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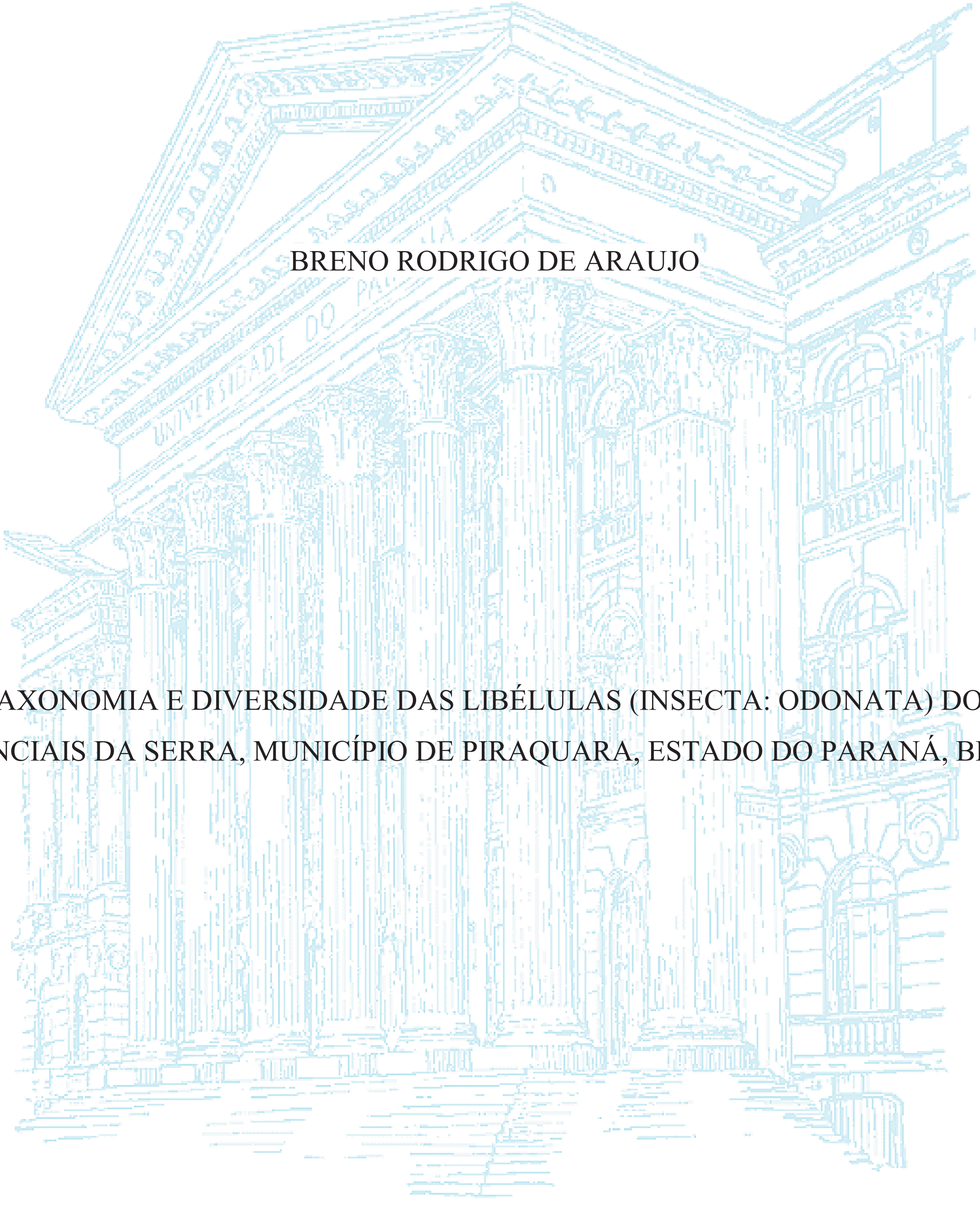

BRENO RODRIGO DE ARAUJO

TAXONOMIA E DIVERSIDADE DAS LIBÉLULAS (INSECTA: ODONATA) DO MANANCIAIS DA SERRA, MUNICÍPIO DE PIRAQUARA, ESTADO DO PARANÁ, BRASIL

CURITIBA

2020

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Orientador: Prof. Dr. Ângelo Parise Pinto
Coorientador: Prof. Dr. André Adrian Padial

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Os membros da Banca Examinadora designada pelo Colegiado do Programa de Pós-Graduação em CIÊNCIAS BIOLÓGICAS (ENTOMOLOGIA) da Universidade Federal do Paraná foram convocados para realizar a arguição da Dissertação de Mestrado de **BRENO RODRIGO DE ARAUJO** intitulada: **Taxonomia e diversidade das libélulas (Insecta: Odonata) do Mananciais da Serra, município de Piraquara, estado do Paraná, Brasil**, sob orientação do Prof. Dr. ANGELO PARISE PINTO, que após terem inquirido o aluno e realizada a avaliação do trabalho, são de parecer pela sua aprovação no rito de defesa.
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CURITIBA, 19 de Fevereiro de 2020.

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RESUMO

As atividades humanas alteram a estrutura, dinâmica e fluxo de energia dos ambientes aquáticos. Por exemplo, o represamento de rios aumenta a incidência solar, a permanência da água e a temperatura, interferindo nas comunidades de libélulas (ordem Odonata). A sensibilidade de espécies de Odonata a distúrbios as torna organismos modelos de bioindicador de qualidade ambiental, entretanto, o conhecimento da fauna de libélulas no Brasil está concentrado próximo a instituições com especialistas e a maior parte do território é subamostrada. Os objetivos desta pesquisa foram: (1) apresentar uma lista abrangente das espécies de Odonata para a área protegida do Mananciais da Serra, (2) fornecer notas taxonômicas para espécies raras ou pouco conhecidas e por fim (3) investigar a influência do represamento na estrutura e composição da comunidade de Odonata em uma área subtropical. A pesquisa foi conduzida no ameaçado domínio da Mata Atlântica, na cadeia de montanhas Serra do Mar em uma área bem preservada no município de Piraquara, estado do Paraná, Brasil. O esforço de amostragem ocorreu entre 2017 e 2019, utilizando diferentes técnicas de coleta em diferentes mesohabitats com ocorrência de libélulas desde bromélias e pequenos riachos à grandes reservatórios. Duas comunidades foram consideradas, uma de área florestada (comunidade local, MS) e outra de um reservatório (comunidade de paisagem homogênea, RP). A alfa e betadiversidade de MS e RP foram investigadas para inferir sobre a homogeneização da paisagem. Além disso, duas ferramentas bioindicadoras de qualidade de habitat foram aplicadas aos nossos dados. Foram amostrados 1.627 exemplares de 9 famílias, 42 gêneros e 83 espécies. Um total de 53 novos registros de ocorrência foram detectados para o Paraná, elevando para 113 o número de espécies de libélulas reportadas para o estado, enquanto *Micrathyria venezuelae* De Marmels, 1989 é registrada pela primeira vez no Brasil. A fêmea da descrição original de *Neocordulia mambucabensis* Costa & T.C. Santos 2000 trata-se de outra espécie de *Neocordulia*. Além disso, duas fêmeas, quatro espécies não descritas e larvas de último estádio de desenvolvimento de quatro espécies foram detectadas. A amostragem de larvas ampliou a abundância de espécies raras e de fêmeas. A diversidade alfa mostrou a comunidade RP como a mais diversa, resultado relacionado à alta ocorrência de espécies generalistas. A composição de espécies e espécies típicas configuram maior heterogeneidade para MS. O alto *turnover* caracteriza um padrão Clementsiano para a metacomunidade, provavelmente devido à conversão e homogeneização do sistema aquático, portanto o reservatório tem uma capacidade quase nula de manter a fauna local. Finalmente, as ferramentas de bioindicação de qualidade de habitat foram eficientes, considerando MS como mais preservada que RP, entretanto, a razão Zygoptera / Anisoptera apresentou menor acurácia do que as razões Libellulidae / other Anisoptera e Coenagrionidae / other Zygoptera respectivamente. A riqueza estimada para o Mananciais da Serra é superior a cem, correspondendo a pelo menos 60% das espécies conhecidas para o Paraná e 10% das espécies brasileiras, o país mais rico em espécies do mundo. O reservatório exclui espécies locais, dando lugar a uma alta diversidade de espécies mais generalistas; no entanto suas áreas circundantes são preservadas mantendo parte do habitat natural e da biodiversidade local, aspecto positivo que mitiga a homogeneização da paisagem.

Palavras-chave: Anisoptera. conservação. faunística. metacomunidade. sistemática. Zygoptera.

ABSTRACT

Human activities alter the structure, dynamics and energy flow of aquatic environments. For example, damming rivers increases solar incidence, water permanence and temperature, interfering with dragonfly communities (order Odonata). The sensitivity of Odonata species to disturbances makes them model organisms of bioindicator of environmental quality, however, knowledge of dragonfly fauna in Brazil is concentrated close to institutions with specialists and most of the territory is under-sampled. The objectives of this research were: (1) to present a comprehensive checklist of Odonata species for the protected area of Mananciais da Serra, (2) to provide taxonomic notes for rare or little-known species and finally (3) to investigate the influence of the dam on the structure and composition of the Odonata community in a subtropical area. The research was conducted in the threatened Atlantic Forest domain, in the Serra do Mar mountain chain in a well-preserved area in the municipality of Piraquara, state of Paraná, Brazil. The sampling effort took place between 2017 and 2019, using different collection methods in different mesohabitats in with dragonflies occurs from bromeliads and small streams to large reservoirs. Two communities were considered, one from a forested area (local community, MS) and another from a reservoir (homogeneous landscape community, RP). The alpha and beta-diversity of MS and RP were investigated to infer about the homogenization of the landscape. In addition, two bioindicator tools for habitat quality were applied to our data. The amount of 1,627 specimens from 9 families, 42 genera and 83 species were sampled. A total of 53 new occurrence records were detected for Paraná, bringing to 113 the number of dragonfly species reported to the state, while *Micrathyria venezuelae* De Marmels, 1989 is registered for the first time in Brazil. The female from the original description of *Neocordulia mambucabensis* Costa & T.C. Santos 2000 is another species of *Neocordulia* In addition, two females, four species not described and larvae of the last stage of development of four species were detected. Larvae sampling increased the abundance of rare species and females. Alpha diversity showed the RP community as the most diverse, a result related to the high occurrence of generalist species. The composition of species and typical species configure greater heterogeneity for MS. The high turnover characterizes a Clementsian pattern for the metacommunity, probably due to the conversion and homogenization of the aquatic system, therefore the reservoir has almost no capacity to maintain the local fauna. Finally, the habitat quality bioindication tools were efficient, considering MS as more preserved than RP, however, the Zygoptera / Anisoptera ratio was less accurate than the Libellulidae / other Anisoptera and Coenagrionidae / Zygoptera ratios, respectively. The estimated richness for Mananciais da Serra is over one hundred, corresponding to at least 60% of the species known for Paraná and 10% of Brazilian species, the country richest in species in the world. The reservoir excludes local species, giving rise to a high diversity of more generalist species; however, its surrounding areas are preserved maintaining part of the natural habitat and local biodiversity, a positive aspect that mitigates the homogenization of the landscape.

Keywords: Anisoptera. conservation. faunistic. metacommunity. systematics. Zygoptera.

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INTRODUÇÃO

As libélulas (ordem Odonata) são insetos cosmopolitas facilmente reconhecidos por pessoas leigas, conhecidas no Brasil também como lava-bunda, lavadeira, jacina entre outros nomes (Costa et al., 2012). Existem um pouco mais que de 6 mil espécies viventes descritas e estimam-se outras 1000 ainda por descrever (Suhling et al., 2015; Pinto, 2016). A riqueza para o Brasil é de 871 a maior já registrada, com estimativa de centenas ainda não descritas (ver Costa et al., 2012; Pinto, 2020). As libélulas são importantes constituintes da comunidade de macroinvertebrados aquáticos, mantêm a estrutura e ciclagem de nutrientes nestes ambientes e podem servir como bioindicadores de qualidade ambiental (Oertli, 2008). Elas dependem das florestas para acessar os recursos necessários para se desenvolver em sua fase de larva (aquática) e adulta (terrestre). Algumas delas são restritas às florestas, de fato, mais de 80% dos gêneros de libélulas neotropicais têm espécies florestais (Paulson, 2006). Mesmo as espécies que não dependem da floresta podem passar parte de sua vida adulta nela (Cordero-Rivera, 2006), se beneficiando de características físicas, fisiológicas, intra e interbióticas da floresta ou apenas como seu refúgio diário e sazonal (Paulson, 2006).

O estado do Paraná apresenta uma acentuada perda de áreas naturais desde o século passado, a ocupação e exploração da Mata Atlântica, 98% de seu território, levaram a um remanescente de 23,54% em 2006 (ver Campanili & Schaffer, 2010). Esta supressão de ambientes naturais diminui a qualidade das águas (ver Agostinho et al., 2005), ambiente no qual as libélulas passam maior parte de seu ciclo de vida (Oertli, 2008). A Mata Atlântica, igualmente ameaçada, é considerada um *hotspot* para conservação devido seus altos níveis de endemismo e ameaça, o domínio contém 1 a 8% das espécies do mundo (Myers et al., 2000; Laurence, 2009).

Níveis altos de degradação como estes são determinantes para eventos de extinções locais via alterações em ambientes aquáticos, como represas, desmatamentos, desvio de riachos, canalização, captação excessiva e poluição (ver Cordero-Riveira, 2006; Suhling et al., 2015; Calvão et al., 2016; Daga et al., 2019). Portanto, mudanças nos cursos de água são uma ameaça crítica à sobrevivência das libélulas (Suhling et al., 2015).

A água é um recurso essencial para as atividades humanas e, consequentemente, represamentos são frequentes (Suhling et al., 2015). Os impactos nas comunidades de Odonata devido ao processo de represamento de rios incluem perda de habitat, aumento da incidência solar, da permanência da água, da temperatura e do material acumulado no fundo (Dijkstra & Lempert, 2003). As mudanças na provisão de recursos de um rio em área florestal para um grande lago causada pelo represamento determinam quais espécies serão capazes de ocupar essa nova conformação de habitat.

O primeiro sistema de abastecimento público de Curitiba foi criado no início do século passado na área hoje chamada de Mananciais da Serra (MASE) (ver Cordeiro, 2008). Atualmente, este sistema de abastecimento possui duas barragens que formam os grandes reservatórios Piraquara I e Piraquara II. O Mananciais da Serra (coord. 48°59'W, 25°29'S, altitude: 1.000 m) representa uma região de especial interesse científico, sendo localidade-tipo de espécies de insetos (e.g. Dalmolin et al., 2004; Paladini & Cavichioli 2015) e por ser uma área de ecotono entre os formações de Floresta Ombrófila Mista e Floresta Ombrófila Densa (Reginato & Goldenberg, 2007). A área é parcialmente protegida pelo Parque Estadual do Marumbi (Governo do Paraná, Decretos nº 7300 de 1990 e nº 1531 de 2007) e outra parte está inserida na APA de Piraquara (Governo do Paraná, Decretos nº 1754 de 1996). A região é administrada pela Companhia de Saneamento do Paraná (SANEPAR), apresenta mais de 100 anos de conservação (ver Reginato & Goldenberg, 2007).

Em relação aos insetos aquáticos, o MASE é praticamente inexplorado. Neste estudo exploramos diversos ambientes aquáticos desde fitotelmas, poças, brejos, pequenos riachos até os grandes reservatórios, como o Piraquara II. Coletamos larvas e adultos com diferentes métodos de amostragem. Adicionalmente, consideramos a comunidade de libélulas da área florestada do MASE como mais próxima da original (local) e a comparamos com a comunidade encontrada no reservatório Piraquara II (alterada) para inferir sobre como represamento pode ter influenciado a comunidade de libélulas e o quanto da comunidade local o reservatório é capaz de manter. Trata-se de um estudo inédito que contribuirá para o conhecimento taxonômico, morfológico e ecológico da fauna regional e do estado. Nossa hipótese é que o represamento causa homogeneização e gera *turnover* de espécies com redução da riqueza de espécies locais.

OBJETIVOS

O objetivo deste estudo foi investigar a fauna de libélulas do Mananciais da Serra e assim contribuir com o conhecimento sobre a diversidade de insetos ao sul Mata Atlântica. Os objetivos específicos são: (1) Inventariar e caracterizar as espécies de Odonata nos Mananciais da Serra e (2) Comparar a diversidade de Odonata nos reservatórios e riachos em área florestada.

Os resultados foram organizados em dois capítulos, o primeiro (Capítulo 1) aborda um inventário com a caracterização e descrição da fauna com notas taxonômicas e o segundo (Capítulo 2) aborda a variação na composição das assembleias entre o reservatório Piraquara II e a área florestada do Mananciais da Serra.

CAPÍTULO 1 - Dragonflies (Insecta: Odonata) from Mananciais da Serra, a Tropical–Araucaria forested ecotonal remnant at southern Atlantic Forest, state of Paraná, Brazil[1]

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Abstract. A comprehensive checklist from the protected area of Mananciais da Serra is given. The survey was conducted in the endangered Atlantic Forest domain at southern Serra do Mar mountain chain into a well-preserved area at Piraquara municipality, state of Paraná, Brazil. The sampling effort was between June 2017 and March 2019 using different collecting techniques in numerous mesohabitats from phytotelma, pools, small streams to large reservoirs. A total of 1,627 specimens from 9 families 42 genera and 83 species were sampled. The amount of 53 new records for Paraná almost duplicate the previous known occurrence in the literature for Odonata in that state and *Micrathyria venezuelae* De Marmels, 1989 is recorded for the first time from Brazil. Furthermore, two females, four ultimate stadium larvae, and four undescribed species were detected. Our study shows that sampling larvae improves the abundance of rare species as well as females. The estimated richness of dragonfly fauna maintained by this area is superior than one hundred, corresponding to 10% of Brazilian species, the species-richest country in the world. These results reiterate warns for the knowledge generated by undersampling areas. Finally, taxonomic notes for few species, including the rare corduliid *Neocordulia mambucabensis* Costa & T. C. Santos, 2000 are given.

Key words. conservation, damselfly, inventory, systematics, taxonomy.

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[1] A ser submetido a revista ZOOLOGIA (FI: 0,743 2018, Qualis biodiversidade: B2) normas disponíveis em: https://zoologia.pensoft.net/about#Author-Guidelines

Introduction

The knowledge about distribution of extant species is critical to several areas of biological sciences and conservation. However, it is strongly biased due to well-known factors such as the sampling effort concentrated in areas near research centers, sites easier to access and taxonomic or social preferences such as by large and charismatic organisms (Oliveira et al. 2016, Troudet et. al 2017). These aspects produce distortions in the interpretation on community composition and local endemism (Oliveira et al. 2016). Faunal inventories are appointed as priority actions to soften these biases, because they provide primary data to drawing conservation strategies and manage the biological diversity, especially for undersampled areas and for poorly known taxa (see Novacek and Cleland 2001, Braby and Williams 2016, Oliveira et al. 2016). Most insect taxa are poorly known groups (Novacek and Cleland 2001, Troudet et al. 2017) and certainly have high risk of extinction (Clausnitzer et al. 2009). Deficiencies and sampling bias on distribution data were revealed to Odonata in South America (see von Ellenrieder 2009, Vianna and De Marco 2012), even for the Brazilian Atlantic Forest, largely known as one of the most studied areas in South America, there are poorly sampled sites (cf. Pinto and Kompier 2018, Pinto 2019 and references therein).

The Atlantic Forest is considered a biodiversity hotspot domain due to its high threat and endemism levels, containing from 1 to 8% of the world's biodiversity (Laurence 2009). This domain occurs in part of Argentina, Paraguay and in 17 Brazilian States (out of 27) and includes at least eight biogeographical sub-regions (areas of endemism, BSR) such was proposed by Silva and Casteleti (2003) (see Ribeiro et al. 2009). The original forest cover remaining for this domain is about 12% and these remnants are spread in hundreds of thousands of fragments, most of them smaller than 50 ha (Ribeiro et al. 2009). The three largest fragments are in the Serra do Mar, from the states of Santa Catarina at south to Rio de Janeiro at north, encompassing 13% of total of the preserved remnants of Atlantic Forest (Ribeiro et al. 2009).

The Atlantic Forest is the most important component of the natural landscape of Paraná’s territory, originally covering 98.10% of its total area (see Campanili and Schaffer 2010), nowadays this coverage is about 13.1% (SOS Mata Atlântica / INPE 2018). The Paraná’s Atlantic Forest has four main vegetational formations: Grassland, Tropical Forest, Semideciduous Seasonal Forest and Araucaria Forest (Roderjan et al. 2002) and encompasses the Araucaria, Interior and Serra do Mar BRSs (sensu Silva and Casteleti 2003). The transition between Araucaria and Serra do Mar BRSs correspond to the same transition between Araucaria Forest and Tropical Forest formations at Serra do Mar mountain chain (see Ribeiro et al. 2009). In this ecotone this study was conducted.

Dragonflies (Odonata) remain as aquatic larvae during most part of the period of their post-embrionary life and are important components of the aquatic communities, responsible for several ecosystem services, maintaining the structure and the cycling of nutrients, thus are bioindicators of environmental quality (e.g. Oertli 2008, Silva et al. 2010). Brazil is the richest country for these insects with about 880 species (Pinto and Kompier 2018) and it is estimated that there is many species waiting to be described (Souza et al. 2017). The Odonata richness of Atlantic Forest was estimated to represent 50% of the Brazilian species (Pinto and Kompier 2018). A single site, in the Serra dos Orgãos formation is the worldwide hotspot in number of species for the order with more than 200 species (Kompier 2015).

Besides the type locality for several species is located in southern Brazil (e.g., the Libellulidae *Libellula herculea* Karsch, 1889 and the Gomphidae *Progomphus virginiae* Belle, 1973) and studies focused on the diversity of dragonflies in the region started at least half of a century ago (e.g. Costa 1971, Teixeira 1971), the region lacks compilations of distributional records at species-level, as well as regional inventories as comprehensive checklists. However, the efforts in diversity of odonates in southern Brazil have been dramatically increased in the last decade, at least for Pampean and Atlantic Forest formations at the state of Rio Grande do Sul (e.g., Renner et al. 2016, Renner et al. 2017, Dalzochio et al. 2018, Pires et al, 2019). However the knowledge about Odonata of Paraná is meager, for instance Vianna and De Marco (2012) found a maximum of about 20 species into a single assemblage recorded at a quadrat area of 1-degree cell size based on a review of the historical records and a few material in collections.

The studied area at Piraquara belongs to the Metropolitan Region of Curitiba and is visited by scientists at least since 1896, when B. Bicego collected the holotype of the Diplopoda *Leptodesmus decipiens* Brölemann, 1902 (Schubart 1955), now in the genus *Brasilodesmus* Brölemann, 1929 (Pena-Barbosa 2020). The municipality houses one of the significant remnants of Atlantic Forest near the capital State at the Serra do Mar mountain chain (Reginato and Goldenberg 2007) This municipality includes the region of the "Mananciais da Serra" (MASE) a conservation area which represent a region of extreme biological importance (Rosa 2003). This is a direct consequence of its special scientific interest, once the locality has several surveys, such as faunistic and floristic inventories (Cáceres 2004, Reginato and Golgenberg 2007, Anjos and Navarro-Silva 2008, Bianchi et al. 2012), it is the type-locality for species of insects (e.g. Dalmolin et al. 2004, Paladini and Cavichioli 2015), also a sanctuary for mammalian threatened or rare species (Cáceres 2004). In addition, represent a well-preserved ecotone between Araucaria and Tropical Atlantic Forests due to more than 100 years of conservation policies at that area (Reginato and Goldenberg 2007). The natural and artificial water bodies of MASE favor the existence of a wide variety of mesohabitats, which potentially maintain a high diversity of dragonflies.

The goal of this study is to provide comprehensive checklist of damselflies and dragonflies (order Odonata) from the region of Mananciais da Serra, southern Atlantic Forest. In addition, the compositional diversity (alpha component) is addressed and new state records and taxonomic notes on the rare Corduliidae *Neocordulia mambucabensis* Costa & T.C. Santos, 2000 are given.

Methods

Study area

This study was conducted in the Serra do Mar mountain chain, in an ecotone between Araucaria Forest and Tropical Atlantic Forest (Reginato and Goldenberg 2007) in a fragment of Atlantic Forest maintained by the water and waste management company of the state of Paraná (SANEPAR). This area includes the "Mananciais da Serra" (MASE) and the drainage system of the reservoirs Piraquara I and Piraquara II, at the municipality of Piraquara, Paraná, Brazil (Fig. 1).

Historically, the protected area "Mananciais da Serra" emerged with the creation of the first public water supply system of Curitiba, capital of the state of Paraná, in1908 (see Cordeiro 2008). Today, the Mananciais da Serra protected area shelters the historic heritage of the supply system that was replaced by two subsequent reservoirs generated by the damming of the Piraquara River, the main of the Piraquara sub-basin (SUDERHSA 2000). The area so-called Mananciais da Serra refers to the water supply system of Piraquara Sub-basin and the forested area in the watershed, that is partially protected by Pico do Marumbi State Park (Paraná State government Decrees nº 7300, 1990 and nº 1531, 2007) and Environmental State Protection Area of Piraquara (Paraná State government Decree nº 1754, 1996) protection areas.

For this survey we considered the vegetal formation to separate two areas, thus the Tropical Atlantic Forest area (TF) correspond to the MASE area (Fig. 1C, Table 1, sampling sites 10–21) and the Araucaria Forest area (AF) correspond to the sites out of the MASE delimitation (Fig 1C, Table 1, sampling sites 1–9). The AF sampling sites are in reservoirs Piraquara I and II banks, configuring most lentic systems into an open landscape and perturbed sites, moreover a river with riparian forest and some small forested areas around the reservoirs configure some lotic or forested sampling sites. In contrast, most TF sampling sites are forested areas and running waters, except for the natural pool (Figure 2D, Table 1, sampling site 15).

Sampling

Several water bodies were investigated such as puddles, pools, tanks, dams, streams etc. (Fig. 2). The adults were obtained with three collection methods between June 2017 and March 2019: (1) a Malaise trap at the field for 108 days, (2) 56 events of active collection with aerial entomological nets and (3) occasional sampling of larvae through sieves. A total of 21 sampling sites were investigated (Fig. 1). Coordinates and mesohabitat are presented in the Table 1. Alive specimens were photographed at the field or with a portable studio under white background.

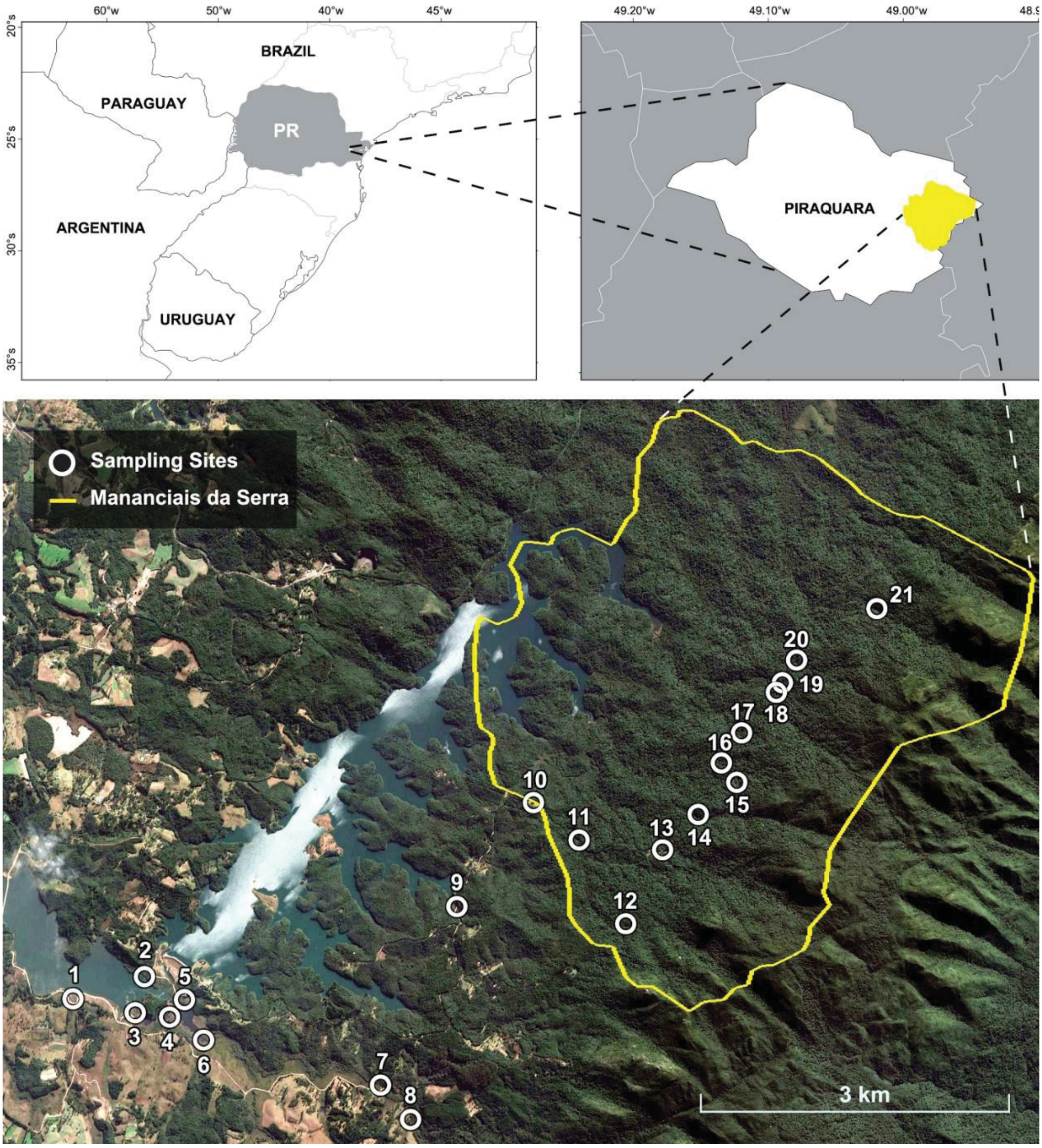

Figure 1. Protected area Mananciais da Serra (MASE), Piraquara municipality, state of Paraná, Brazil and sampling sites of Odonata (A–C): (A) Paraná; (B) Piraquara and MASE; (C) MASE limits in yellow. Numbers 1–21 correspond to the sampling sites. Abbreviations: PR: Paraná.

Table 1. Sampling sites, coordinates and mesohabitats description for Odonata at the protected area Mananciais da Serra, Piraquara municipality, state of Paraná, Brazil. “Catchments” refers to small dams of the old water supply system.

Collection site	Coordinates		Mesohabitats
	Latitude	Longitude	
1. RPIV. Piraquara II reservoir bank	-25.509284°	-49.038360°	Lentic, banks without macrophytes and grassland surrounding; Lotic, small second order river crossing grasslands flowing into the reservoir
2. RPV. Piraquara II reservoir bank	-25.507368°	-49.031490°	Lentic, with macrophytes and forested surrounding
3. RPIII. Piraquara II reservoir bank	-25.510484°	-49.032375°	Lentic, part with macrophytes and banks without macrophytes; Semilotic, Piraquara river trough area
4. Piraquara II reservoir adjacent area	-25.510865°	-49.029077°	Lentic, pool attached with Piraquara II reservoir with macrophytes and *Pinus* forested area
5. RPI. Piraquara II reservoir bank	-25.509353°	-49.027647°	Lentic, with different macrophytes; open grass field; and forested surroundings with semi-lentic channel in the reservoir margin
6. RPII. Piraquara II reservoir bank	-25.512844°	-49.025808°	Lentic, swamps with grass and macrophytes grass; Lotic, fourth order river gradually flowing into the reservoir
7. River II. River with riparian forest	-25.516721°	-49.008813°	Lotic, fourth order river with modified riparian forest, cloudy water, sandy bottom
8. Farm marsh. Flood area near to the street	-25.519690°	-49.005925°	Lentic, shallow swamp with grass vegetation
9. Street. Running water above street	-25.501302°	-49.001491°	Lotic, shallow water course in opened area
10. Base lodge	-25.492325°	-48.994150°	Open field, grass camp around housing
11. River I. River in forested area	-25.495550°	-48.989764°	Lotic, riparian forest well preserved, rocky, leaf and sandy bottom
12. Salto catchment. Stream in forested area	-25.502778°	-48.985278°	Lentic, reservoir with dense leaf bottom; Lotic, stream past the reservoir with rocky bottom
13. Carvalho catchment. Stream in forested area	-25.496389°	-48.980000°	Lentic, reservoir with concrete bottom; Lotic, second order stream with rocky bottom; adjacent opened area.
14. Braço do Carvalho catchment. Stream in forested area	-25.493333°	-48.978333°	Lentic, concrete reservoir with leaf and sandy bottom; Lotic, second order stream with rocky bottom
15. Natural pool	-25.490625°	-48.974656°	Lentic, natural pool in opened area without water flux, clay bottom
16. Mico catchment	-25.488889°	-48.976111°	Lotic, first order stream in a reservoir out of order, riparian forest softly altered
17. Aqueduto. Forested area with small streams	-25.486289°	-48.974170°	Lotic, first order streams with riparian forest well preserved; Semi lentic shallow water accumulating near to the small rivers
18. Cayguava catchment. Stream in forested area	-25.482792°	-48.970836°	Lotic, second order stream with well-preserved riparian forest, rocky and sandy bottom; Lentic, Cayguava reservoir, sandy and leaf bottom
19. Site F. Flooded forested area	-25.481960°	-48.970261°	Semi-lotic, shallow waterbodies with semi-flowing water
20. Iporan catchment. Stream in forested area	-25.480000°	-48.968889°	Lotic, second order stream with well-preserved riparian forest, rocky bottom; Lentic, Iporan reservoir with sandy and leaf bottom
21. Ipiranguinha river. River in forested area	-25.475547°	-48.961192°	Lotic, third order river with well-preserved riparian forest, rocky bottom; Lentic, Ipiranguinha reservoir with sandy and leaf bottom

Curation and identification

The specimens were identified at the species level with the aid of stereomicroscopes, comparison with original descriptions and specimens previously identified by specialists. Species with dubious status due to insufficient taxonomic information (e.g., in the genus *Limnetron* Föster, 1907), specimens under poor condition of preservation (e.g., in the genus *Brechmorhoga* Kirby, 1894), or genus with putative undescribed species (e.g. *Heteragrion* Selys, 1862) are cited as sp., but are recognized as distinct biological entities. The specimens were dried in absolute acetone and deposited in the Coleção Entomológica Padre Jesus Santiago Moure, Departamento Zoologia, Universidade Federal do Paraná, Curitiba (DZUP) and in the Entomological Collection of the Museu Nacional, Universidade Federal do Rio de Janeiro, Rio de Janeiro (MNRJ).

New records

To register new State occurrences, the known distributions of each species were compiled from publications in scientific journals, books, catalogs and specialized literature (e.g. original descriptions and revisions), thus gray literature such as unpublished monographies, dissertations and thesis, abstracts, websites or even records lacking voucher material were discarded. Regular digital databases (e.g. Web of Science) were constantly checked for data on the species occurrence. The full references list with previous records in the literature will be included in the Catalog of the Brazilian Taxonomic Fauna (Pinto 2020).

Analysis

Alpha diversity was analyzed based on richness and abundance. The rarefaction and extrapolation curves using an individual-based (abundance) approach was conducted with the software EstimateS (Version 9.1.0, Colwell 2013) with extrapolation up to 15,000 individuals (S_{est} and SE of Colwell et al. 2012).

Results

Community richness and composition

A total of 1,627 specimens from 9 families, 42 genera and 83 species were sampled. Species list, sampling site, new occurrence records to Paraná and specimens reared (adults emerged in laboratory) are presented in the Table 2. The AF area is predominantly lentic and TF sampling sites are mainly lotic, except for the natural pool (see Table 1, sampling site 15, Fig. 2D). Natural pool was the richest site with 25 species (8 exclusives). The richness and more abundant families were Libellulidae and Coenagrionidae (Fig. 3). No species with crepuscular behavior was collected. The rarefaction and extrapolation curves with their standard deviation based on number of individuals (Fig. 4) shows the observed richness towards estimated richness of 73 species for TF (observed 50 spp.) and 108 species for the reginal pool (observed 83 spp.). A significant portion of the community, 36 species, had five or less specimens collected, from which 21 are single or doubletons. All families were more abundant in the Tropical Forest except for Libellulidae.

Figure 2. Mesohabitats of the sampling sites of Odonata in the protected area Mananciais da Serra, Piraquara municipality, state of Paraná, Brazil: (A) Piraquara II reservoir banks; (B) Piraquara II reservoir with macrophytes; (C) Ipiranguinha River; (D) Natural pool; (E) streamlet with semi-flowing water at Aqueduto; (F) Cayguava catchment reservoir of the old Piraquara supply system. Photos: A–D, F BRA (2019); (E) APP.

Table 2. Species list, abundance and new State records for Odonata at the protected area Mananciais da Serra, Piraquara municipality, state of Paraná, Brazil. Sampling sites 1–21 as in Table 1. Abbreviations: AF = Araucaria Forest, NR = New State Record, TF = Tropical Atlantic Forest.

Taxa	Sampling site	Abundance	Reared larvae	AF	TF	NR
Zygoptera						
Perilestidae						
Perilestes fragilis Hagen in Selys, 1862	12, 13, 20	24	x		x	x
Lestidae						
Archilestes exoletus (Hagen in Selys, 1862)	12, 15	5			x	
Lestes auritus Hagen in Selys, 1862	15	27			x	x
L. dichrostigma Calvert, 1909	4, 12	2		x	x	x
L. pictus Hagen in Selys, 1862	15	5			x	x
L. tricolor Erichson *in* Schomburgk, 1848	5	2		x		
Heteragrionidae						
Heteragrion aurantiacum Selys, 1862	7, 11	7		x	x	x
H. freddiemercuryi Lencioni, 2013	11, 12, 18–21	189			x	x
Heteragrion sp. A	12, 13, 17, 18, 20	53			x	
Heteragrion sp. B	11–13, 18	51			x	
Calopterygidae						
Hetaerina brightwelli (Kirby, 1823)	11–13, 18, 19, 21	23	x		x	x
H. hebe Selys, 1853	7, 12, 13	5		x	x	x
H. longipes Hagen *in* Selys, 1853	11, 12, 17, 18	10			x	x
H. rosea Selys, 1853	1	3		x		x
Coenagrionidae						
Acanthagrion gracile (Rambur, 1842)	1, 2, 4–6	18		x		x
A. lancea Selys, 1876	1–3, 5, 6, 15	55	x	x	x	x
A. truncatum Selys, 1876	3, 6	7		x		x
Aceratobasis macilenta (Rambur, 1842)	7	1		x		x
Argia sordida Hagen in Selys, 1865	13, 17, 18, 20, 21	217			x	x
Forcepsioneura sancta (Hagen in Selys, 1860)	12, 13, 15–18, 20, 21	68			x	
Homeoura chelifera (Selys, 1876)	1–3, 5, 6, 8, 13, 15, 18	65	x	x	x	
Ischnura capreolus (Hagen, 1861)	2, 3, 5, 6, 8, 15	30		x	x	x
I. fluviatilis Selys, 1876	3, 13, 15	6		x	x	x
Leptagrion elongatum Selys, 1876	15	1			x	x
L. macrurum (Burmeister, 1839)	12, 15, 18, 19, 20	28			x	x
Minagrion mecistogastrum (Selys, 1876)	5, 7	3		x		
M. waltheri (Selys, 1876)	6	1		x		
Oxyagrion simile Costa, 1978	15	34			x	
O. terminale Selys, 1876	1–6, 8, 9	45		x		
Telebasis carmesina Calvert, 1909	4, 6	2		x		x
T. theodori (Navás, 1934)	5, 6	13		x		x
T. willinki Fraser, 1948	2–6, 15	43		x	x	x

Table 2. Continued.

Taxa	Sampling site	Abundance	Reared larvae	AF	TF	NR
Anisoptera						
Aeshnidae						
Castoraeschna castor (Brauer, 1865)	15	1			x	x
Castoraeschna cf. margarethae Jurzitza, 1979	15	1			x	
Coryphaeschna perrensi (McLachlan, 1887)	2, 3, 5, 6	9	x	x		
Limnetron sp.	12, 13, 18, 20, 21	12			x	
Remartinia l. luteipennis (Burmeister, 1839)	6	1		x		
Rhionaeschna bonariensis (Rambur, 1842)	8	1		x		
R. brasiliensis (von Ellenrieder & Costa, 2002)	5	1		x		
R. confusa (Rambur, 1842)	3	1		x		x
R. decessus (Calvert, 1953)	15, 18	3			x	x
R. punctata (Martin, 1908)	4, 10, 12–14, 18	17			x	x
R. planaltica (Calvert 1952)	12, 14, 15, 18, 20	26	x	x	x	
Gomphidae						
Aphylla theodorina (Navás, 1933)	15	2			x	x
Phyllogomphoides annectens (Selys, 1869)	11, 18, 20	7	x		x	
Phyllocycla diphylla (Selys, 1854)	1	1		x		x
Progomphus complicatus Selys, 1854	5, 7, 18	4		x	x	x
Progomphus aff. *gracilis* Hagen *in* Selys, 1854	11, 13, 18, 20	32			x	
Corduliidae *s.l.*						
Neocordulia mambucabensis Costa & Santos, 2000	11, 12, 20	7	x		x	x
Libellulidae						
Brechmorhoga nubecula (Rambur, 1842)	13	1			x	x
Brechmorhoga sp. A	20	1			x	
Brechmorhoga sp. B	13, 18, 21	3			x	
Dasythemis mincki mincki (Karsch, 1889)	2, 4, 6, 13, 17, 18	18		x	x	x
Dasythemis sp.	1, 6	4		x		
Diastatops intensa Montgomery, 1940	2, 3	8		x		x
Dythemis nigra Martin, 1897	2	3		x		x
Erythemis peruviana (Rambur, 1842)	5	1		x		x
Erythrodiplax acantha Borror, 1942	15	16			x	x
E. anomala (Brauer, 1865)	4, 6	5		x		x
E. castanea (Burmeister, 1839)	2, 5, 6, 15	37		x	x	x
E. fusca (Rambur, 1842)	1, 3, 5, 6, 18	20		x	x	
E. hyalina Förster, 1907	4, 13, 15	5		x	x	x
E. media Borror, 1942	1–6, 20	48	x	x	x	x
E. melanorubra Borror, 1942	1–7, 13, 15	100	x	x	x	x
E. paraguayensis (Förster, 1905)	3, 15	4		x	x	x
Erythrodiplax sp.	1, 3, 5, 6	36		x		
Macrothemis imitans imitans (Karsch, 1891)	1–3	9		x		x
Macrothemis tenuis Hagen, 1868	7	1		x		x
Miathyria marcella (Selys in Sagra, 1857)	2, 5, 7, 10, 13	7		x	x	x
M. simplex (Rambur, 1842)	1, 3, 5, 6	6		x		x
Micrathyria hypodidyma Calvert, 1906	2, 3, 5–7	24		x		

Table 2. Continued.

Taxa	Sampling site	Abundance	Reared larvae	AF	TF	NR
Micrathyria stawiarskii Santos, 1953	5	1		x		
M. venezuelae De Marmels, 1989	8	1			x	x
Nephepeltia flavifrons (Karsch, 1889)	5, 6	10		x		x
Oligoclada laetitia Ris, 1911	1–3	9		x		x
Orthemis discolor (Burmeister, 1839)	1, 13	4		x	x	
Pantala flavescens (Fabricius, 1798)	1, 6, 10, 13, 15	16		x	x	
Perithemis mooma Kirby, 1889	2, 3, 5, 6	13		x		
Planiplax erythropyga (Karsch, 1891)	1–3, 5	25	x	x		x
Tauriphila xiphea Ris, 1931	2, 3, 5, 6	10	x	x		x
Tramea binotata (Rambur, 1842)	6, 15	2		x	x	x
T. cophysa Hagen, 1867	5, 15	3		x	x	
T. rustica De Marmels & Rácenis, 1982	3, 6	7		x		x
9 Famílies, 44 genera, 83 spp.	-	1,627	-	55	50	53

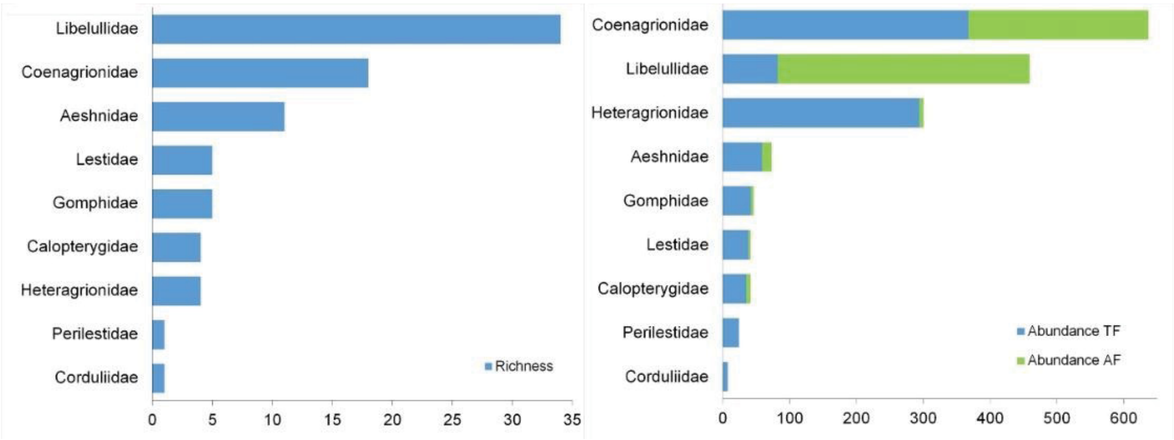

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Figure 3. Richness and absolute abundance of Odonata families in the protected area Mananciais da Serra, Piraquara municipality, state of Paraná, Brazil. (A) Regional pool richness; (B) Araucaria Forest (AF) and Tropical Atlantic Forest (TF) abundance.

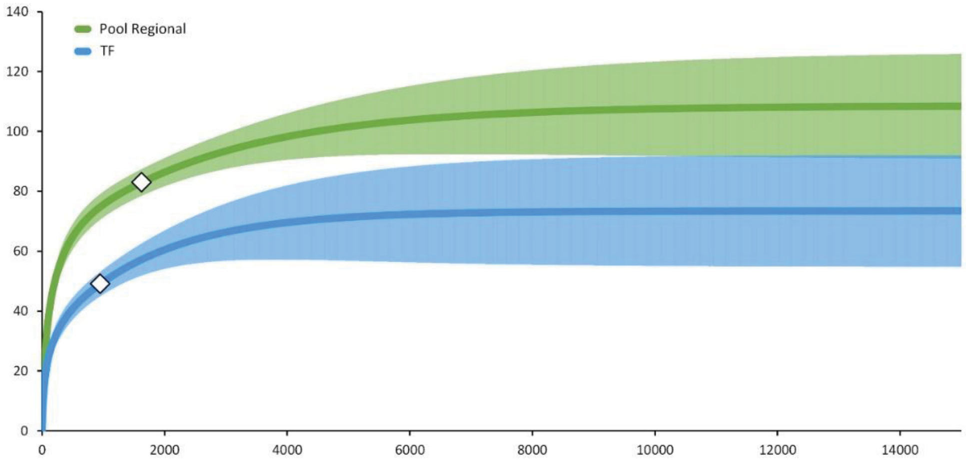

Figure 4. Rarefaction and extrapolation curves up to 15,000 individuals based on abundance data in the protected area Mananciais da Serra, Piraquara municipality, state of Paraná, Brazil.

Diamonds shows the observed richness: Pool regional (green), 83 species in 1627 individuals (estimated richness 108); Tropical Atlantic Forest (TF, blue), 50 species in 947 individuals (estimated richness 73).

The hitherto unknown females of *Heteragrion freddiemercuryi* Lencioni, 2013 and *Planiplax erythropyga* (Karsch, 1891) were collected. Four species with unknown larvae emerged at laboratory, i.e., (1) *P. erythropyga*, (2) *N. mambucabensis*, (3) *Heteragrion* sp. and (4) *Acanthagrion lancea* Selys, 1876 (Fig. 5D), so these F-0 exuviae are available for description. In addition, five undescribed species were detected from the genera *Heteragrion* Selys, 1862 (1 sp., Heteragrionidae), *Progomphus* Selys, 1854 (1 sp., Gomphidae), and *Brechmorhoga* Kirby 1894, *Erythrodiplax* Brauer, 1868 and *Dasythemis* Karsch, 1889 (1 sp. each, Libellulidae) which should be described in elsewhere.

Taxonomic notes

Four of the identified species are of special taxonomic interest due to poorly known, show morphological variation or are unexpected occurrence and will be commented here.

Neocordulia mambucabensis. A series of seven adults of *Neocordulia mambucabensis* (Figs 6C, 7) allows to discuss its taxonomic status. This species was described based on a male holotype and female paratype from Rio Mambucaba river, collected at the highlands (about of 2,000 m a.s.l.) of the Serra da Bocaina National Park (Costa and Santos 2000b). The type locality has a dubious location and potentially was mistakenly cited as Rio de Janeiro State in the original description; however, they were collected at the headquarters of the park at the São José do Barreiro municipality, state of São Paulo (APP unpublished). Both specimens were collected among a series of ultimate stadia larvae of *Neocordulia* Selys, 1882 and at least five adults emerged in the laboratory. The female paratype has been firstly determined as *N. setifera* (Hagen *in* Selys, 1871), *N. androgynis* (Selys, 1871) and, *N. carlochagasi* Santos, 1967, and it appears that been ultimately associated to the holotype of *N. mambucabensis* mainly due to the collection site. In the same series of emerged adults of the *N. mambucabensis* there are three males of *N. matutuensis* Machado, 2005, which were misidentified as *N. setifera* by Costa & Santos (2000b) (APP unpublished). Furthermore at the type locality and nearby areas of *N. mambucabensis* it occurs in sympatry with *N. androgynis, N. setifera*, *N. matutuensis* (Costa and Santos 2000a,b, APP unpublished), and virtually also *N. carlochagasi* Santos, 1967. Recently *N. mambucabensis* was recorded from Serra dos Orgãos (cf. Kompier, 2015) and the voucher specimens together with the type series were deposited in the entomological collection of the MNRJ and it was destroyed in the fire of 2018 (APP, unpublished data).

Figure 5. Habitus of Zygoptera from the protected area Mananciais da Serra, Piraquara municipality, state of Paraná, Brazil: (A) *Perilestes fragilis* Hagen in Selys, 1862, Perilestidae; (B) *Lestes auritus* Hagen in Selys, 1862, Lestidae; (C): *Heteragrion freddiemercuryi* Lencioni, 2013, Heteragrionidae; (D) *Acanthagrion lancea* Selys, 1876, Coenagrionidae; (E) *Leptagrion macrurum* (Burmeister, 1839), Coenagrionidae; (F) *Telebasis carmesina* Calvert, 1909, Coenagrionidae. Photos BRA.

The taxonomy of the genus *Neocordulia* is plagued by imprecisions and misidentifications and has been difficult with a few specific statuses questionable (see Pinto and Carvalho 2011). This is critical to the females that are poorly known, once five out of the 16 species the female still unknown. A series of six males and one female were collected in different moments and in three different collection sites at MASE. Five of them were reared in laboratory, including a single female. All the males correspond to the same biological entity and, to ensure the identification,

Figure 6. Habitus of Anisoptera from the protected area Mananciais da Serra, Piraquara municipality, state of Paraná, Brazil: (A) *Rhionaeschna planaltica* (Calvert 1952), Aeshnidae; (B) *Aphylla theodorina* (Navás, 1933), Gomphidae; (C): *Neocordulia mambucabensis* Costa & T. C. Santos, 2000, Corduliidae s.l.; (D) *Erythrodiplax castanea* (Burmeister, 1839); (E) *Planiplax erythropyga* (Karsch, 1891), Libellulidae; (F) *Tramea rustica* De Marmels & Rácenis 1982, Libellulidae. Photos BRA.

it was made by comparison to the original description and photos of the holotype (now lost). The female was collected with two other males and after the emergence it was identified by association with the male. Additionally, there is no evidence of co-occurrence of any other species of *Neocordulia* in the MASE area. However, our female has significant differences compared to the original description and illustrations by Costa and Santos (2000b).

The dorsal margin of the subgenital plate is regular in lateral view, almost straight (Fig. 7A, C). while it show a strong concavity in the original description (Fig. 7B, D), the apex reach posteriorly <0.5 of ninth abdominal segment (S9) (Fig. 7A, C), while surpasses posterior 0.5 of the length of ninth abdominal segment (S9) in the original description (Fig. 7B,D). In ventral view, the distal margin is regularly curved (slightly convex) with roughly acute tips and mesial cleft Y-shaped (Figs 7E), versus distal margin is accentuated curved clearly concave with rounded tips and mesial cleft V-shaped (Figs 7F). Therefore, based on inconsistencies observed and new data of speciemns from MASE we suspect that the allotype (sic, paratype) female of *N. mambucabensis* was misidentified, as well as the additional females in Kompier (2015). The unknow larvae will be described in elsewhere.

Erythrodiplax acantha Borror, 1942 was described based on a series of four males collected by F. W. Bauer in São Paulo Capital (Borror 1942) and no additional data was published about this species being considered recently as Critical Endangered in the RedList of that State (Pinto 2018, São Paulo State government Decree nº 63.853). It can be considered an exception among the large and taxonomic difficult genus *Erythrodiplax*, being easily identified due to its unique shape of the vesica spermalis, specially by the thorn-shaped (spine) median process (Borror 1942). The eleven examined males agree fairly well with the original description (Borror 1942, p. 199) except by the general coloration. Our specimens are somewhat lighter brownish-yellow in opposite to black and brown from the type series, postfrons is not flattened and lacking bluish metallic reflections, although show purplish metallic reflections. In general color variation could be due to ontogenetic changes, aspect well documented including by Borror (1942), for instance in *Erythrodiplax hyalina* Förster, 1907. However, it cannot be explained only by the age of the specimens, because MASE adults are apparently mature with evidence of senility (pruinosity and hard exoskeleton). Most likely coloration and not unflattened postfrons are populational phenomena.

Heteragrion freddiemercuryi Lencioni, 2013 (Fig. 5C), the second more abundant species, was described from Peruibe, a lowland area (10 m a.s.l.) of São Paulo State (Lencioni 2013). Here we found an abundant population living in a highland (1,000 m a.s.l.). extending considerably, it ranges of occurrence and open questions one its lowland habitat preferences

Planiplax erythropyga is a species rare in entomological collections (Garrison et al. 2006) and its flyer behavior makes it difficult to collect. The sampling site RPIII (Fig. 2A) had a successful collection event in with 15 males were collected in a period of 3 hours. The males were abundant near the banks without macrophytes, probable preferred mesohabitat arena of this species.

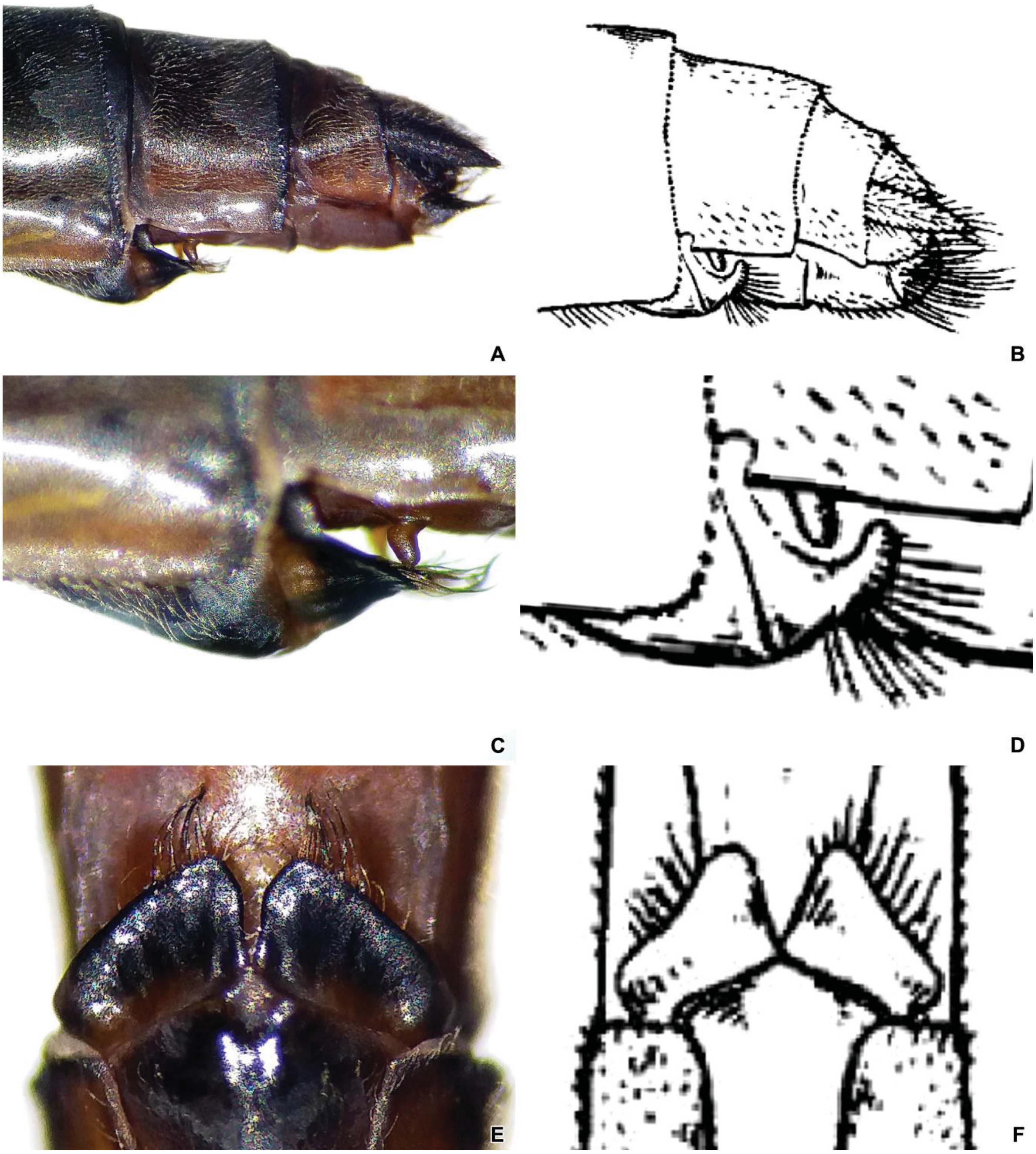

Figure 7. Terminalia of female of the *N. mambucabenis* Costa & T.C. Santos 2000: (A–C) Reared specimen from Mananciais da Serra, Piraquara municipality, state of Paraná, Brazil; (D–F) from Costa and Santos (2000) specimen from the type locality at São Paulo, Brazil; (A, B, D, E): S8–10 and subgenital plate in lateral view; (C, F) subgenital plate in ventral view. Photos: A–C APP.

Geographic records

A total of 53 new occurrence records are observed for the state of Paraná (Table 2, Figs 5, 6) and *Micrathyria venezuelae* De Marmels, 1989 is recorded for the first time from Brazil. The species recorded for the first time to Paraná and previous known distributions complied from the literature are presented below.

List of species recorded for the first time to the state of Paraná with previous known distribution data.

1. *Perilestes fragilis* Hagen *in* Selys, 1862 (Fig. 5A)

Distribution: Guyana[?], BRAZIL: AM[?], MG, ES, RJ, SP, PR*.

Remarks: The records from Amazonia State and Guyana probably is due to misidentification because most likely it is an endemic species of Atlantic Forest; thus, these occurrences should be checked.

2. *Lestes auritus* Hagen *in* Selys, 1862 (Fig. 5B)

Distribution: Argentina, BRAZIL: MG, RJ, PR*, SC, RS.

3. *Lestes dichrostigma* Calvert, 1909

Distribution: Venezuela, Argentina, BRAZIL: MT, MG, SP, PR*, RS.

4. *Lestes pictus* Hagen *in* Selys, 1862

Distribution: Peru, Argentina, BRAZIL: MT, MG, ES, RJ, SP, PR*, RS.

5. *Heteragrion freddiemercuryi* Lencioni, 2013 (Fig. 5C)

Distribution: BRAZIL: SP, PR*.

Remarks: See taxonomic notes.

6. *Heteragrion aurantiacum* Selys, 1862

Distribution: Paraguay, Argentina, BRAZIL: BA, MG, ES, RJ, SP, PR*

7. *Hetaerina brightwelli* (Kirby, 1823)

Distribution: BRAZIL: PA, MG[?], ES, RJ, SP, PR*.

Remarks: Santos (1970) cited this species from National Park of Itatiaia without locality. Itatiaia massif is in the boundaries of Rio de Janeiro and Minas Gerais, thus the record for MG pending confirmation.

8. *Hetaerina hebe* Selys, 1853

Distribution: Venezuela, BRAZIL: PB[?], MG, ES, RJ, SP, PR*, SC[?], RS.

Remarks: Garrison (1990) cited PB doubtful; specimens from SC most likely is this species but pending confirmation.

9. *Hetaerina longipes* Hagen *in* Selys, 1853

Distribution: Paraguay, Argentina, BRAZIL: MG, ES, RJ, SP, SC, PR*, RS.

10. *Hetaerina rosea* Selys, 1853

Distribution: Peru, Bolivia, Paraguay, Argentina, Uruguay, BRAZIL: CE, RO, MT, BA, MG, MS, ES, RJ, SP, PR*, RS.

11. *Acanthagrion gracile* (Rambur, 1842)

Distribution: Peru, Bolivia, Paraguay, Argentina, Uruguay, BRAZIL: CE, MT, BA, MG, MS, ES, RJ, SP, PR*, RS.

Remarks: Northern South America records most likely refers to other species (cf. Mauffray and Tennessen 2019). Thus, records northern than Bolivia (e.g., Peru, Mexico as cited by Heckman 2008) must be checked.

12. *Acanthagrion lancea* Selys, 1876 (Fig. 5D)

Distribution: Colombia[?], Peru, Paraguay, Argentina, Uruguay, BRAZIL: MG, MS, ES, RJ, SP, PR*, SC, RS.

Remarks: Northern South America records most likely refers to other species (cf. Mauffray and Tennessen 2019). Thus, records northern than Bolivia (e.g., Peru, Mexico as cited by Heckman 2008) must be checked.

13. *Acanthagrion truncatum* Selys, 1876

Distribution: Venezuela, Guyana. BRAZIL: PI, TO, MT, GO, BA, MG, MS, SP, PR*.

14. *Aceratobasis macilenta* (Rambur, 1842)

Distribution: BRAZIL: MG, RJ, SP, PR*, SC.

15. *Argia sordida* Hagen *in* Selys 1865

Distribution: BRAZIL: MG, MS, ES, RJ, SP, PR*.

Remarks: Record to MS is out of Atlantic Forest domain, distant from previous known records, thus must be checked.

16. *Ischnura capreolus* (Hagen, 1861)

Distribution: Mexico south to Panama. Trinidad and Tobago, Colombia, Venezuela, Ecuador, Peru, Bolivia, Guyana, Suriname, French Guiana, Paraguay, Argentina, BRAZIL: RR, PA, AM, AC, PI, CE, PB, PE, MT, RO, GO, BA, MG, MS, ES, RJ, SP, PR*, RS.

17. *Ischnura fluviatilis* Selys, 1876

Distribution: Venezuela, Ecuador, Peru, Bolivia, Guyana, Suriname, French Guiana, Chile, Paraguay, Argentina, Uruguay, BRAZIL: PA, AM, MA, CE, PB, PE, MT, RO, MG, MS, ES, RJ, SP, PR*, RS.

18. *Leptagrion elongatum* Selys, 1876

Distribution: BRAZIL: BA[?], ES, RJ, SP, PR*.

Remarks: Lencioni (2017) mentioned this species from BA, but we not located records in the literature, thus the occurrence in that State pending confirmation.

19. *Leptagrion macrurum* (Burmeister, 1839) (Fig. 5E)

Distribution: BRAZIL: BA, ES, RJ, SP, PR*, SC.

20. *Telebasis carmesina* Calvert, 1909 (Fig. 5F)

Distribution: Bolivia, Paraguay, Argentina, BRAZIL: MT, MG, MS, RJ, SP, PR*, SC, RS.

21. *Telebasis theodori* (Navás, 1934)

Distribution: Argentina, BRAZIL: PR*, SC, RS.

22. *Telebasis willinki* Fraser, 1948

Distribution: Bolivia, Paraguay, Argentina, Uruguay, BRAZIL: BA, MG, MS, SP, PR*, RS.

23. *Castoraeschna castor* (Brauer, 1865)

Distribution: Suriname, BRAZIL: MG[?], ES, RJ, SP, PR*.

Remarks: Santos (1970) cited from National Park of Itatiaia without locality. Itatiaia massif is in the boundaries of Rio de Janeiro and Minas Gerais, thus the record for MG pending confirmation.

24. *Rhionaeschna confusa* (Rambur, 1842)

Distribution: Chile, Paraguay, Argentina, Uruguay, BRAZIL: RJ, PR*, SC, RS.

25. *Rhionaeschna decessus* (Calvert, 1953)

Distribution: BRAZIL: RJ, PR*.

Remarks: Part of the records in von Ellenrieder (2003) and Carvalho & Salgado (2004) refers to *R. decessus*-complex and *R. punctata*-complex (Silva et al. in prep.).

26. *Rhionaeschna punctata* (Martin, 1908) (Fig. 6A)

Distribution: BRAZIL: MG, ES, RJ, SP, PR*, SC, RS.

Remarks: Part of the records in von Ellenrieder (2003) and Carvalho & Salgado (2004) refers to *R. decessus*-complex and *R. punctata*-complex (Silva et al. in prep.).

27. *Aphylla theodorina* (Navás, 1933) (Fig. 6B)

Distribution: Venezuela, Peru, Guyana, Argentina, BRAZIL: PE, SE, MT, RO, MG, MS, ES, RJ, SP, PR*, RS.

28. *Phyllocycla diphylla* (Selys, 1854)

Distribution: Venezuela, Argentina[?], BRAZIL: AM[?], AL, MG, ES, SP, PR*.

Remarks: Heckman (2006, p. 615) cited occurrence to Argentina and AM (latter record reproduced in Koroiva et al. 2020), but we did not locate the references.

29. *Progomphus complicatus* Selys, 1854

Distribution: Paraguay, Argentina, BRAZIL: CE, BA, MG, ES, RJ, SP, PR*, SC, RS.

30. *Neocordulia mambucabensis* Costa & T.C. Santos, 2000 (Figs 6C, 7)

Distribution: Brazil: RJ, PR*.

Remarks: See taxonomic notes.

31. *Brechmorhoga nubecula* (Rambur, 1842)

Distribution: Mexico, Belize, Costa Rica, Panama, Trinidad and Tobago, Colombia, Venezuela, Ecuador, Peru, Paraguay, Argentina, BRAZIL: AM, CE, MT, BA, MG, ES, RJ, SP, PR*, SC, RS.

32. *Dasythemis mincki mincki* (Karsch, 1890)

Distribution: Paraguay, Argentina, Uruguay, BRAZIL: GO, MG, ES, RJ, SP, PR*, RS.

33. *Diastatops intensa* Montgomery, 1940

Distribution: Colombia, Peru, Paraguay, Argentina, Uruguay, BRAZIL: PA[?], MT, MG, MS, RJ, SP, PR*, RS.

Remarks: Heckman (2006, p. 147) cited occurrence to PA, but we did not locate the reference.

34. *Dythemis nigra* Martin, 1897

Distribution: Mexico south to Panama, Trinidad and Tobago, Colombia, Venezuela, Ecuador, Peru, Guyana, Suriname, French Guiana, Paraguay, Argentina, BRAZIL: RR, PA, AM, CE, PE, MT, RO, GO, BA, MG, MS, ES, RJ, SP, PR*, SC, RS.

35. *Erythemis peruviana* (Rambur, 1842)

Distribution: USA south to Panama, Trinidad and Tobago, Colombia, Venezuela, Guyana, Suriname, French Guiana, Ecuador, Peru, Bolivia, Paraguay, Argentina. BRAZIL: RR, PA, AM, MA, CE, PE, SE, MT, RO, GO, BA, MG, MS, ES, RJ, SP, PR*, SC, RS.

36. *Erythrodiplax acantha* Borror, 1942

Distribution. BRAZIL: SP, PR*.

Remarks: See taxonomic notes.

37. *Erythrodiplax anomala* (Brauer, 1865)

Distribution: Argentina, BRAZIL: BA, RJ, SP, PR*, RS.

38. *Erythrodiplax castanea* (Burmeister, 1839) (Fig. 6D)

Distribution: Belize, Guatemala, Costa Rica, Trinidad and Tobago, Colombia, Venezuela, Guyana, Suriname, French Guiana, Ecuador, Peru, Bolivia, Paraguay, Argentina, BRAZIL: PA, AM, CE, PE, MT, RO, GO, BA, MG, MS, ES, SP, RJ, PR*, SC.

39. *Erythrodiplax hyalina* Förster, 1907

Distribution: Paraguay, Uruguay, BRAZIL: MG, RJ, SP, PR*, SC, RS.

40. *Erythrodiplax media* Borror, 1942

Distribution: Bolivia, Paraguay, Argentina, Uruguay, BRAZIL: MA[?], MG, RJ, SP, PR*, SC, RS.

Remarks: De Marco (2008) recorded this species to MA, in a transitional site between Caatinga and Amazonia. Due to strongly out from the known distribution in the Atlantic Forest, Pampean and Chacoan formations we suspect be a misidentification.

41. *Erythrodiplax melanorubra* Borror 1942

Distribution: Venezuela, Ecuador, Peru, Bolivia, French Guiana, Chile, Paraguay, Argentina, BRAZIL: MG, MS, RJ, SP, PR*, SC, RS.

42. *Erythrodiplax paraguayensis* (Förster, 1905)

Distribution: Colombia, Venezuela, Ecuador, Bolivia, Guyana, Suriname, Paraguay, Argentina BRAZIL: RR, MA, CE, MT, MG, MS, RJ, SP, PR*, RS.

43. *Macrothemis imitans imitans* Karsch, 1890

Distribution: Colombia, Venezuela, Ecuador, Bolivia, Guyana, Suriname, Paraguay, Argentina, BRAZIL: MT, BA[?], MG, MS, ES, RJ, SP, PR*, SC, RS.

Remarks: Barbosa et al. (2019) mentioned this species from BA and PR, but we do not locate records in the literature. Hence the occurrence in BA pending confirmation. Our specimens confirm the occurrence of this species in PR.

44. *Macrothemis tenuis* Hagen, 1868

Distribution: Argentina, BRAZIL: MG, ES, RJ, SP, PR*.

45. *Miathyria marcella* (Selys *in* Sagra, 1857)

Distribution: USA to Panama, Trinidad e Tobago, Colombia, Venezuela,, Ecuador, Peru, Bolivia, Guyana, Suriname, French Guiana Paraguay, Argentina, Uruguay, BRAZIL: RR, PA, AM, MA, CE, PE, MT, BA, MG, MS, ES, RJ, SP, PR*, RS.

46. *Miathyria simplex* (Rambur, 1842)

Distribution: Mexico, Belize, Guatemala, Honduras, Costa Rica, Panama, Cuba, Haiti, Dominican Republic, Puerto Rico, Trinidad e Tobago, Colombia, Venezuela, Ecuador, Peru, Guyana, Suriname, French Guiana, BRAZIL: PA, AM, MT, MS, ES, RJ, SP, PR*, RS.

47. *Micrathyria venezuelae* De Marmels, 1989

Distribution: Venezuela, Ecuador, Argentina, BRAZIL: AM, PR*.

48. *Nephepeltia flavifrons* (Karsch, 1889)

Distribution: Mexico, Belize, Guatemala, Honduras, Costa Rica, Colombia, Venezuela, Ecuador, Peru, Bolivia, Suriname, French Guiana, Paraguay, Argentina, BRAZIL: RR, PE, MT, RO, BA, MG, ES, RJ, SP, PR*, SC, RS.

Remarks: Bastos et al. (2019) mentioned this species from AC, PA, and MS, but we did not locate records in the literature. In a recent checklist from MS (Rodrigues and Roque 2017) this species is not mentioned.

49. *Oligoclada laetitia* Ris, 1911

Distribution: Argentina, BRAZIL: MG, MS, RJ, SP, PR*, RS.

50. *Planiplax erythropyga* (Karsch, 1891) (Fig. 6E)

Distribution: Argentina, Uruguay, BRAZIL: PR*, RS.

51. *Tauriphila xiphea* Ris, 1931

Distribution: Paraguay, Argentina, BRAZIL: ES, RJ, PR*, RS.

52. *Tramea binotata* (Rambur, 1842)

Distribution: USA to Panama, Trinidad e Tobago, Colombia, Venezuela, Ecuador, Peru, Suriname, French Guiana, Paraguay, Argentina, BRAZIL: AM, PE, MT, BA, MG, MS, ES, RJ, SP, PR*, RS.

53. *Tramea rustica* De Marmels & Rácenis, 1982 (Fig. 6F)

Distribution: Colombia, Venezuela, Bolivia, Suriname, French Guiana, Paraguay, Argentina, BRAZIL: AM, MT, RO, MG, MS, RJ, PR*.

Discussion

Community richness and composition

The first inventory for Mananciais da Serra revealed an impressive rich community with 83 species for a small sampled area and shows its potential for future research. Observed richness is statistically a subsampling for regional pool (Fig. 4), although is close to the estimated richness of 108 species. The estimated richness possibly is very close to the regional pool community due to expected species to occur in this area and not sampled such as common species (e.g. *Erythemis* vesiculosa (Fabricius, 1775)), wide range species (e.g. *Erythrodiplax* umbrata (Linnaeus, 1758)), the crepuscular ones (e.g. *Triacanthagyna* spp. Selys, 1883) and the sighted but not collected *Erythemis attala* (Selys *in* Sagra, 1857), *Perithemis icteroptera* (Selys *in* Sagra, 1857) and unidentified species of the genera *Mnesarete* Cowley, 1934, Mescistogaster *Platystigma* Kennedy, 1920, *Gynacantha* Rambur, 1842 and *Libellula* Linnaeus, 1758. Another evidence of the higher richness is that almost half of the community species (36) had less than five specimens collected, possibly a consequence of the disparities of collection effort across the sampling sites and relative abundance in the field.

Standard Deviation of TF and Regional Pool almost not overlapping shows that TF community is complementary to AF to compose the regional pool community. This aspect is being investigated by Araujo et al. (in press).

The natural pool sampling site is unique among the other sites in TF, it is characteristically a lentic system, without any running water. The rocky soil does not support the development of large trees, so this area is not shaded by the vegetation. This influence on physical, chemical and biological conditions of water environment and permits most insolation, one of the abiotical feature most important in filtering Odonata species occurrence (see Dijkstra and Clausnitzer, 2006), a refuge among predominant lotic systems and forested areas. These aspects allow the occurrence of a unique faunal composition with some well-established abundant species, such as *Lestes auritus* Hagen *in* Selys, 1862, *Oxyagrion simile* Costa, 1978, *Erythrodiplax castanea* (Burmeister, 1839) and *Erythrodiplax acantha* Borror, 1942. Interestingly, this fauna is composed by 14 species of lentic habitat preferences (*Acanthagrion lancea* Selys, 1876, *E. acantha*, *E. castanea*, *Erythrodiplax hyalina* Föster, 1907, *Erythrodiplax melanorubra* Borror, 1942, *Erythrodiplax paraguayensis* (Föster, 1905), *Homeoura chelifera* (Selys, 1876), *Ischnura capreolus* (Hagen, 1861), *Ischnura fluviatilis* Selys, 1876, *Pantala flavescens* (Fabricius, 1798), *Rhionaeschna planaltica* (Calvert, 1952), *Telebasis willinki* Fraser, 1948, *Tramea binotata* (Rambur, 1842) and *Tramea cophysa* Hagen, 1867) that also occurs in AF area, eight exclusive species and three that occurs in neighboring TF sampling sites.

All families were more abundant in TF except Libellulidae. Despite being the richest family, its representatives occurred at a low frequency in TF, possibly due to the low availability of characteristically lentic system and its preference, similar results were found by Pires et al. (2019).

Different methods of collection can be complementary improving the diversity sampling of Odonata (De Almeida et al. 2013). In this study the sieve method does not improved the richness, but it was important to obtain rare species and females proportionally less abundant than males in collections (e.g. Paulson and Jenner 1971, see also De Almeida et al. 2013). Five from seven specimens of *Progomphus* aff. *Gracilis* Hagen *in* Selys, 1854 were collected with sieve, the same occurred for the rare species *Neocordulia mambucabensis* Costa e T. C. Santos, 2000, including the single female. Furthermore, the sieve method allowed to sample the single and undescribed female of *Planiplax erythropyga* (Karsch, 1891), four from five females of *Limnetron* sp. Föster, 1907 and four from five females of *Phyllogomphoides annectens* (Selys, 1869). In addition, the collection of larvae can improve the records of crepuscular species as evidenced by Reels (2011) and as discussed by Pinto (2019).

Similarly to other exploratory survey researches, the crepuscular species (besides sight) were not sampled (Renner et al. 2016, 2017), possibly due to timing survey (Reels 2011), collector negligence due to its flier behavior as occurs for some corduliids (see Pinto 2019) or the shortened flying period that makes them less susceptible to capture.

Geographic records

The richness of 83 species overcome the literature records for the state of Paraná (60 spp., unpublished data) and the 53 new occurrences almost duplicates the state records. It can be explained largely because of undersampling, possibly potentiated by gap of studies in entomological collections or data compilation surveys (Vianna and De Marco Júnior 2012). Some of the new records were strongly expected and predictable such as widespread species (e.g., *Acanthagrion gracile* (Rambur, 1842), Fig. 5D), species recorded in Paraná's neighboring States in Rio Grande do Sul and Santa Catarina (e.g. *Leptagrion macrurum* (Burmeister, 1839)), *Telebasis carmesina* Calvert, 1909, *Lestes auritus* Hagen *in* Selys, 1862, Figs 5B, E, F). Some records are interesting because contribute to expand species occurrence (e.g. *Rhionaeschna decessus* (Calvert, 1953), Fig. 6A) or because are rare in collections (e.g. *N. mambucabensis* and *P. erythropyga*, Figs 6C, F). An endangered species was recorded, *Erythrodiplax acantha* (Estado de São Paulo 2018).

Conclusions

The richness maintained by Mananciais da Serra represents 10% of the Brazilian Odonata (data based on Pinto 2020) and at least 60% of the species known for Parana state. This survey is a clear example of how undersampling areas can generate gaps of knowledge that lead to inconsistences, such as distribution patterns. The high number of new records and the new species are evidences of a neglected area and alerts for its potential odonate richness. *Micrathyria venezuelae* é registrada pela primeira vez para o Brasil. The female of the original description of *Neocordulia mambucabensis* Costa & T.C. Santos 2000 is another species of *Neocordulia*. Considering the high deforestation of Paraná's Atlantic Forest and the majority remnants concentrated in small fragments, it should be investigated (as proposed by Paulson, 2006) to understand how this partitioning of the forest cover can influence the Odonata diversity and how the fauna recolonizes reforested areas. The data presented here are unprecedented and contribute to the taxonomic and morphological knowledge, including adults and larval data, of the local Odonata community.

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CAPÍTULO 2 - Influence of river damming on a dragonfly community structuring at subtropical forest (Insecta: Odonata): landscape homogenization and biodiversity composition in southern Atlantic Forest [2]

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Abstract

1. Human activities alter the structure, dynamics and energy flow in rivers and lakes, e.g. river damming process increase the solar incidence, the water permanence and temperature, threatening dragonflies.

2. Given that Odonata species are sensible to environmental changes, two communities from a forested area (quasi-pristine assemblage, MS) and from a reservoir (homogeneous landscape assemblage, RP) were investigated.

3. Analysis on species composition indicate that MS community is more heterogeneous. The high turnover in communities characterize a Clementsian pattern in metacommunity, probably due to the water system conversion and homogenization. In summary, the reservoir had an almost nil capacity to maintain the local fauna.

4. RP assemblage had highest species richness, Shannon-Wiener diversity and Pielou's evenness, result related to the high occurrence of generalist's species. The community found in slow (RP) and running (MS) water system is almost totally different.

5. Ratio tools proposed by Oliveira-Junior & Juen (2019) and Šigutová et al. (2019) were effective and the more accurate was the Coenagrionid / other Zygoptera and Libellulidae / other Anisoptera instead of Zygoptera / Anisoptera ratio.

6. Although reservoir do comprise a completely generalist community, the water supply system implies in the preservation of part of the native habitat in its surrounding areas, therefore maintaining the local biodiversity.

Keywords: Coenagrionid, damselfly, homogeneity, Libellulidae, metacommunity, turnover.

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Introduction

Odonata in Tropical forests and species dependence on forest

> "[…] globally, many more odonates occur in tropical ecosystems than in all others combined"
> (Orr, 2006).

In tropical regions the forest has an essential role in providing the resources needed to maintain most of the species of dragonflies in all stages of its life cycle, at least 70% of all Odonata earth's diversity (Corbet, 2006; Orr, 2006). Moreover, many species are restricted to neotropical forests, more than 80% of neotropical dragonfly genera have forest species (Paulson, 2006). Even the non-forest dependent species can spend part of their adult life there (Cordero-Rivera, 2006) benefiting on physical, physiological, intra and inter-biotic features or just using it as their daily and seasonal refuge (Paulson, 2006).

Human activities and its impact on diversity - Solar incidence and forest integrity

Dragonflies are considered sun-loving insects (Cordero-Rivera, 2006). Sunlight is one of the most important characteristics influencing Odonata success (Paulson, 2006). As predominantly ectothermic insects, adults of most species fly during the period of greatest daylight incidence (Corbet, 1999). Cordero-Rivera et al. (2006) compiled several factors supporting the dependence of forests for the maintenance of Odonata biodiversity: forests are place of feeding, larval development, protection and reproduction. Degradation levels are determinant to local extinctions, such as dams, deforestation, stream diversion, channeling and pollution (see Cordero-Riveira 2006, Suhling et al., 2015, Calvão et al. 2016, Daga et al. 2019). However, the pristine conditions of riparian forest is the most investigated factor (Petersen 1992, Smith et al. 2007, Simaika & Samways 2009, Oliveira-Junior et al. 2017), sometimes pointed out as the main determinant for the Odonata assemblages (Oliveira-Junior et al. 2017). The integrity of the riparian forest determines physical, chemical and biological conditions and limits the sunstroke, filtering out the occurrence of dragonflies (Dijkstra and Clausnitzer, 2006; Oliveira-Junior et al., 2017).

River damming effects

Despite the extraordinary diversity in tropical forests, this is the most threatened and poorly studied (Corbet, 2006). Human activities alter the structure, dynamics and flow of energy in rivers and lakes, impacting the occurrence of Odonata (Paulson, 2009). The main factors that threaten biodiversity in tropical rivers are habitat loss and degradation, introduction of exotic species, overexploitation, pollution, excessive diversion and water intake (Allan & Flecker, 1993; Ramírez et al., 2008; Daga et al., 2019). Changes in watercourses are a critical threat to dragonfly survival (Suhling et al., 2015) and the sensitivity of some species makes them vulnerable to changes in their habitat (Oertli, 2008).

A frequent change in Brazilian watercourses is river damming, for water supply or hydroelectric energy production (see Moretto et al., 2012). The impacts on the communities of Odonata communities due to the river damming process include the increased solar incidence, water permanence, temperature and material accumulated in the bottom (Dijkstra & Lempert, 2003), conditions very different from those found in lotic waters. Punctual or continuous disturbances in watercourses generate individual and community responses, which may include: (1) loss of diversity, (2) species substitution with the arrival of opportunistic species, and (3) decrease in average size of dominant species (Gray, 1989).

However, changes 1 and 2 are antagonistic, so that the loss of diversity can be offset by the arrival of opportunistic species, compensating for the loss of species (Ferreira-Peruquetti, 2003). Thus, environmental degradation at different levels may or may not influence absolute richness, since this metric do not consider other aspects such as origin, ecological function or biology (Pereira et al., 2019; Oliveira-Junior & Juen, 2019).

The increase of sunlight incidence caused by river damming is a significant change in the abiotic characteristics of the aquatic environment, since in forested areas, sunlight can be reduced at least to 25%. The limitation can be explained by the body size, because slender-bodied dragonflies are more susceptible to overheating and desiccation (corbet, 1999; Paulson, 2006; see also Oliveira-Junior et al., 2017; Oliveira-Junior & Juen, 2019. Pereira et al., 2019).

Water is an essential resource for human activities and, therefore, river damming is a frequent change in streams. Changes in the provision of resources from a forested area to a large lake caused by the river damming of a river determines which species will be able to occupy this new habitat conformation. The effects of degradation on the biodiversity of Brazilian tropical forests are further studied in the Amazonian domain (Nessimian et al., 2008; Brasil et al., 2014; Monteiro-Junior et al., 2015; Faria et al., 2017; Oliveira-Junior & Juen, 2019; Pereira et al., 2019), for the Atlantic Forest, the most degraded, studies are sparse (Ferreira-Peruquetti & De Marco, 2002; Renner et al., 2016; Dalzochio, 2018).

Objetive

The purpose of this study is to investigate how the river damming affects Odonata assemblages in subtropical forests. We compared the Odonata community from a reservoir for water supply to a well-preserved forest area upstream in a drainage system in the southern Atlantic Forest domain. Our hypothesis is that river damming causes homogenization and generates species turnover with a reduction of richness of local species.

Material and Methods

Study area. This study was undertaken in a remnant of Atlantic Forest in Mananciais da Serra, at Piraquara municipality, Paraná State, Brazil. A comprehensive checklist of the region was published by Araujo et al. (in press). The region encompasses a well-preserved area of Atlantic Forest with numerous streams dammed to form two large reservoirs for water supply for Curitiba and its metropolitan region (Fig. 1). The vegetation formation is Araucaria Forest and Tropical Forest (Reginato & Goldenberg et. al., 2007).

Samplings. Ten sampling sites were sampled twice, totalizing twenty collecting events. Half in the forested area and half in the modified landscape from forest and natural grasslands to an open area. Forested sites (MS) represent the native fauna of near pristine, in which the water system is predominantly lotic and shaded by the forest. Open landscape (RP) at the banks of the Piraquara II reservoir, represents the altered area, in which the water system is predominantly lentic with higher level primary production with macrophytes (Fig. 1). Were sampled sites with the potential higher diversity because a randomization sampling method could not represent the fauna of each assemblage. The sampling was undertaking from December 2018 to March 2019 with an interval of 30–60 days between the first and second collecting event of each site. A modified scheme of the sampling method by Peck et al. (2001) was adopted with site delimited by a transect of 150 meters, perpendicularly subdivided every 30 meters, totalizing 45,000 m² of sampling area per site (Fig. 2). All collecting events were conducted in sunny days with duration of three hours between 09:30 and 13:30 (UTC−03:00, time zone).

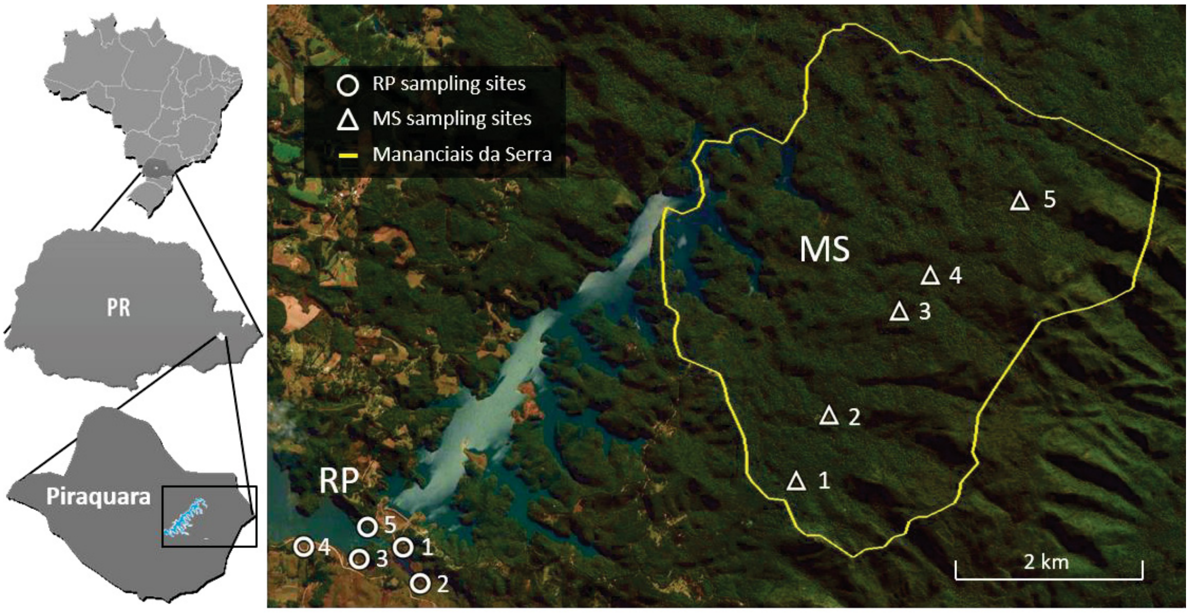

Fig. 1. Sampling sites of adult Odonata at Piraquara municipality, Paraná state, Brazil. Geometric shapes refer to the assemblage sampling sites: Piraquara II reservoir (RP, circles) and Forested sites (MS, triangles). Mananciais da Serra area delimited in yellow.

Curation and identification. Procedures follow Araujo et al. (in prep). The specimens were dried in absolute acetone and deposited in the Entomological Collection Pe Jesus Santiago Moure, Departamento de Zoologia, Universidade Federal do Paraná, Curitiba, Brazil (DZUP) and entomological collection of the Museu Nacional, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil (MNRJ).

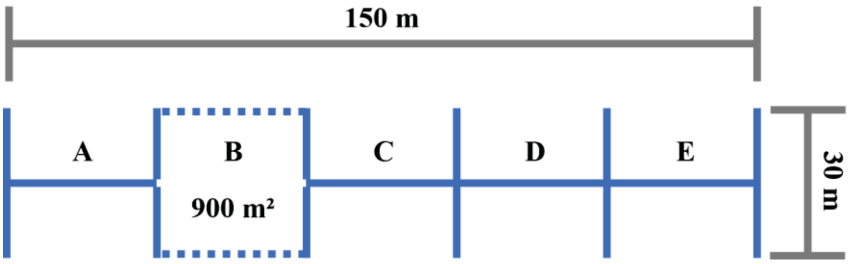

Fig. 2. Sketch of sample design applied to sampling sites of Piraquara II reservoir (RP) and Forested sites (MS) assemblages from the protected area Mananciais da Serra, Piraquara municipality, state of Paraná, Brazil.

Analysis. The following analyses were conducted using the software R with the goal to compare the MS and RP assemblages: (1) ANOVAs with permutation was used to test for differences among sites considering species richness, diversity and equitability, (2) PERMANOVAs and 'betadisper' (Anderson et al., 2006) analyses using hellinger transformation and Raup Crick distance index were used to evaluate the differences in species composition and compositional variation among sites, (3) Dufrêne-Legendre Indicator Species Analysis was used to identify typical species of each site class (MS or RP) through fidelity and relative metrics (*sensu* Dufrêne & Legendre 1997), (4) Pattern-based analysis of metacommunity structure to understand the pattern of distribution as described in Leibold et al. (2002).

Bioindicator tool application. The bioindicator ratio tools Zygoptera / Anisoptera (Oliveira-Junior & Juen, 2019) and Coenagrionid / other Zygoptera or Libellulidae / other Anisoptera (Šigutová et al., 2019) were applied using the species richness for RP and MS communities.

Results

Community richness and composition

A total of 950 specimens from seven families, 36 genera and 61 species were sampled (Table 1). Twenty-two species were exclusive to MS, while forty-three from RP and four occurred in both (Fig. 3). The most abundant taxa in MS were Coenagrionidae (212 specimens) at family level and *Argia* (178) at generic level, while in RP they were Libellulidae (322) and *Erythrodiplax* (186). The richness rate of Anisoptera for MS was 0.545 and for RP 0.697. The richness ratios of Coenagrionidae / other Zygoptera and Libellulidae / other Anisoptera for MS were 0.300 and 0.417 respectively and for RP 0.923 and 0.833 (Fig. 6).

Betadiversity

The community of RP had highest species richness (Fig. 4a), Shannon-Wiener diversity (Fig. 4b) and Pielou's evenness (one-factor ANOVA with permutations: $P < 0.05$, Fig. 4c). Even so, the compositional variation was greater in MS (betadisper approach using Raup-crick index, $P < 0.05$, Fig. 5).

Table 1. Species list, and occurrence at the protected area Mananciais da Serra, Piraquara municipality, state of Paraná, Brazil. Abbreviations: RP = Piraquara II reservoir community, MS = Forested sites community.

Taxa	RP	MS
Zygoptera		
Perilestidae		
Perilestes fragilis Hagen *in* Selys, 1862		x
Heteragrionidae		
Heteragrion freddiemercuryi Lencioni, 2013		x
Heteragrion sp. A		x
Heteragrion sp. B		x
Calopterygidae		
Hetaerina brightwelli (Kirby, 1823)		x
H. hebe Selys, 1853		x
H. longipes Hagen *in* Selys, 1853		x
Hetaerina rosea Selys, 1853	x	
Coenagrionidae		
Acanthagrion gracile (Rambur, 1842)	x	
A. lancea Selys, 1876	x	
A. truncatum Selys, 1876	x	
Argia sordida Hagen in Selys, 1865		x
Forcepsioneura sancta (Hagen *in* Selys, 1860)		x
Homeoura chelifera (Selys, 1876)	x	
Ischnura capreolus (Hagen, 1861)	x	
I. fluviatilis Selys, 1876	x	
L. macrurum (Burmeister, 1839)		x
Minagrion mecistogastrum (Selys, 1876)	x	
M. waltheri (Selys, 1876)	x	
O. terminale Selys, 1876	x	
Telebasis carmesina Calvert, 1909	x	
T. theodori (Navás, 1934)	x	
T. willinki Fraser, 1948	x	
Anisoptera		
Aeshnidae		
Coryphaeschna perrensi (McLachlan, 1887)	x	
Limnetron sp.		x
Remartinia l. luteipennis (Burmeister, 1839)	x	
R. confusa (Rambur, 1842)	x	
R. decessus (Calvert, 1953)		x
R. punctata (Martin, 1908)		x
R. planaltica (Calvert 1952)		x

Table 1. Continued.

Taxa	RP	MS
Gomphidae		
Phyllogomphoides annectens (Selys, 1869)		x
Phyllocycla diphylla (Selys, 1854)	x	
Progomphus complicatus Selys, 1854	x	x
Progomphus aff. *gracilis* Hagen *in* Selys, 1854		x
Libellulidae		
Brechmorhoga sp. B		x
Dasythemis mincki mincki (Karsch, 1889)	x	x
Dasythemis sp.	x	
Diastatops intensa Montgomery, 1940	x	
Dythemis nigra Martin, 1897	x	
Erythemis peruviana (Rambur, 1842)	x	
Erythrodiplax castanea (Burmeister, 1839)	x	
E. fusca (Rambur, 1842)	x	
E. hyalina Förster, 1907		x
E. media Borror, 1942	x	
E. melanorubra Borror, 1942	x	x
E. paraguayensis (Förster, 1905)	x	
Erythrodiplax sp. A	x	
Macrothemis i. imitans (Karsch, 1891)	x	
Miathyria marcella (Selys *in* Sagra, 1857)	x	x
M. simplex (Rambur, 1842)	x	
Micrathyria hypodidyma Calvert, 1906	x	
M. stawiarskii Santos, 1953	x	
Nephepeltia flavifrons (Karsch, 1889)	x	
Oligoclada laetitia Ris, 1911	x	
Orthemis discolor (Burmeister, 1839)	x	
Pantala flavescens (Fabricius, 1798)	x	
Perithemis mooma Kirby, 1889	x	
Planiplax erythropyga (Karsch, 1891)	x	
Tauriphila xiphea Ris, 1931	x	
Tramea binotata (Rambur, 1842)	x	
T. rustica De Marmels & Rácenis, 1982	x	
7 Famílies, 36 genera, 61 spp.	43	22

Metacommunity-analysis

The multivariate permutational ANOVA indicated different species compositions between areas ($P < 0.05$). Two typical species were detected in MS and 11 in RP (Table 2). Analysis of the metacommunity structure indicates a Clementsian pattern organization.

Table 2: Typical species of Piraquara II reservoir (RP) and Forested sites (MS) assemblages from the protected area Mananciais da Serra, Piraquara municipality, state of Paraná, Brazil. Mesohabitat preference, indicator values and probability for each typical species.

Typical species	Assemblage	Indicator value	Probability	Mesohabitat preference
Argia sordida Hagen *in* Selys, 1865	MS	0.70	0.002	Lotic water in shaded forested areas
Forcepsioneura sancta (Hagen *in* Selys, 1860)	MS	0.70	0.001	Shallow semi-lotic water in forested areas
Erythrodiplax melanorubra Borror, 1942	RP	0.97	0.001	Lentic
Acanthagrion lancea Selys, 1876	RP	0.90	0.001	Lentic
Erythrodiplax media Borror, 1942	RP	0.90	0.001	Lentic
Homeoura chelifera (Selys, 1876)	RP	0.90	0.001	Lentic
Oxyagrion terminale Selys, 1876	RP	0.90	0.001	Lentic
Acanthagrion gracile (Rambur, 1842)	RP	0.70	0.001	Lentic
Erythrodiplax fusca (Rambur, 1842)	RP	0.70	0.003	Lentic
Erythrodiplax sp. A	RP	0.70	0.002	Lentic
Perithemis mooma Kirby, 1889	RP	0.70	0.004	Lentic
Planiplax erythropyga (Karsch, 1891)	RP	0.70	0.005	Lentic
Telebasis willinki Fraser, 1948	RP	0.70	0.004	Lentic

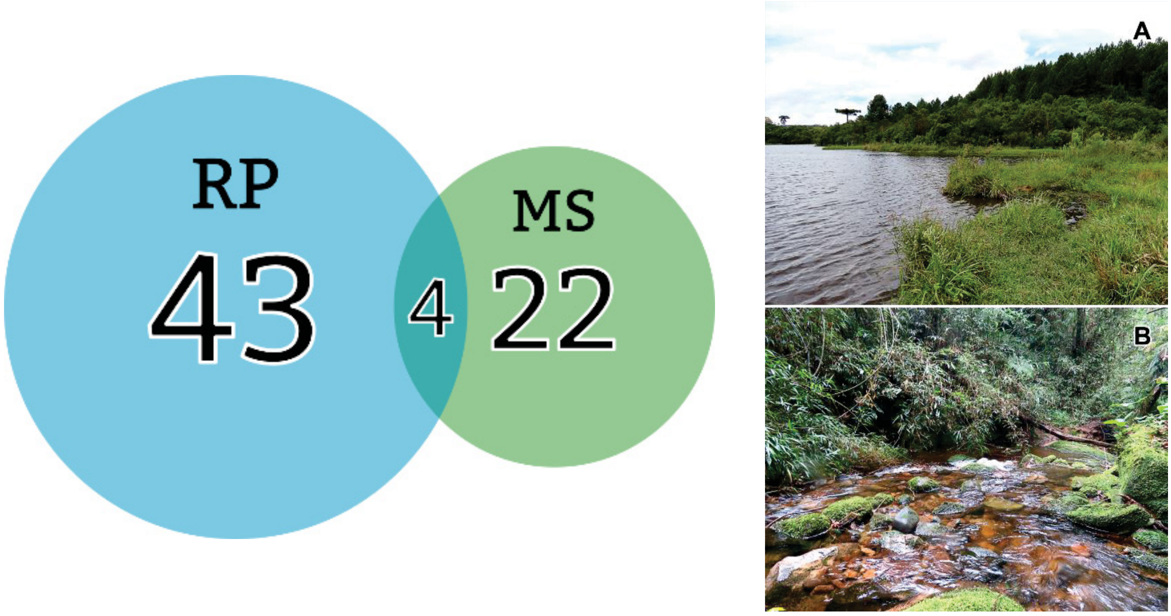

Fig. 3. Venn diagram of richness found in Piraquara II reservoir (RP) and Forested sites (MS) assemblages from the protected area Mananciais da Serra, Piraquara municipality, state of Paraná, Brazil. (A) Reservoir Piraquara II (RP); (B) Ipiranguinha river (MS). Photos: BRA.

Bioindicator tool application

Both tools conferred greater integrity to the MS. The Zygoptera / Anisoptera ratio had the lowest difference for RP (0.69) and MS (0.54), while the biggest difference in ratio was found for the Coenagrionid / other Zygoptera with 0.92 for RP and 0.30 for MS (Fig.4).

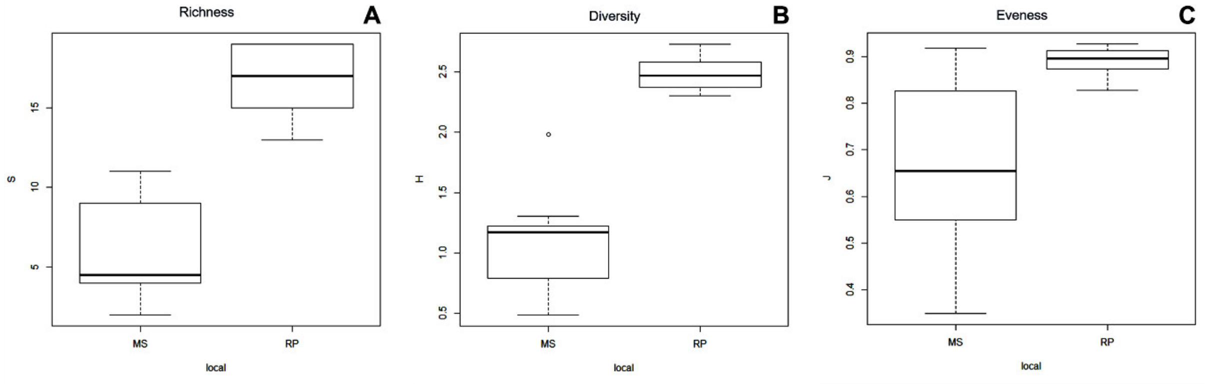

Fig. 4. Diversity analysis for Piraquara II reservoir (RP) and Forested sites (MS) assemblages from the protected area Mananciais da Serra, Piraquara municipality, state of Paraná, Brazil. (A) Richness, (B) Shannon-Wiener diversity and (C) Pielou's evenness (one-factor ANOVA with permutations: $P < 0.05$).

Discussion

Community and Odonata as bioindicator of habitat integrity

Increases of the solar incidence, the offer of slow water environments, the water permanence and the material accumulated on bottom are the most well-known perturbations of river damming (Dijkstra & Lempert, 2003). The local forest was flooded transforming several mesohabitats of shaded running water into a less complex of slow water systems (homogenization process). Our results are clear to identify which facets of Odonata biodiversity are mostly affected. River damming excluded some local species potentially with preference by lotic mesohabits by species with common and wide range distributions, a tendency of lentic systems (Corbet, 1999; Ferreira-Peruquetti & De Marco, 2002). The area of occurrence of local species had decreased by modification and the substitute fauna are strongly associated to areas of macrophytes banks.

The RP community is characterized by no forest-dependent species, typical of the open area. They were easily collected due to behavior and abundance on the field, considered opportunistic, widely distributed and with great potential for dispersal and colonization (see De

Almeida et al., 2013; Paulson, 2006; Oliveira-Junior & Juen 2019). The disturbance of the landscape allowed the colonization of 39 species not specialized in breeding in forested habitats, which almost double the richness of the local community.

Interestingly, disturbed areas hosted higher species richness than pristine sites, which can have different explanations. At one hand, higher richness in the more homogeneous landscape could indicate that intensity and duration of the perturbations do not reach the threshold to decrease the biodiversity, in line with the hypothesis of intermediate disturbance (see Petraits, 1989). On the other hand, higher biodiversity may indicate a not obvious impact: the promotion of expansion species with high geographical distribution in detriment to local and endemic species, as well explained in the "Biodiversity Conservation Paradox" (see Vellend, 2017).

Indeed, the MS community is characterized by species dependent on the forest, somewhat catholic in their places where larvae reproduce, therefore, with low dispersion and specialists associated with their mesohabitat (see Paulson, 2006). The local community is sensitive to major changes in their habitat and is largely dependent on intact running water in forest environments (see Clausnitzer et al., 2009).

Several studies consider different responses from community parameters (e.g., richness) to Odonata at the suborder level. (Oliveira-Junior & Juen, 2019; Oppel, 2005, Pereira et al., 2019). Oliveira-Junior & Juen (2019), for example, consider the Zygoptera / Anisoptera ratio as a tool to detect environmental impacts in Amazonia streams. Ratios above 0.54 in the observed richness and abundance of Zygoptera / Anisoptera are considered well-preserved streams, while below 0.41 are considered perturbed. Thus, if it works for Atlantic Forest streams, MS streams with a general Zygoptera richness ratio of 0.454 can be considered moderately preserved. Considering the abundance, the MS had 0.926 of Zygoptera with can be classified as preserved. However, the ecological diversity found by Šigutová et al. (2019) in the suborders of Odonata improve the ratio of Zygoptera / Anisoptera tool. They suggest the Coenagrionid richness ratio compared to other Zygoptera and Libellulidae compared to other Anisoptera for greater accuracy in forest degradation. Applying this tool, MS had 3 (0.300) species of Coenagrionidae from 10 Zygoptera and 5 Libellulidae (0.417) from 12 Anisoptera. This approach can be used to classify the RP community, in which there were 12 (0.923) species of Coenagrionidae species from 13 Zygoptera and 25 Libellulidae (0.833) species of from 30 Anisoptera. Thus, this approach reflected the level of degradation of RP and MS, because the greater these proportions the greater the degradation.

This increase in accuracy the response of taxa to environmental changes and refines the understanding of the factors driving Odonata composition and the use of bioindication tools.

However, the use of less inclusive taxa, e.g., genus, virtually allow accurate the prediction of disturbance but it also turns the correlations more complex making difficult its applicability to monitoring programs. For example, even within the Coenagrionidae there are non-generalist species that occur in forested areas, such as *F. sancta* and the same occurs for the Gomphidae, which is composed most of lotic strong forest-dependent species, even presenting species with lentic habitat preference occurring in open areas such as *Phyllocycla* and *Aphylla*. The dichotomy between Zygoptera and Anisoptera is naïve and certainly is strongly biased. This dichotomy overlooks that in despite of the members of each suborder have a common evolutionary history, i.e. they are monophyletic, each lineage diversified spatio-temporally independently, undergone distinct selective pressures leading to exclusive histories at genus or even at closely related species levels. Habitat preferences and consequently ecological responses are strongly heterogenous within each suborder, both damselflies and dragonflies have phytotelma-breeding, riverine, lentic, crepuscular, forest-dependent, generalist species etc. Therefore, this field is open to innovations and certainly more refined strategies should be used to capture the actual ecological signal from each taxonomic arrangement. It was suggested the occurrence of bigger dragonflies in modified areas can difficult the occurrence of the minor ones by competition even with favorable environment (Pereira et al. 2019). However, it is local dependent, and in our study bigger odonates from Zygoptera and Anisoptera were observed in more pristine habitat.

Community description and Betadiversity

Studies analyzing habitat quality indicates a replacement of endemic species or species with higher habitat specificity for those of a broader occurrence, generalist and with low demands on environmental parameters (Ferreira-Peruquetti & De Marco, 2002; Roque et al., 2017).

However, the prevalence of Anisoptera species sampled can be explained in part by sampling bias, due to most studies show the tendency to sample abundant generalist species instead of specialist Anisoptera (see De Almeida et al., 2013).

Only four species cooccurred in MS and RP (Fig. 3). The species occurred in both communities *Dasythemis mincki mincki* (Karsch, 1889), *Erythrodiplax melanorubra* Borror, 1942, *Miathyria marcella* (Selys *in* Sagra, 1857), *Progomphus complicatus* Selys, 1854 are all species of southern Southam America or strongly widespread species in Western Hemisphere as whole. Although, to infer about the question if they are originally from the local community or they are generalist species that occupied MS after river damming, the habitat preference and abundance should be considered. *Progomphus* includes species predominantly of lotic species, the single specimen collected in RP was in a forested area around the reservoir and the same occurs to *E. melanorubra* and *M. marcella*, they are characteristic lentic species and the single specimen collected for MS was in a open area in the less forested sampling site. *Dasythemis m. mincki* occurred in lentic mesohabitats in both areas (RP and MS) and also was collected in MS in an open field. Ferreira-Peruquetti & De Marco (2002) detected species of characteristics lentic habitats "invading" lotic systems (e.g., *I. fluviatilis*) but not the contrary. Lotic environments generate lentic mesohabitats at river reach between rifles and pools of the streams and even natural structures can block the water flux forming a semi-lotic mesohabitat. In contrast, for slow waters the presence of lotic or semi-lotic mesohabitats is less likely due to factors like dissolved oxygen and temperature. The few semi-lotic mesohabitats found in Piraquara II reservoir (RP) were in areas in which the streams flow to the reservoir, sampling site where *Progomphus* species were collected. Thus, adults of *P. complicatus*, *M. marcella* and *E. melanorubra* are collected near to mesohabitat in which larvae not rearing. *Dasythems m. mincki* was perching in lentic habitats in both communities, so this species can be considered as persistent, a local species that can reproduce in the reservoir.

Araujo et al. (in press) investigated the community of a natural pool above 'Piraquara II' dam and their finds compared to RP community shares 10 species typically from lentic environments raising questions on the Clementsian pattern observed here. This additional data can be associated to the loss of β-diversity with a wider special scale observation (see Siegloch, 2018). The addition of a lentic site in MS could improve the cooccurrence species due to its lentic mesohabitat, the predominant system in RP. Instead of this improve, the number of species shared between RP and MS plus Natural Pool would be 13, a small part of a total of 79 species (including Natural pool species). In addition, this species are wide distributed and do not represent the most vulnerable species.

Lakes and bogs are not common in tropical forests and the lake species are usually in artificial reservoirs (Sahlén, 2006), so the natural pool community can configure one rare mesohabitat and these species can be confined into small areas in preserved forests. In other hand, some common and widespread species can be originated from another degraded area (see Renner et al., 2016). If these species were considered as local species, the reservoir contribution to the maintenance of local biodiversity goes from almost nil to about 20%.

Homogenization

There is paradox controversy on the expected inversely proportional values between homogenization and richness and directly proportional relation between heterogeneity and level of presentation. The belief that most homogeneous landscape, hence more disturbed, presents less richness is not always true. Recently was found higher heterogeneity in altered streams in Eastern Amazon (Oliveira-Junior & Juen, 2019). This possibility poses doubts in the assumption that the dam caused homogenization, since the amount of mesohabitats provided by the reservoir is large. There are banks with species of macrophytes, mesohabitats of semi-running water that flow into the reservoir, few remnants of well-preserved riparian forests.

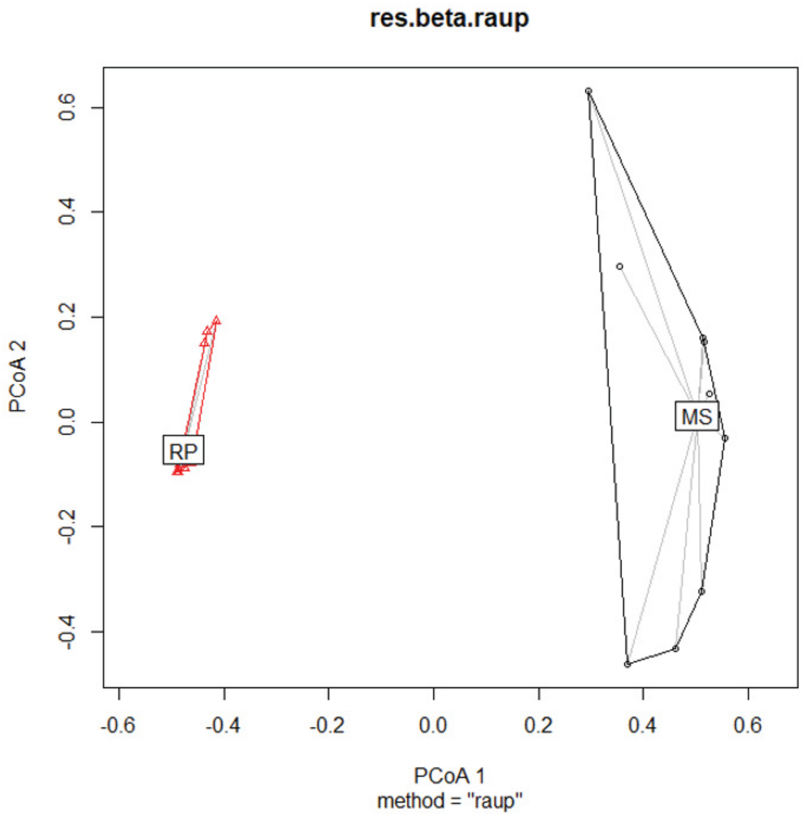

Fig. 5. Variation of composition using betadisper approach with Raup-crick index of Piraquara II reservoir (RP) and Forested sites (MS) assemblages from the protected area Mananciais da Serra, Piraquara municipality, state of Paraná, Brazil.

However, the suppression of lotic waters and original forests is an undeniable modification in the landscape, causing a huge impact in the area. In contrast of this question, the variation of composition was greater (Fig. 5) in MS, what may be caused by a greater heterogeneity of mesohabitats compared to RP. The typical species analysis endorses this conclusion due to the low number of typical species for MS compared to RP and since these have different mesohabitats preferences: *Forcepsioneura sancta* (Hagen *in* Selys, 1860) and *Argia sordida* Hagen *in* Selys, 1865 are species of shaded forested areas, however the first occurs in very specific type of semi-flowing shallow water and the second occurs characteristically in lotic systems along Atlantic Forest in southeastern and southern Brazil. The eleven typical species shows that the sampling sites of RP are quite similar, and beyond that all typical species of RP occurs in lentic systems and most are associated to macrophytes. These results indicate RP as environmental homogeneous condition compared to MS.

Metacommunity species

The metacommunity structure analysis revealed a Clementsian pattern with discrete communities distributed with an abruptly composition change, which is indeed expected given the high compositional differences between RP and MS. Indeed, a discrete pattern is related to the high rate of unique species (0.934). This distribution reveals an almost complete substitution of the local fauna (MS) beside the higher richness of RP.

The Clementsian pattern could be explained mainly by the water systems and forest coverage occurring in MS (most lotic and forested) and RP (most lentic and opened). The dispersal capability, a key factor to large scales, should not be a predictor here due to the local scale of observation (see Siegloch, 2018). The distribution can be determined by the heterogeneity of the environment filtering the species by settlement capacity, especially due to the environmental conditions (Oliveira-Junior & Juen, 2019), more specifically the mesohabitats and its conditions. The same result was found by Siegloch (2018) with aquatic insects' assemblage and the structural differences were quality and flow water (oxygen concentration, electrical conductivity and water velocity) and in riparian forest complexity, most factors changed by river damming. At the same time the physical vegetation structure makes the environment available to some species while prevents the occurrence of others (see Hykel et al, 2019), e.g. species with endophytic oviposition that depends on plants to reproduce (see Suhling et al., 2015). Is important to point that the diversity results found here are at local scale and can vary according to the scale of observation (Siegloch, 2018).

Physical and biotical influences on Odonata prediction

Studies assigned to the suborder Zygoptera (with high surface area to volume ratio) the association to shaded and preserved streams and the opposite to Anisoptera (Oliveira-Junior et al., 2015, 2017). The reasons are due to differences in thermoregulation, dispersal capacity and environmental sensitivity of each suborder (Oliveira-Junior et al., 2017). Oliveira-Junior & Juen (2019) proposed the use of the ratio of Zygoptera / Anisoptera as a bioindication tool for habitat quality. However, Šigutová et al. (2019) drew attention to the Odonata families that do not conform to this pattern and suggested that the ratio of Coenagrionidae for Zygoptera and Libellulidae for Anisoptera represents groups that better indicates habitat degradation. Both tools were effective but the Coenagrionid / other Zygoptera and Libellulidae / other Anisoptera had accurate results since the clear difference in habitat quality was best represented by a wide difference in the ratio. Although, the use of other arrangement can have different results, such as the division of forests and non-forests, lotic and lentic or flying and perchers groups.

Oliveira Junior & Juen (2019) tested environmental influence on the Odonata suborders throughout preserved and altered streams and in all analysis the environment factors explain less than 0.25 of determining the variation in streams community. So, they suggest that major part of determining Odonata community in small streams may be not explained by environmental factors but can be by biotical interactions or variables still not explored or measured, such as the capacity of an area to maintain different mesohabitats, specially a high number of the specific ones. In addition, biological parameters not evaluated, such as competition and trophic cascade, should be key factors segregating pristine forest species from those occupying degraded areas (Knight et al., 2005; Dijkstra & Clausnitzer, 2006: Šigutová et al., 2019) another perspective to understand the drivers of Odonata biodiversity occurrence.

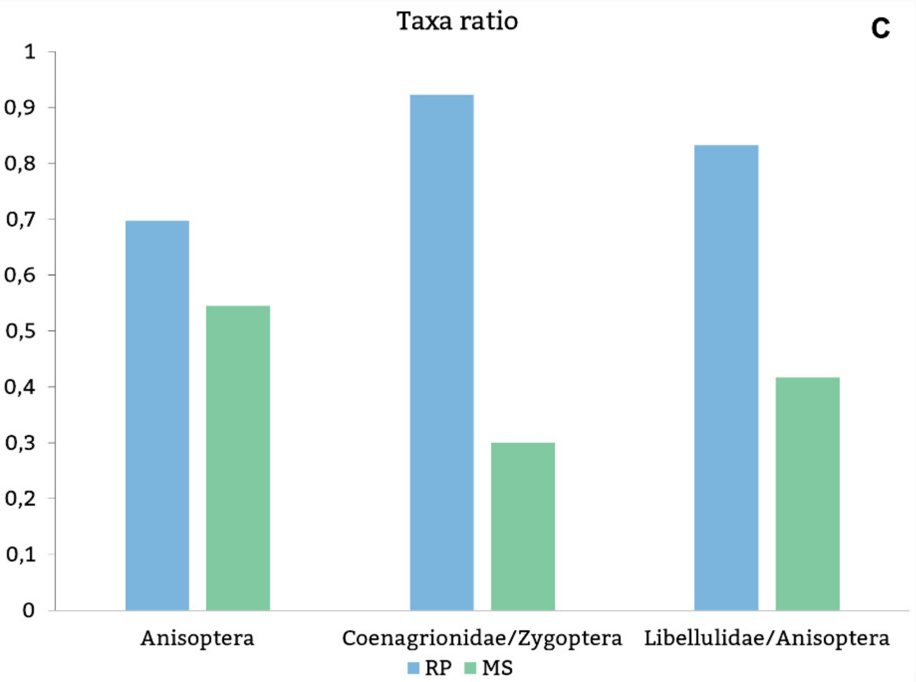

Fig. 6. Ratio tools proposed by Oliveira-Junior & Juen (2019) and Šigutová et al. (2019) applied for Piraquara II reservoir (RP) and Forested sites (MS) assemblages from the protected area Mananciais da Serra, Piraquara municipality, state of Paraná, Brazil

The variation on composition between MS and RP reflects the river damming impacts on Odonata community. Almost all species of local community were replaced most probably due to the physical and biotical changes resulted by the water system conversion and homogenization. The community found in slow (RP) and running (MS) water system are almost totally divergent. It seems that the major system determines the most species and the mesohabitats refines this occurrence plus biological interactions. The complexity of mesohabitats should be proportional to the richness and the forest ones are the most fragile and the most difficult to recover. Thus, the mesohabitats easily reproducible harbor the most common species.

Consequently, to preserve Odonata species is necessary to keep their habitat features near to pristine in order to preserve the more susceptible mesohabitats. In other words, the maintenance of forest lotic species, the more threatened (Clausnitzer et al., 2009) and of low distribution, needs more attention to the preservation of the original characteristics of their habitats. Use the reservoir for water supply implies in the preservation of the surrounding areas, therefore maintaining part of the native habitat and consequently the local biodiversity. Therefore, in addition to preserving large areas of preserved forest, is necessary to detect and protect the vulnerable areas in which the sensible local fauna species live for a real maintenance of biodiversity. Other non-aquatic groups often achieve diversity 'gains' demonstrated by dragonflies should not occur as the terrestrial and soil dependent species due to the forested area replaced by an aquatic environment.

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CONCLUSÃO

O Mananciais da Serra abriga 83 espécies de libélulas em 42 gêneros e 9 famílias, porém estima-se que a riqueza seja um pouco mais de cem espécies. O elevado número de novos registros de ocorrência para o estado do Paraná (53) exemplifica como as lacunas no conhecimento devido a subamostragem podem levar a erros de interpretação. *Micrathyria venezuelae* é registrada pela primeira vez no Brasil. A amostragem de larvas ampliou a abundância de fêmeas e espécies raras. A fêmea da descrição original de *Neocordulia mambucabensis* Costa & T.C. Santos 2000 se trata de outra espécie de *Neocordulia*. Quatro espécies desconhecidas, larvas em último estádio e fêmeas também desconhecidas de espécies já descritas foram detectadas.

As ferramentas de bioindicação de qualidade de habitat foram eficientes, resultando MS como mais preservado que RP, entretanto, a razão Zygoptera / Anisoptera apresentou menor acurácia do que as razões Libellulidae / Anisoptera e Coenagrionidae / Zygoptera. O reservatório tem capacidade quase nula de manter as espécies locais, mantendo isoladamente uma alta riqueza de espécies generalistas. Os principais fatores decorrentes do represamento que influenciam a comunidade de libélulas são a homogeneização da paisagem e conversão do sistema aquático de lótico para lêntico. Entretanto, as áreas no entorno do reservatório são bem preservadas e mantêm as espécies locais mais sensíveis, mitigando os efeitos da homogeneização. A região do Mananciais da Serra apresenta alto potencial de manutenção da biodiversidade, mantém pelo menos 60% das espécies conhecidas para o Paraná e 10% da riqueza de libélulas do Brasil.

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