in the Universidade Federal do Rio de Janeiro (UFRJ), Brazil.

Analysis of data. The species richness (S) observed in each stream was calculated by aggregating the collected data from adults and immatures that were identified through comparison with emerged immatures or by association. To determine the species richness sampled in the Serra da Bodoquena, all data from the four rivers' transects were combined. The estimated number of species in each stream was calculated using the estimator Jacknife of 2nd order, because it is considered the best estimation method for aquatic environments (Melo & Froelich 2001). Species accumulation curves were plotted for each site and for all sites pooled. All analyses were performed with the aid of the statistical program EstimateS 8.0 (Colwell 2006).

RESULTS

Faunal composition. In Serra da Bodoquena, we collected 548 specimens of 33 species (see Table I), distributed in 5 families. Libellulidae was the most dominant, with 13 species, followed by Gomphidae (8 species), Coenagrionidae (7 species), Protoneuridae (4 species) and Calopterygidae (1 species). The most dominant genera were *Acanthagrion* Selys, 1876, *Erythrodiplax* Brauer, 1868, *Macrothemis* Hagen, 1868 and *Progomphus*, with 3 species each (*A. aeopilum*, *A. gracile*, *A. chararum, E. fusca*, *E. paraguayensis*, *E. umbrata*, *M. hemichlora*, *M. heteronyncha*, *M. imitans*, *P. intricatus*, *Progomphus* sp1 and sp2), following by *Neoneura* Selys, 1860 with 2 species (*N. ethela* and *N. sylvatica*).

The most abundant species was *Hetaerina rosea* (Calopterygidae) (Δ = 138), following by *Phyllocycla* sp. (Gomphidae) (Δ = 98) and *Argia indocilis* (Coenagrionidae) (Δ = 88).

Species Richness. The Aquidaban River showed the largest number of species (S = 25), followed by Salobra River (S = 20) and Laudejá River (S = 17). The Perdido River presented the lowest species richness (S = 11) (Table I).

The collector's curves (Fig. 2), when plotted for each river, show that in the first three expeditions, significant in number of species were added, generating a pronounced upward line. The collector's curve started its trend of stability from the 5th sample. The same is observed when the collector's curve for all sites is plotted (Fig. 3), where about 50% of species (17 of 33 species collected) in the Serra da Bodoquena were already collected by the 2nd or 3rd survey. The collector's curve started its trend of stability (asymptote) from the 5th sample, when about 75% of species were obtained (Fig. 3).

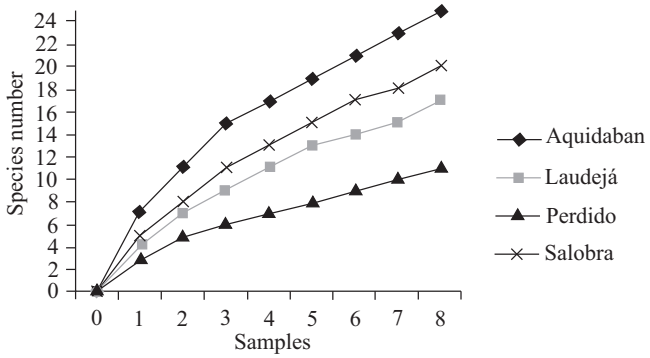

Fig. 2. Odonata species diversity observed curve in the rivers sampled in the Serra da Bodoquena-MS, Brazil (August 2007 to November 2008).

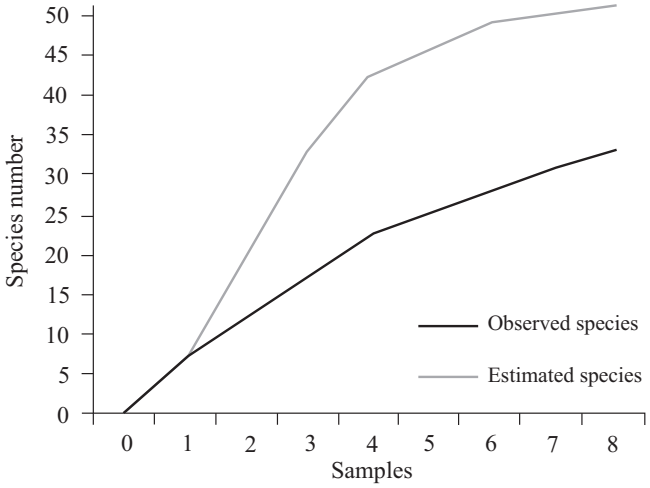

Fig. 3. Collector's curve (species observed) and the accumulation species' curve (species expected) of Odonata in the rivers sampled in the Serra da Bodoquena-MS, Brazil (August 2007 to November 2008).

Estimated Species Richness. The analysis of Jackknife 2nd estimated that the all species collected had reached a total of 51 species on the Serra da Bodoquena. As noted, Aquidaban River have shown the largest number of species (Sej = 41), followed by Salobra River (Sej = 33) and Laudejá

Table I. Odonata species from Serra da Bodoquena-MS, Brazil, with the number of collected individuals in each river (August 2007 to November 2008).

Species and families	Collected number of individuals in rivers				
	Perdido	Laudejá	Aquidaban	Salobra	Total
Calopterygidae					
Hetaerina rosea Selys, 1853	26	4	42	59	131
Coenagrionidae					
Acanthagrion aeopilum Tenessen, 2004	0	0	8	0	8
Acanthagrion graciale (Rambur, 1842)	0	0	0	4	4
Acanthagrion chararum Calvert, 1909	0	0	0	4	4
Argia indocilis Navás, 1934	19	8	36	25	88
Enallagma novaehispanie Calvert, 1907	5	1	1	14	21
Oxyagrion chapadense Costa, 1978	2	2	1	2	7
Telebasis sp. Selys, 1865	0	1	0	0	1
Protoneuridae					
Epipleoneura venezuelensis Rácenis, 1955	0	0	0	1	1
Neoneura ethela Williamson, 1917	0	3	1	7	11
Neoneura sylvatica Hagen in Selys, 1886	14	6	5	0	25
Peristicta muzoni Pessalcq & Costa, 2007	1	0	1	2	4
Gomphidae					
Agriogomphus ericae (Belle, 1966)	5	5	3	14	27
Archaeogomphus sp. Williamson, 1919	0	1	1	0	2
Cyanogomphus sp. Selys, 1873	0	0	1	0	1
Gomphoides imfumata (Rambur, 1842)	0	0	1	0	1
Phyllocycla sp. Calvert, 1948	14	69	6	9	98
Progomphus intricatus Hagen in Selys, 1858	0	0	3	0	3
Progomphus sp. 1 Selys, 1854	0	0	3	0	3
Progomphus sp. 2 Selys, 1854	0	0	3	0	3
Libellulidae					
Brechmorhoga sp. Kirby, 1894	0	3	0	1	4
Dythemis multipunctata Kirby, 1894	1	2	11	3	17
Erythemis vesiculosa (Fabricius, 1775)	0	0	2	0	2
Erythrodiplax fusca (Rambur, 1842)	0	0	8	8	16
Erythrodiplax paraguaensis (Förster, 1905)	0	1	1	4	6
Erythrodiplax umbrata (Linnaeus, 1758)	0	1	1	2	4
Macrothemis hemichlora (Burmeister, 1839)	2	1	0	0	3
Macrothemis heteronycha (Calvert, 1909)	0	0	1	0	1
Macrothemis imitans imitans Karsch, 1890	0	1	30	0	31
Miathyria marcella Selys in Sagra, 1857	0	6	5	2	13
Micrathyria longifasciata Calvert, 1909	0	0	0	3	3
Orthemis sp. Hagen, 1861	3	0	0	1	4
Perithemis mooma Kirby, 1889	0	0	1	0	1
Total	92	115	176	165	548

River (Sej = 29) and Perdido River (Sej = 20) (Table II).

The species accumulation curve (e.g. species estimated) when plotted for each river showed a tendency to stabilize in the same way that as noted in collector's curves (Fig. 4). The accumulation curve started its trend of stability (asymptote) from the 5th sample, when about 95% of species were obtained (Fig. 3). The ratio analysis indicated that 12 samples would be needed to reach the possible number of species.

Table II. Number of Odonata species observed (S), estimated (J2) and number of rare species in the sampled rivers in the Serra da Bodoquena-MS, Brazil (August 2007 to November 2008).

Indexes/Places	Perdido	Laudejá	Aquidaban	Salobra	Serra da Bodoquena
Number of Species (S)	11	17	25	20	33
Estimate number of Species (J2)	20	29	41	33	51
Singletons	2	7	11	3	6
Doubletons	2	2	1	4	2
Uniques	0	1	9	4	14
Duplicates	2	4	3	3	6

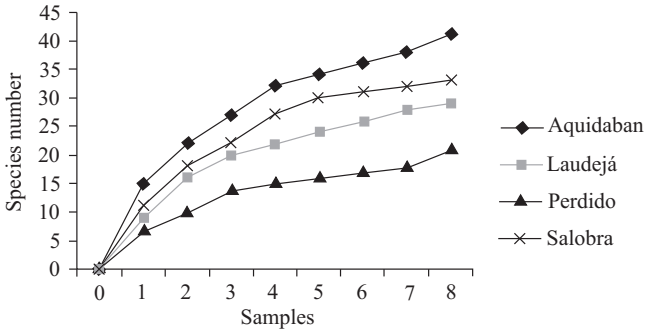

Fig. 4. Species accumulation curve (species estimated) of Odonata in the rivers sampled in the Serra da Bodoquena-MS, Brazil (August 2007 to November 2008).

Rare species. From the total of 33 species collected in all the sampled rivers, six species were represented by a single individual (singletons) (*Telebasis* sp., *Epipleoneura venezuelensis*, *Cyanogomphus* sp., *Gomphoides infumata*, *Macrothemis heteronyncha* and *Perithemis mooma*) and two by two individuals (doubletons) (*Archaeogomphus* sp. and *Erythemis vesiculosa*). Fourteen species were found only in one of the sampled rivers (uniques) (*Acanthagrion aeopilum*, *Acanthagrion gracile*, *Acanthagrion chararum*, *Telebasis* sp., *Epipleoneura venezuelensis*, *Cyanogomphus* sp., *Gomphoides infumata*, *Progomphus intricatus*, *Progomphus* sp. 1 and sp. 2, *Erythemis vesiculosa*, *Macrothemis heteronyncha*, *Micrathyria longisfasciata* and *Perithemis mooma* and six were found in two sampled rivers (duplicates) (*Archaeogomphus* sp., *Brechmorhoga* sp., *Macrothemis hemichlora*, *Macrothemis imitans* and *Orthemis* sp.). The river that contained the most singletons species was the Aquidaban River (11 spp.) (*Enallagma novaehispanie, Telebasis* sp., *Neoneura ethela*, *Peristicta muzoni*, *Archaeogomphus* sp., *Cyanogomphus* sp., *Gomphoides infumata*, *Erythrodiplax paraguayensis*, *Erythrodiplax umbrata*, *Macrothemis heteronyncha*, *Perithemis mooma*) (Table II). Nine species were unique to the Aquidaban River: *Acanthagrion aeopilum*, *Cyanogomphus* sp., *Erythemis vesiculosa*, *Gomphoides infumata*, *Macrothemis heteronyncha*, *Progomphus intricatus*, *Perithemis mooma and Progomphus* sp. 1 and sp. 2. Four species were unique to the Rio Salobra: *Acanthagrion gracile, Acanthagrion chararum, Epipleoneura venezuelensis* and *Micrathyria longifasciata*. The Laudejá River had only 1 unique species: *Telebasis* sp., and the Perdido River had no unique species (Table I).

DISCUSSION

Faunal Composition. Libellulidae (S = 13) was most diverse family, containing about 40% of all collected specimens. A comparison with other studies on the diversity of Odonata shows that this pattern is common in the Neotropical Region. In São Paulo State (Costa *et al.* 2000) and Espírito Santo State, for example, about 50% of the known species belong to this family (Costa & Oldrini 2005). Recent papers such as Anjos-Santos & Costa (2006), Souza & Costa (2006) and Muzón *et al.* (2008) have also found a high number of species from this family. This pattern is attributed to the generally large body size of the species in this family, which increases vagility and consequently dispersion and distribution. Furthermore, in larger species, thermoregulation is made possible by solar radiation (May 1979, 1991), and thus they are more frequently found in open areas. In species of smaller body size, as in the diverse and abundant Zygoptera suborder, thermoregulation seems to be by convection (due to smaller body size) (May 1979, 1991), thereby permitting occupation of shaded places such as forest. Given that most of our sampling areas were mainly surrounded by open areas (pasture) and degraded riparian forest, it is to be expected that species of the suborder Anisoptera (the larger-bodied species) are predominant in Serra da Bodoquena.

In addition, Kalkman *et al.* (2008) assumes that some genera of Neotropical Odonata are more diverse in high altitudes, due to the particular climate that creates a wide variety of habitats. The author explains that genera like *Argia*, *Heteragrion*, *Palaemnema*, *Acanthagrion*, *Telebasis, Phyllogomphoides*, *Progomphus*, *Erythrodiplax* and *Micrathyria* are easier to be found in hilly areas. This probably contributes to the high diversity observed in some genera found in this study, as *Acanthagrion*, *Erythrodiplax* and *Progomphus*.

Species richness. The diversity of tropical Odonata species is, in part, explained by the high diversity of aquatic environments in tropical forests (Orr 2006). The pattern of species richness found in our study is probably due to the

physical characteristics of the studied rivers and the degree of surrounding landscape heterogeneity. Within some of the factors cited as influencing Odonata species richness (see Vannote *et al.* 1980; Minshall 1984; Townsend 1989; Ward 1992; Clenaghan *et al.* 1998; Jonsen & Taylor 2000; Puth & Wilson 2001; Cortes *et al.* 2002; Wiens 2002), certainly the amount and diversity of microhabitat within a given stretch of the river seem to be important. The immature stages of many species of Odonata inhabit various types of aquatic environments, but in most cases, exhibit preferences for specific types of habitats and substrates (Carvalho 1999), moreover, most adults exhibit territorial behavior, while remaining near the streams from which they emerged. Thus, the characteristics of rivers reflect as much on the species richness as does the quality of the surrounding terrestrial environment. The Aquidaban River had the highest species richness and highest estimated number of species (S = 25 respectively), possibly because this site possessed the greatest number of microhabitats (sand, rocks and leaf litter), thereby allowing the establishment of a greater number of species and consequently resulting in greater diversity. Along these lines, the Perdido River is relatively homogeneous in terms of substrate (mainly stones and isolated macrophytes), restricting the established number of species; the same was observed for the other rivers.

Rare species. The number of singletons and doubletons observed in this work (6 and 2 species, respectively) may have been directly influenced by our sampling method because the active method of adult capture can result in a high probability of recording "vagrant" species of low abundance (*i.e.*, rare species). Indeed, most of the rare species we encountered were not collected as immatures. Moreover, the catch by this method can be highly dependent on the ability of the collector (Uieda & Castro 1999) as well as the flight capacity and agility of the species. The high number of species observed in only one river (Aquidaban River) was likely directly influenced by substrate. Gomphidae, for example, sampled in this river, tend to occur in waters with vegetation along the margins or protected springs with sandy substrates and moderately stable hydrological cycles.

Overall, these numbers of Odonata species demonstrate the need for more intensive surveys to document the complete fauna of Odonata in the Serra da Bodoquena; the information in this paper will hopefully help in the development of strategies on conservation and preservation of this unique biome.

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