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Article

Odonata of the state of Maranhão, Brazil: Wallacean shortfall and priority areas for faunistic inventories

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Abstract: Environmental changes are worrying in a scenario with large knowledge gaps on species diversity and distribution. Many species may become extinct before they are known to science. Considering this scenario, the present study aims to evaluate the known distribution of the species recorded for Maranhão state in Brazilian northeast region and discuss knowledge gaps about Odonata indicating the priority areas for faunistic inventories. Using primary and secondary data together, we present convex minimum polygons of the distribution of all the species registered for the state. In addition, we created maps with the richness of species and number of records of Odonata in the Maranhão state. In primary data sample 269 specimens, represented by 17 genera and 30 species were collected. Of the 30 species collected, 17 are new records for the state of Maranhão; of these, 35.29% are geographically widespread species, occurring in practically all regions of Brazil. Considering the records in the literature, there was a 68% increase in the number of Odonata species known for Maranhão. The most unexplored region is the Cerrado of the state of Maranhão. Furthermore, the transition regions between Cerrado and Amazônia and between Cerrado and Caatinga are also unknown. All these areas are a priority for faunistic inventories.
Keywords: *Anisoptera, checklist, patterns of diversity, Zygoptera.*

Odonata do estado do Maranhão, Brasil: Déficit wallaceano e áreas prioritárias para inventários faunísticos

Resumo: As mudanças ambientais são preocupantes em um cenário com muitas lacunas de conhecimento sobre a distribuição das espécies. Várias espécies podem ser extintas antes mesmo de serem conhecidas pela ciência. Considerando este cenário, o presente estudo tem como objetivo avaliar a distribuição conhecida das espécies de Odonata registradas para o Maranhão, na região nordeste do Brasil e discutir sobre as lacunas de conhecimento sobre Odonata, indicando áreas prioritárias para inventários faunísticos. Usando os dados primários e secundários juntos, nós apresentamos polígonos mínimos convexos da distribuição de todas as espécies registradas para o estado neste estudo. Além disso, criamos mapas com a riqueza de espécies e número de registros de Odonata no Maranhão. Para os dados primários foram coletados 269 indivíduos, representando 17 gêneros e 30 espécies. Das 30 espécies amostradas, 17 são novos registros para o Maranhão; dessas, 35,29% são espécies com ampla distribuição geográfica, ocorrendo em praticamente todas as regiões do Brasil. Considerando os registros na literatura, houve um aumento de 68% no número de espécies conhecidas para o Maranhão. A região mais desconhecida é o Cerrado do Maranhão. Outrossim, a região de transição Cerrado e Amazônia, e a transição entre Cerrado e Caatinga são também desconhecidas. Todas essas áreas são prioritárias para inventários faunísticos.
Palavras-chave: *Anisoptera, checklist, padrões de diversidade, riachos urbanos, Zygoptera.*

Introduction

Historically, environmental changes have become increasingly frequent and intense, posing a serious problem for the maintenance of biodiversity (Bush et al. 2008). The consequences are more worrying in places where the knowledge about the geographic distribution of the species is restricted or nonexistent (De Marco & Vianna 2005). This gap is called Wallacean shortfall (Hortal et al. 2015). As a result, many species may be extinct before they are known to science (Pimm et al. 2014). These uncertainties make it difficult to define priority areas for conservation due to the lack of knowledge of the true biodiversity.

In Brazil, the geographical distribution of Odonata is poorly known. Despite of increase of collection effort in many regions the geographical distribution still remains poorly known. In details, some species have already been collected or studied in only approximately 29% of the country's total area (Miguel et al. 2017). The Northeast region of the country, which contains parts of the Cerrado, Caatinga and Amazon biomes, is one of its most environmentally diverse regions (Leal et al. 2005; MMA 2009). However, the biodiversity of most organisms is not well known within this region, such as aquatic insects of the orders Odonata (De Marco 2008), Ephemeroptera (Shimano et al. 2013) and Heteroptera (Dias-Silva et al. 2013). In this context, Maranhão state stands out negatively among the states of the northeast region as there are few published works on Odonata records (De Marco 2008), which may be a reflection of the shortage of professionals specialized in aquatic entomology in this region of the country (Shimano et al. 2013; Nessimian et al. 2014), as well as the lack of financial resources for the public promotion of science in Brazil (Gibney 2015).

It is known that Odonates are sensitive to environmental alterations in all of their life stages (Mendes et al. 2017). Due to the fact that they are thermoregulators, characteristics related to their ecophysiology, light, which influences the environmental temperature (De Marco et al. 2015) and environmental integrity (Oliveira-Junior et al. 2017) are very important variables for the distribution of species in tropical streams (Monteiro-Júnior et al. 2014; Brasil et al. 2017). Therefore, total or partial removal of riparian vegetation alters light/temperature levels and the environmental integrity of the streams, and consequently destabilizes the communities of Odonata (Carvalho et al. 2013; Oliveira-Junior et al. 2015, 2017). Furthermore, changes in Odonata communities may adversely affect other communities. The absence of these predators should change the trophic organization of riparian zones and this causes loss of ecological integrity (Samways 1993).

Considering that little knowledge exists about Odonata in the Maranhão state (De Marco 2008; Miguel et al. 2017); which is part of the last Brazilian agricultural frontier called MATOPIBA (an acronym of the names of the states of Maranhão, Tocantins, Piaui and Bahia) where there is intense agricultural pressure on natural landscapes for the expansion of soybean cultivation (Spera et al. 2016), studies of this order within this region are extremely relevant. Considering this scenario, the present study's objective evaluates the known distribution of the species recorded for Maranhão state in Brazilian northeast region and discuss knowledge gaps about Odonata indicating the priority areas for faunistic inventories as a conservation allowance.

Material and Methods

1. *Study area*

The state of Maranhão has an area of 331.937 km^2, and includes the phytogeographical domains of Amazonian Forest, Cerrado and Caatinga (Correia-Filho et al. 2011; MMA 2009), according to the Köppen classification system is *Aw* climate type (tropical savanna). This type of climate is primarily characterized by a dry winter (from December to May) and rainy summer (from July to November). In contrast, the state's remaining area, which is predominantly Amazon rainforest, is classified as climate type *Am* (tropical rainy), characterized by a long rainy season throughout the year (Peel et al. 2007; Huete et al. 2006).

The study was carried out in tributaries of the Itapecuru River, in the municipality of Codó, located in the eastern meso–region of Maranhão state, Brazil. This municipality is in a Cerrado–Caatinga transition zone, and has an area of 4,698 km^2 (Feitosa & Almeida 2002). The predominant phytogeographical domain is the Cerrado, presenting Cerrado *stricto sensu* phytophysiognomies, composed mainly of shrub vegetation and medium-sized trees such as Cajueiro (*Anacardium occidentale* L.); Cerradão, which presents denser vegetation with larger trees such as Bacuri (*Platonia insignis* Mart.); and riparian forest on the banks of rivers and streams, generally composed of medium and large trees, pioneers, non-pioneers and some shrubs. It also presents the Mata de Cocal formation, where Babaçu (*Orbignya phalerata* Mart.) (Sousa et al. 2016) and Carnaúba [*Copernicia prunifera* (Mill.) H.E.Moore] palm trees predominate. The Mata dos Cocais, which extends from the Amazon in central–west Maranhão to the Caatinga in western Piauí, is a type of transitional vegetation cover between tropical, equatorial and semi-arid climates (Nunes et al. 2012). The region's topography varies between flat and gently undulating with modest altitudes relative to the Brazilian relief, with an average of 47 m (Vasconcelos Gama et al. 2007).

The municipality is drained by the Itapecuru river basin and micro basins of the Codozinho and Saco rivers (Feitosa & Almeida 2002; Sousa et al. 2016). Riparian vegetation of the Itapecuru River tributaries within the study area is mostly characterized by the Riparian Forest physiognomy. However, streams present considerable levels of alteration resulting from the intensive use of soil for crops and pasture, and the use of water resources for food and leisure (Feitosa & Almeida 2002). In general, streams' riparian vegetation is narrow or absent and many small streams are ephemeral, containing running water only during periods of high rainfall (such as from January to April) due to the prolonged dry season, typical of northeast Brazil.

2. *Primary data collection*

Odonata adults were collected from nine tributaries belonging to the Itapecuru river basin in the northeast region of Brazil (Fig. 1). The collects were realized twice in each stream, both being in the 2016 year. The streams are perennial, however, eventually becoming temporary in extreme dry events, common in northeastern Brazil. The first collect was realized in May, and the second in Juny. Specimens were collected along the margins of each stream using an entomological net, during a one hour collection period along a 100 m section. Sampling at each

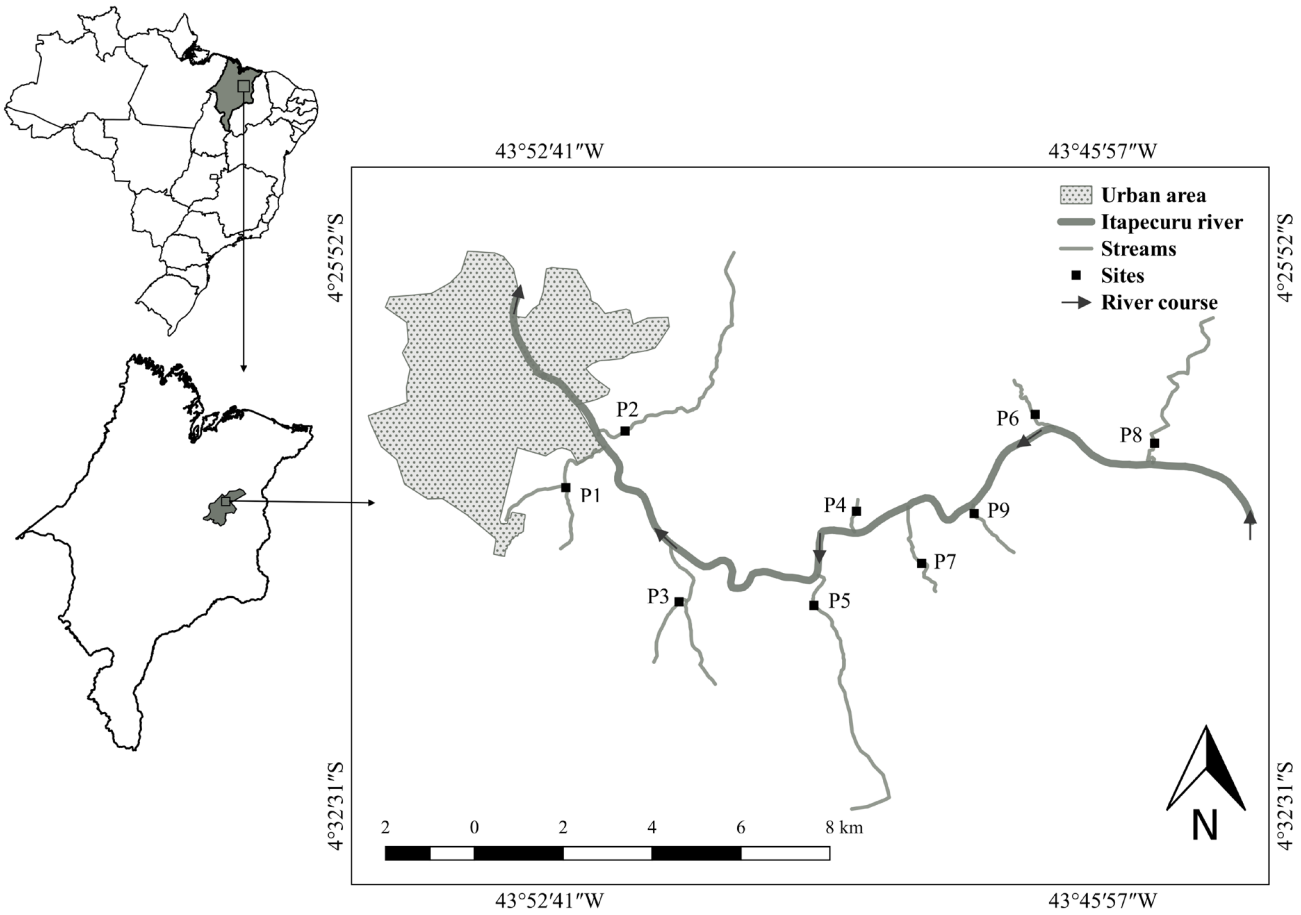

Figure 1. Location of Odonata collection points in tributaries of the Itapecuru River in Codó, Maranhão, Brazil.

point was always performed on sunny days between 11:00 am and 2:00 pm (Monteiro-Júnior et al. 2015). The collected specimens were conditioned and preserved in accordance with the protocol of Lencioni (2006). For the taxonomic identification of the collected specimens, specific keys were used (Heckman 2006; Lencioni 2005, 2006, 2013; Garrison et al. 2006; Belle 1988, 1996; Pessacq 2014; Garrison & Ellenrieder 2015); when necessary, comparisons were made with specimens already identified and deposited in the collection of the Ecology and Conservation Laboratory, Universidade Federal do Pará; and, expert confirmation.

3. Secondary data collection

In order to create species distribution polygons, we used georeferenced distribution data for collected species already used in other studies (Brasil et al. 2018; Calvão et al. 2014), in addition to data that has been compiled from articles, books and museums by De Marco & Vianna (2005) and Juen & De Marco (2012) and recently updated by Martins (2016).

4. Data analysis

The occurrence data for species collected during this sampling event was tabulated along with the other records for the Brazil. We then selected only the species that occurred in this study and, subsequently, the occurrences plotted and geoprocessed in QGis 2.14.0-Essen (QGis 2011) software. The occurrence points of each species were used to create the Minimum Convex Polygon (Nilsen et al. 2008). This type of polygon is limited by the outermost points of the occurrence set, graphically demonstrating the probable areas of occurrence of these species.

To define the priority areas for faunal inventories, we used all Odonata records for the state of Maranhão (primary and secondary data) for the preparation of two maps, one with species richness values and another with the number of records. We followed the same method used by De Marco & Vianna (2005), the maps were divided into a grid with 1-degree cells. The maps of the species richness and records were made in the R program using the lets.presab.points functions of the letsR package (R Core Team 2014; Vilela & Villalobos 2015).

Results

1. Description of communities

A total of 269 specimens represented by 17 genera and 30 species were collected. The suborder Anisoptera presented the highest species richness, with 17 species, representing 56.6% of the total sampled. The suborder Zygoptera presented only 13 species, with 43.4% of the total collected. However, considering the abundance of individuals,

Zygoptera were more representative, with 170 specimens, or 63% of the total collected; while Anisoptera presented only 99 individuals, representing 37% of the total.

The most frequently occurring taxa were *Acanthagrion aepiolum* Tennessen, 2004 found in seven streams (77% of streams), followed by *Acanthagrion kennedii* Williamson, 1916 and *Erythrodiplax basalis* Kirby, 1889 in five streams (56% of the total), *Argia reclusa* Selys, 1865 in four streams (or 44%), and *Perithemis* sp.1 in three streams (or 33%). The remaining taxa represents less than 25% of the total species, whose distribution was restricted to a maximum of two streams (Table 1).

2. *Spatial distribution of species*

Of the 30 Odonata species reported in this study, 17 are new records for the state of Maranhão. Of these new records, 35.29% are geographically widespread species, occurring in practically all regions of Brazil, from the southernmost Cerrado to the northern Amazon. The remaining 64,71% are species with a more restricted geographic distribution, occurring in a limited fashion or in a specific region of the country (Table 1; Fig. 2), however the occurrence of *Micrathyria paruensis* Geijskes, 1963 is the first record of this specie to Brazil.

Table 1. List of Odonata species sampled in the study with points of occurrence and known distribution for the Brazilian states, and species already been recorded in other works for the state of Maranhão. Acronym of the Brazilian states: AC = Acre. AL = Alagoas. AM = Amazonas. AP = Amapá. BA = Bahia. ES = Espirito Santos. GO = Goiás. MA = Maranhão. MG = Minas Gerais. MS = Mato Grosso do Sul. MT = Mato Grosso. PA = Pará. PB = Paraíba. PE = Pernambuco. PR = Paraná. RJ = Rio de Janeiro. RO = Rondônia. RR = Roraima. RS = Rio Grande do Sul. SC = Santa Catarina. SP = São Paulo. TO = Tocantins.

Species sampled in the study with known distribution for the Brazilian states and other records for the state of Maranhão.				
Suborder/Species	**Points of occurrence**	**Distribution in Brazil**	**Other records for Maranhão**	**Reference**
Anisoptera				
Diastatops obscura Fabricius, 1775	P1	AC. AM. AP. BA. ES. GO. MA. MG. MS. MT. PA. PB. PE. PR. RJ. RO. RR. SP and TO	*Brachymesia herbida* Gundlach, 1889	De Marco (2008)
Erythemis haematogastra Burmeister, 1839	P1	AC. AM. AP. BA. ES. GO. MA. MG. MS. MT. PA. PB. PE and SP	*Erythemis plebeja* Burmeister, 1839	De Marco (2008)
Erythrodiplax basalis	P1. P3. P4. P6 and P7	AC. AM. GO. MA. MS. MT. PA. PE. PR. RJ. RO. RR. RS and SP.	*Erythemis carmelita* Williamson, 1923	De Marco (2008)
Erythrodiplax fusca	P4 and P7	AC. AM. BA. ES. PA. PE. RJ. SP. GO. MA. MG. MS. MT. PR. RO. RR. RS and SC	*Erythemis peruviana* Rambur, 1842	De Marco (2008)
* *Erythrodiplax latimaculata* Ris, 1911	P7	AM. GO. MG. MS. MT. PE. RJ. RS and SP	*Erythemis vesiculosa* Fabricius, 1775	De Marco (2008)
Erythrodiplax sp.1	P3	-	*Erythrodiplax media* Borror, 1942	De Marco (2008)
* *Erythrodiplax umbrata*	P2 and P9	AC. AM. AP. BA. ES. GO. PA. PE. PR. MG. MS. MT. RJ. RO. RR. RS and SP	*Erythrodiplax paraguayensis* Förster, 1905	De Marco (2008)
** *Micrathyria artemis* Ris, 1911	P7	AM. AP. BA. ES. GO. MG. MS. MT. PA. RJ. RO and SP	*Micrathyria marcella* Selys, 1857	De Marco (2008)
** *Micrathyria divergens* Westfall, 1992	P8	MG	*Micrathyria ocellata* Martin, 1897	De Marco (2008)
** *Micrathyria paruensis*	P4	-	*Nephepeltia phryne* Perty, 1834	De Marco (2008)
Micrathyria pseudeximia Westfall, 1992	P1	AM. GO. ES. MA. PA. PR. MG. MS. MT. RJ and RO	*Orthemis discolor* Burmeister, 1839	De Marco (2008)
* *Nephepeltia flavifrons* Karsch, 1889	P7	AC. MG. MS. MT. PA. PE. RJ. RR. and SP	*Perithemis laís* Perty, 1834	De Marco (2008)
Orthemis ambinigra Calvert, 1909	P6	BA. ES. MA. PE. RJ. RS and SC	*Zenithoptera anceps* Pujol-luz, 1993	De Marco (2008)
Perithemis sp.1	P1. P5 and P7	-	*Uracis fastigiata* Burmeister, 1839	Costa (1997)
Perithemis sp.2	P7	-	*Uracis imbuta* Burmeister, 1839	Costa (1997)
** *Perithemis thais* Kirby, 1889	P1	AM. AP. ES. PA. MS. MT. RJ. RO and SP	*Micrathyria mengeri* Ris, 1919	Costa (2002)

Continuation Table 1.

Species sampled in the study with known distribution for the Brazilian states and other records for the state of Maranhão.				
Suborder/Species	**Points of occurrence**	**Distribution in Brazil**	**Other records for Maranhão**	**Reference**
Zenithoptera lanei Santos, 1941	P3 and P4	AC. AM. BA. ES. GO. MA. MS. MT. PA. PE. RJ. RO. SC. SP and TO	*Uracis siemensi* Kirby, 1897	Pujol-luz and Fonseca (1997)
Zygoptera				
** *Acanthagrion aepiolum*	P1. P2. P4. P5. P6. P7 and P8	MS. PA. PR and SP	*Ischnura fluviatilis* Selys, 1876	De Marco (2008)
** *Acanthagrion kennedii*	P1. P2. P3. P4 and P7	PA		
** *Acanthagrion truncatum* Selys, 1876	P8	BA. GO. MG. MS. MT. SP and TO		
* *Argia reclusa*	P1. P5. P6 and P8	AL. GO. MG. MS. MT. RS and SP		
Argia sp.1	P7	-		
Epipleoneura metallica Rácenis, 1955	P3 and P5	AM. BA. GO. MA. MG. MT. PA and TO		
** *Epipleoneura westfalli* Machado, 2001	P5	MT. PA and RO		
** *Hetaerina curvicauda* Garrison, 1990	P5	GO. ES. MS. MT and RO		
Hetaerina sanguínea Selys, 1853	P6 and P8	AM. MA. PA. RO and RR		
* *Ischnura capreolus*	P8	AC. AM. BA. ES. GO. MG. MS. MT. PA. PE. RJ. RR. RS and SP		
** *Neoneura fulvicollis* Selys, 1886	P7	GO. PA and SP		
** *Perilestes solutus* Williamson & Williamson, 1924	P6 and P9	GO. MT. PA. RO and RR		
* *Telebasis coccinea* Selys, 1876	P3	BA. GO. MS. MT. SP and TO		

* First record for Maranhão state. ** First record for Maranhão state and Northern region.

When we analyze each suborder separately, were found to have similar spatial distributions. The two suborders have records of common species with wide spatial distribution. For instance, *Erythrodiplax umbrata* Linnaeus, 1758 occurs from the southernmost Cerrado to the northern Brazilian Amazon. *Ischnura capreolus,* 1861 Hagen occurs the southernmost Cerrado to the northern Brazilian Amazon.

Analysing the Odonata records to Maranhão state we can see that every state practically has priority for faunal inventories. Futhermore, the knowledge gaps are even greater when we consider the distribution of records by Biomes. This happens because although there are few records it focuses on the Amazon portion. The portion of Cerrado, mainly the east of Maranhão is a region where knowledge about the Odonata fauna is almost non-existent (Figure 3).

Discussion

1. Community description

The species with the highest frequency of occurrence and abundance in this study are known as common organisms in altered environments. For example, *A. aepiolum* has a strong relationship with the loss of native vegetation (Rodrigues et al. 2016). Similarly, *E. basalis* has been shown to be a common species in lentic environments (Calvão et al. 2013), being an excellent indicator of impacted areas (Monteiro-Júnior et al. 2013; Monteiro-Júnior et al. 2015; Oliveira-Junior et al. 2015). *A. reclusa* was also related to altered environments in previous studies (Dutra & De Marco 2015). However, *A. reclusa* was related to environments preserved in the studies of Carvalho et al. (2013) and

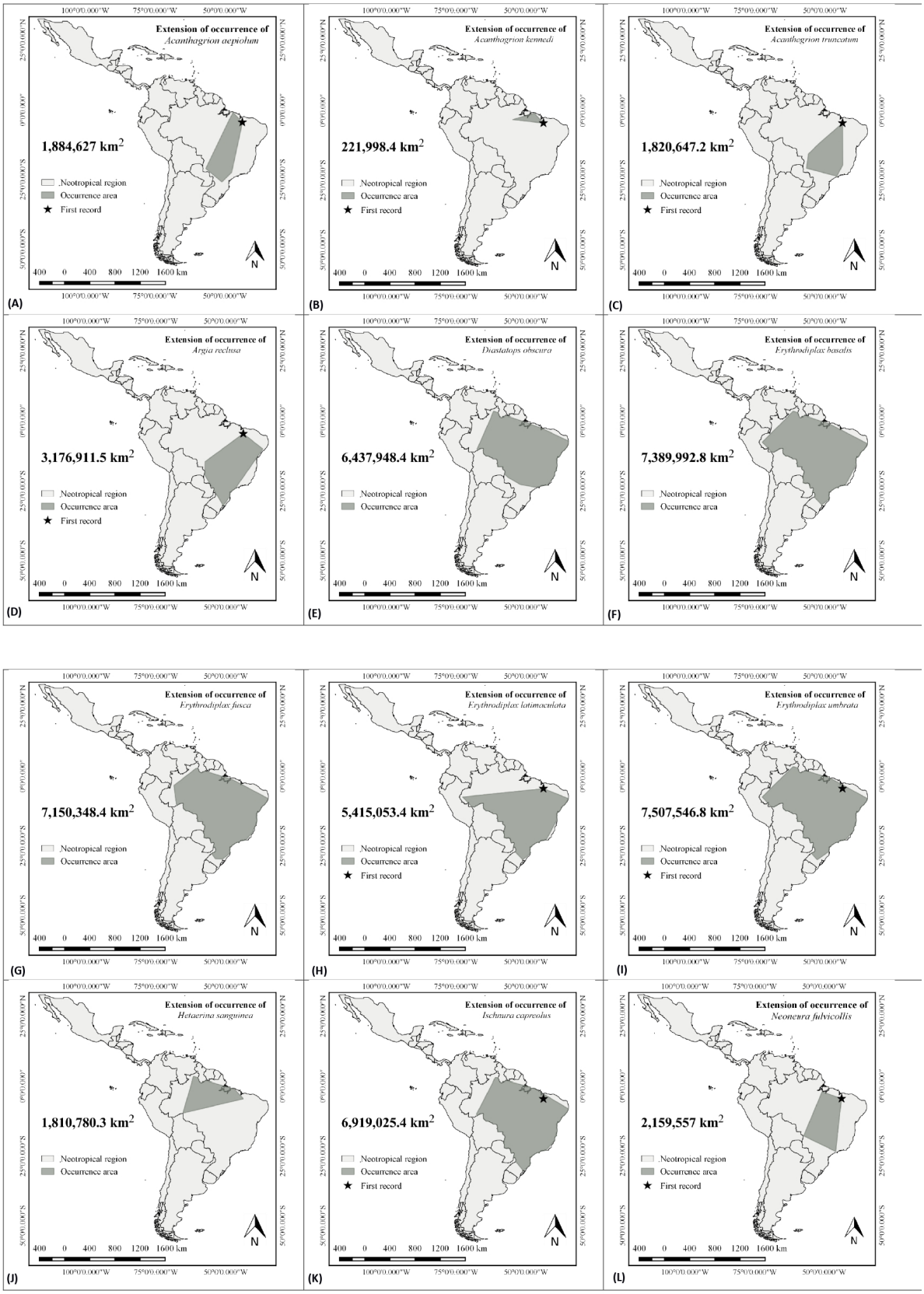

Figure 2. Spatial distribution and new records of Odonata species from Maranhão state, Brazil.

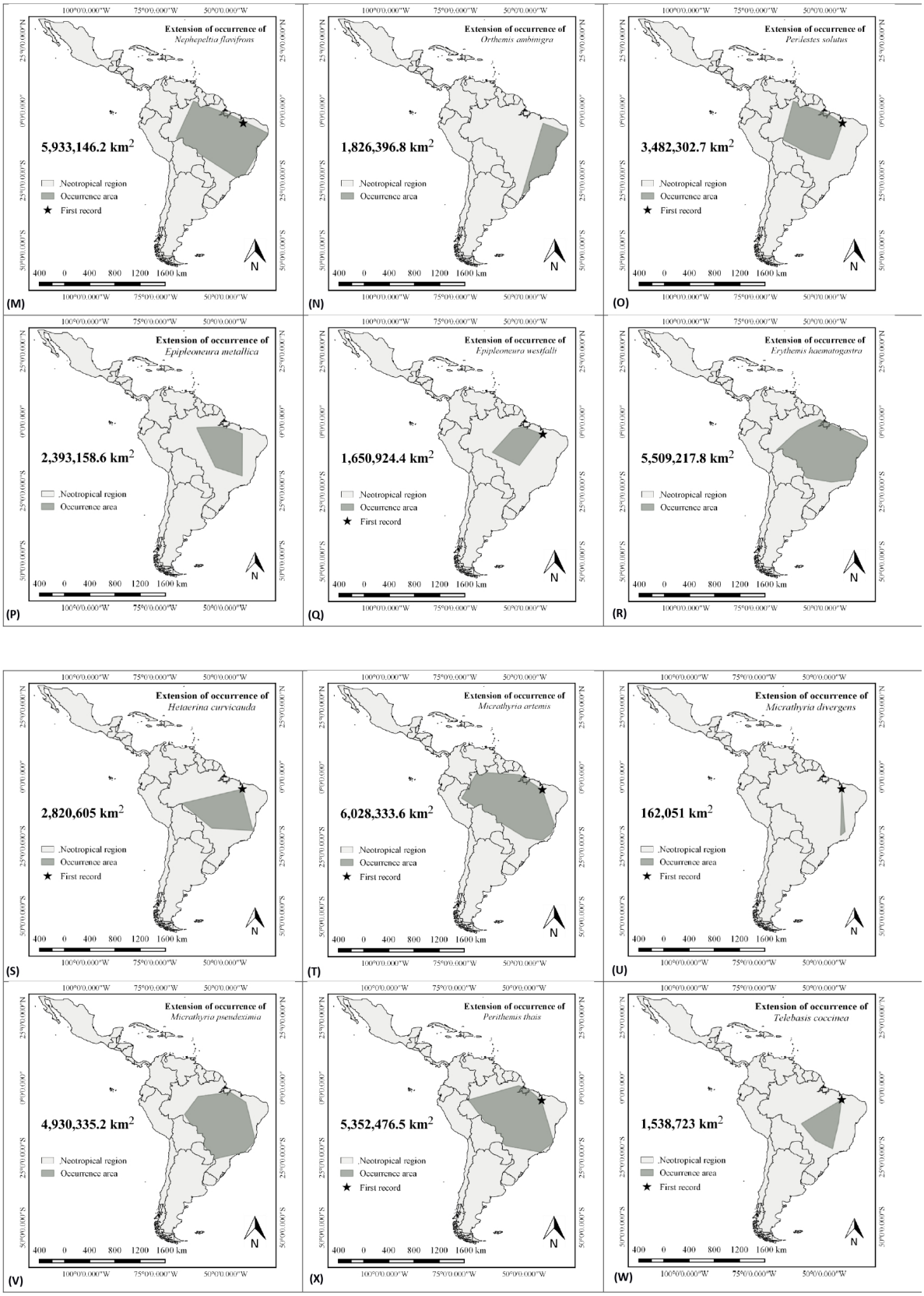

Figure 2. Spatial distribution and new records of Odonata species from Maranhão state, Brazil.

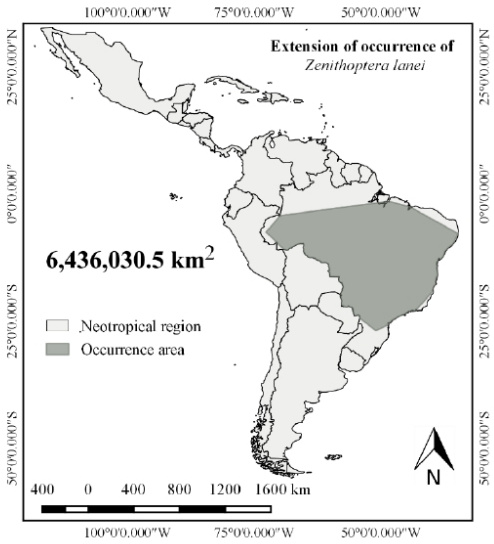

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Figure 2. Spatial distribution and new records of Odonata species from Maranhão state, Brazil.

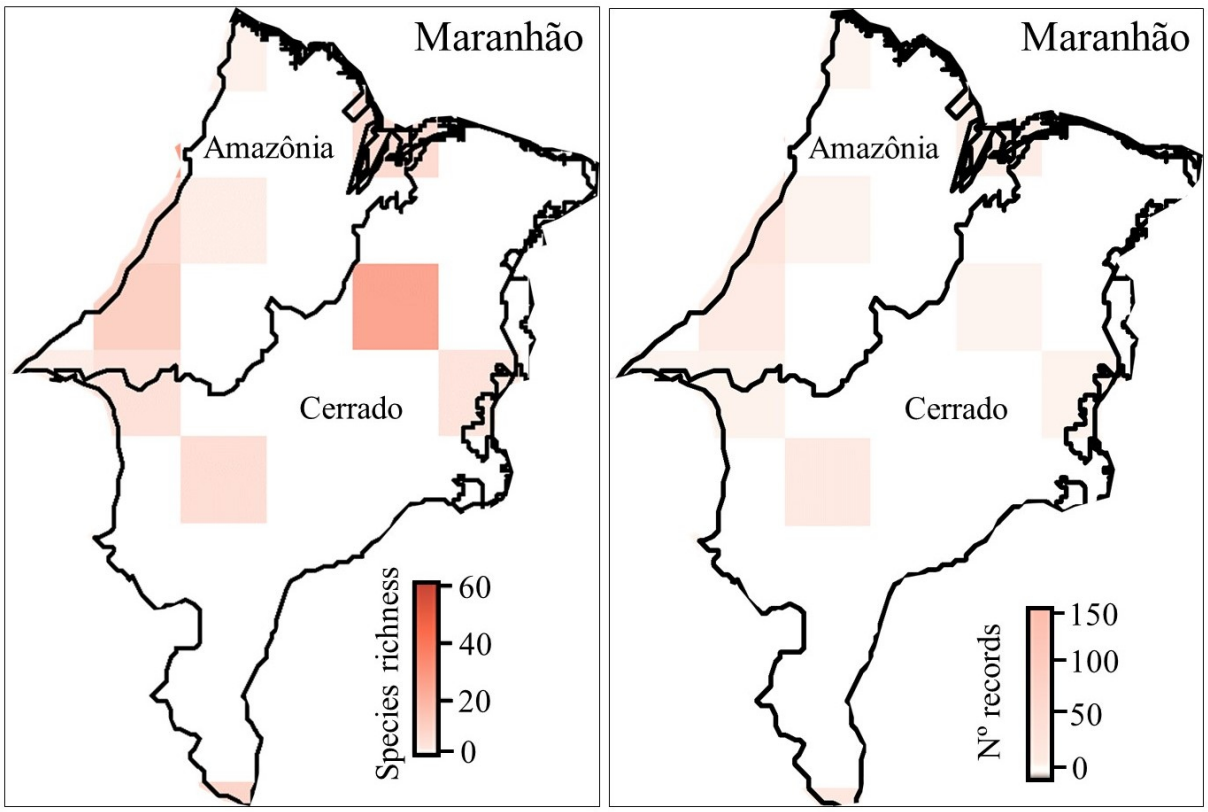

Figure 3. Records and species richness of Odonata in Maranhão state.

Juen et al. (2014) conducted in the Cerrado and Cerrado–Amazon Forest transition areas. This suggests that other factors, such as resource availability, climate and/or temperature, or even biogeographic patterns (Brasil et al. 2018) may affect the territorial behavior of this specie or the way they perceive environmental variation. It is possible that *A. reclusa* can occur in altered areas, but that have small strip of riparian forest for maintaining a spot of propitious habitat.

It is also worth mentioning that many owners in the region build private pools for family leisure, causing water damming in the channels. In some cases, the stream banks are widened and lined with bags of sand and/or concrete. The water flow in these places is controlled according to the owner's interest. This activity may be favoring the occurrence of generalist organisms, which have a greater tolerance for open areas, such as some species of the genera *Erythrodiplax* and *Micrathyria* (De Marco 2008). The change in stream flow may over time lead to a change in species composition, locally wiping out those that are typical of more pristine lotic environments and favoring the entry of more generalist species from more lentic or semi-lentic environments (Juen et al. 2014).

2. *Spatial distribution of species*

Most of the species registered in Maranhão state have a distribution in Cerrado areas. The species *M. pseudeximia* Westfall*, E. latimaculata* Ris and *E. basalis* have occurrence records in practically all the domains, however, they occur in greater concentration in Cerrado. In contrast to these results, *M. divergens* Westfall, which is reported in this study, is recorded only in regions of the Atlantic Forest. Another case similar to this involves the species *Orthemis ambinigra* Calvert previously reported for Maranhão in the study of De Marco (2008), which also concentrates most of its records in areas of the Atlantic Forest. This results shows the collection gaps in this region (Almeida et al. 2010).

The majority of records for *H. curvicauda* Garrison, *T. coccinea* Selys, and *Epipleoneura westfalli* Machado were concentrated in the midwest region of the country, whereas *M. divergens* and *A. kennedii* were recorded only in the Southeast and Northern regions of the country, respectively. *A. aepiolum*, which had a large occurrence in the Southern Neotropical region (Lozano 2013), was recently reported for the state of Pará in the study by Calvão et al. (2016), Rondônia state in Brazil and Peru and Bolivia (Lencioni 2017) stateand now for Maranhão in this study.

Only 29% of the Brazil's total area has geographic distribution data for Odonata and, considering the production of scientific articles, 45%, 20.6% and 16% were published in the Southeast, North and Central West regions respectively (Miguel et al. 2017). For this reason, it is possible that the highest number of records in these regions (Southeast, North and Central West), when compared to the Northeast, is a bias related to the greater collection effort in these regions. Therefore, it is important to have a considerable increase in Odonata collections in the Northeast of Brazil so that it is possible to reduce the Wallacean shortfall. This would also allow for a more robust biogeographic analysis of the order (De Marco 2008).

In the present study, 42.31% of the species are reported for the first time in the Northeast region of Brazil. In addition, the occurrence of *M. paruensis* was recorded, which until then had no certainty in its occurrence for Brazil and was only previously suggested by Heckman (2006). These results suggest that in addition to the Odonata biogeographic factors, a lack of research investments are generating species distribution data that is strongly skewed by the spatial distribution of universities, research centers and specialists (De Marco & Vianna 2005; Nóbrega & De Marco 2011).

Greater knowledge of species distribution and environments can be used as a tool for selecting new conservation units (Nóbrega & De Marco 2011), and also contributes to robust analyses of the socioeconomic and environmental situation on a regional scale. This work contributes to the knowledge of the fauna of Maranhão state, where high species diversity is expected due to its biogeographic and environmental characteristics, however, in contrast it is one of the states where there are fewer studies on Odonata fauna in the country (De Marco & Vianna 2005). In addition, it enhances the importance of the Northeast region of Brazil for biodiversity conservation, considering that the region is home to several common Odonata species from the Cerrado, Amazon and even the Atlantic Forest. Therefore, despite being an initial effort, with only nine points sampled, this study contributes to minimizing the Wallacean shortfall of the Northeast region and indicates the priority areas. The most unknown region is the Cerrado of the state of Maranhão. Furthermore, the transition regions between Cerrado and Amazônia and between Cerrado and Caatinga are also unknown. All these areas are a priority for faunistic inventories.

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Author Contributions

Rafael Costa Bastos: Contribution to data collection; Substantial contribution in the concept and design of the study; Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intelectual content.

Leandro Schlemmer Brasil: Substantial contribution in the concept and design of the study; Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intelectual content.

Fernando Geraldo De Carvalho: Substantial contribution in the concept and design of the study; Contribution to critical revision, adding intelectual content.

Lenize Batista Calvão: Substantial contribution in the concept and design of the study; Contribution to critical revision, adding intelectual content.

José Orlando De Almeida Silva: Substantial contribution in the concept and design of the study; Contribution to critical revision, adding intelectual content.

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Conflicts of interest

The authors declare that they have no conflict of interest related to the publication of this manuscript.

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