Biota Neotropica 18(2): e20170352, 2018
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
Article

# Effects of an atypical drought on the benthic macroinvertebrate community in a tropical reservoir

*Maria José Pinheiro Anacléto[1]* Raphael Ligeiro[1], José Etham de Lucena Barbosa[2], Joseline Molozzi[2] & Marcos Callisto[3]*

*[1]Universidade Federal do Pará, Instituto de Ciências Biológicas, Laboratório de Ecologia e Conservação, Belém, PA, Brasil*
*[2]Universidade Estadual da Paraíba, Departamento de Ciências Biológicas, Programa de Pós-Graduação em Ecologia e Conservação, Campina Grande, PB, Brasil*
*[3]Universidade Federal de Minas Gerais, Instituto de Ciências Biológicas, Departamento de Biologia Geral, Laboratório de Ecologia de Bentos, Belo Horizonte, MG, Brasil*
**Corresponding author: Maria José Pinheiro Anacléto, e-mail: mariajose_anacleto@yahoo.com.br*

ANACLÉTO, M. J. P., LIGEIRO, R., BARBOSA, J. E. de L., MOLOZZI, J., CALLISTO, M. **Effects of an atypical drought on the benthic macroinvertebrate community in a tropical reservoir**. Biota Neotropica. 18(2): e20170352. http://dx.doi.org/10.1590/1676-0611-BN-2017-0352

***Abstract:*** Atypical drought events have increasingly occurred in Brazil over the last years due to global climate changes. However, their consequences on aquatic biota in reservoirs are poorly known. We tested the hypothesis that macroinvertebrate communities are negatively affected by atypical drought events, given the sensitivity of many *taxa* to environmental changes. We predicted that: (a) there would be changes in limnological and sediment parameters between a regular year and an atypical year, (b) abundance and richness of the genera of Chironomidae and of exotic species would be higher due to the enhanced ability of these organisms to adapt to changes in the physical environment, and (c) community structure metrics (i. richness; ii. % richness; iii. abundance; iv. % abundance) would be affected by disturbance indices (i. Buffer Disturbance Index-BDI; ii. Local Disturbance Index-LDI; iii. Integrated Disturbance Index-IDI) in both years. The study was carried out in the reservoir of the Nova Ponte Hydroelectric Power Plant, state of Minas Gerais, comparing two sampling periods: a regular climatological year (2010) and an atypical drought year (2014). A total of 40 sampling sites were defined along the shore of the reservoir, and types of land use in the surrounding area of each site were measured, as well as physical habitat conditions, sediments, and benthic macroinvertebrate communities. Sampling was performed at these sites in the end of the rainy season in both years. The intensity of anthropogenic modifications was assessed at local scale and in the areas (*buffers*) surrounding the sampling sites using quantitative disturbance indices. There were striking differences in limnological parameters and sediment characteristics between sampling periods. Taxonomic richness was significantly lower in the drought year. As opposed to our predictions, richness and abundance of Chironomidae and exotic species did not increase with the atypical drought event. Besides, most community structure metrics showed a significant relationship with disturbance indices only during the regular climatological year, thus indicating that the large-scale effects of water stress may override the conditions of local habitats and the surrounding landscape. Therefore, in addition to a correct political-environmental management of water resources at local-scale, which includes maintaining the water quality and the riparian and landscape integrity, addressing large-scale climate issues is required for the maintenance of the ecological integrity of tropical reservoirs.

**Keywords:** *Benthic fauna, exotic species, ecological integrity, water stress, climate changes.*

# Efeitos de uma seca atípica sobre a comunidade de macroinvertebrados bentônicos em um reservatório tropical

***Resumo*:** A ocorrência de episódios atípicos de seca vem crescendo nos últimos anos no Brasil em decorrência de mudanças globais no clima. Entretanto, as consequências disso para a biota aquática são ainda pouco conhecidas. Testamos a hipótese de que comunidades de macroinvertebrados são negativamente afetadas por eventos de seca atípica, dada a sensibilidade de muitos *taxa* às alterações ambientais. Nossas predições foram que (a) parâmetros limnológicos e características de sedimento seriam alterados em um ano de seca atípica, (b) encontraríamos maior abundância e riqueza de gêneros de Chironomidae e de espécies exóticas dada à alta capacidade destes organismos de adaptarem-se às mudanças no ambiente, (c) métricas de estrutura de comunidade (i. riqueza; ii. % riqueza; iii. abundância e iv. % abundância) seriam afetadas por índices de distúrbio (i. Índice de Distúrbio no Buffer-IDB; ii. Índice de Distúrbio Local-IDL e iii. Índice de Distúrbio Integrado-IDI) em ambos os anos. O estudo foi realizado no reservatório da Usina Hidrelétrica de Nova Ponte, Minas Gerais, comparando dois períodos amostrais: um ano climatológico normal (2010) e um ano de seca atípica (2014). Foram definidos 40 sítios amostrais na região litorânea do reservatório onde foram mensurados os tipos de usos do solo no entorno, condições de habitats físicos, características limnológicas na coluna d'água, sedimento e comunidades de macroinvertebrados bentônicos. A intensidade de alterações antrópicas foi avaliada em escala local e no entorno dos pontos amostrais (*buffers*) por meio de índices de distúrbio. Observamos diferenças expressivas nos parâmetros limnológicos e nas características dos sedimentos entre os dois períodos amostrais. A riqueza taxonômica foi significativamente menor no ano de seca. Ao contrário do esperado, os valores de riqueza e abundância de Chironomidae e de espécies exóticas não aumentaram com o evento extremo de seca. Paralelamente, a maioria das métricas de estrutura de comunidade apresentou relação significativa com os índices de distúrbio somente durante o ano climatológico normal, indicando que os efeitos de estresse hídrico em larga escala podem se sobrepor às condições locais de habitat e de paisagem circundante. Portanto, deve ser considerada não só a correta gestão político-ambiental de recursos hídricos em escala local, que inclui a manutenção da qualidade da água e da integridade da região ripária e uso do solo da região de entorno, mas também abordar questões climáticas em larga escala faz-se necessário para a manutenção da integridade ecológica em reservatórios tropicais.

**Palavras-chave:** *Fauna bentônica, espécies exóticas, integridade ecológica, estresse hídrico, mudanças climáticas.*

## Introduction

Scarcity of water resources is one of the most debated environmental issues worldwide, as it is one of the greatest challenges of this century (Dobrovolski & Rattis 2015), and changes in rainfall regimes are responsible for exacerbating the occurrence of droughts across the globe (Ledger et al. 2012). Extreme climatic events have been increasing over the last fifty years in southeastern Brazil (Marengo 2009). From 2012 to 2014, the drought resulted in 56 trillion liters of water deficit per year due to a precipitation approximately 16% lower than the yearly historical average (Getirana 2015). That is why the extended drought in 2014 caused huge economic losses in hydropower energy generation (Getirana 2015). In general, rains have been lower than the Climatological Normal, and 2013 and 2014 were classified as very dry years according to the report on the assessment of precipitation in river basins of the Minas Gerais State Water Management Institute (IGAM 2014). The water level in Nova Ponte Hydroelectric Power Plant reservoir (Nova Ponte HPP), in the State of Minas Gerais, was 84% of its total volume in April 2010, end of the rainy season. In April 2014, this volume reached 25%, and in April 2015, it reached 22% (ONS 2015). Climate change studies have shown increased occurrence of atypical drought events (Romm 2011, Gaeta et al. 2014), and their consequences on aquatic macroinvertebrates communities such as loss of native species, expansion of exotic species and changes in nutrient cycling (Carpenter et al. 2011).

Changes in water temperature, food web dynamics, species composition and ecosystem productivity have been observed in reservoirs with the increase of overall air temperature (Williamson et al. 2009). Therefore, it is possible that reservoirs can act as environmental sentinels of signs of climate changes, as being proposed for lakes (Taner et al. 2011). Studies show that decreased water level in these environments cause habitat degradation and have impact on aquatic organisms, including dryness of sediments and death of macrophytes at the littoral zone and the consequent simplification of assemblages (Hofmann et al. 2008, Sutela et al. 2013, Magbanua et al. 2015). Hydropower plant reservoirs are already very unstable environments, because water depletion is usually high and changes in water level are frequent (Tang et al. 2016). Hence, climate changes are expected to further magnify the unstable conditions in reservoirs due to increased occurrence of atypical droughts (Magbanua et al. 2015). One of the major impacts of decreased water level in reservoirs is the exposure and drying of sediments in the shore (Bond et al. 2008, Hofmann et al. 2008). This exposure leads to physical habitat homogenization and decreased complexity in shore sediments, consequently reducing the availability of food resources and refuge for aquatic biota (Hofmann et al. 2008, Kaufmann et al. 2014a, b).

Few ecological studies in tropical regions have assessed the environmental integrity of hydropower reservoirs over time (e.g., Mackay et al. 2010). However, sampling at distinct environmental conditions is necessary to detect trends of changes in freshwater assemblages (Resh et al. 2013), including those generated by large-scale climate changes (Lake 2000, Lake 2003). Analyses of the ecological conditions of these ecosystems have been conducted using water quality bioindicators (Martins et al. 2015), including benthic macroinvertebrate community (Morais et al. 2017) and exotic species (Azevêdo et al. 2016, Linares et al. 2017). The integrated analysis of biological metrics and information on land use, physical habitat conditions, and water quality enables ecological assessment at multiple spatial scales (Macedo et al. 2016, Ferreira et al. 2017, Castro et al. 2017). The identity of bioindicators in reservoirs is different from that of streams and rivers, e.g. insect orders Ephemeroptera, Plecoptera, and Trichoptera (EPT), which are considered good indicators in lotic ecosystems but are rarer in lakes and reservoirs (Borisov et al. 2016). On the other hand, Chironomidae are very abundant and diverse in lentic ecosystems. This family can dwell in a wide range of environmental conditions (Corbi & Trivinho-Strixino 2016, Saulino et al. 2017), shows a good response to environmental degradation (Árva et al. 2015, Brandimarte et al. 2016), and is a potential biological indicator of climate changes (Ilyashuk & Ilyashuk 2007). Recently, Morais et al. (2017) pointed out that water level depletion on hydropower reservoirs favours chironomids as early colonizers, as they rapidly colonize recently-flooded areas.

Another metrics which have been gaining importance in biomonitoring studies are the presence and abundance of exotic species (Linares et al. 2017). These species can cause deep changes in ecosystems and their communities if they become invasive, and are considered the second leading cause of biological diversity loss, after habitat loss (Strayer 2010, Silva & Barros 2011). The introduction and constant dispersal of exotic species in aquatic ecosystems are facilitated by human activities (e.g., ballast water transport, use of species as fish bait, releases from recreational production, and juvenile fixation onto ship hulls) (Sousa et al. 2008). Reservoirs are especially vulnerable to the invasion of exotic species as they receive continuous input of biological materials derived from the main river and its tributaries (Rocha et al. 2011). These species might be subsequently transported downstream and colonize other sections of the river basins (Rocha et al. 2011). The increase in extended droughts might also change the environmental filters that determine how successful exotic species are in colonizing new habitats (Rahel & Olden 2008, Gama et al. 2017, McDowell et al. 2017). However, in certain situations, water stress might reduce the negative effects of exotic species on the environment, minimizing the spatial overlap between native and exotic species (Taner et al. 2011).

Considering that extreme drought events tend to be more frequent over the next decades (IPCC 2016), the aim of this study was to assess how composition and structure of benthic macroinvertebrate communities change in atypical drought conditions in a hydroelectric power plant reservoir in the Brazilian cerrado. We worked with the hypothesis that an extreme drought event is detrimental to macroinvertebrate communities, with the exception of organisms resistant to environmental changes, including the

Chironomidae family and the exotic species. Our first prediction is that macroinvertebrate diversity might decrease with decreased water volume, with a simultaneous increase in Chironomidae richness and abundance. Our second prediction is that the abundance of exotic species might increase in the drier year, as these species usually have high ecological plasticity and are tolerant to environmental changes. Finally, our third prediction is that disturbances acting at different spatial scales might affect the biological metrics, but this influence is not as strong in genera of Chironomidae and in exotic species.

## Material and Methods

### *1. Study Area*

Nova Ponte Reservoir is located in the middle section of the Araguari river basin in the Cerrado of Minas Gerais State, southeastern Brazil (Figure 1). It was built in 1987 and started to operate in 1994. According to Köppen's classification, the climate in the region is AWA (tropical with hot rainy summers and dry winters), with temperatures ranging between 14ºC and 30ºC and mean annual rainfall of approximately 1700 mm/year (Durães et al. 2001). Dry season typically spans from May to September, whereas rainy season spans from October to April. Nova Ponte Reservoir is the largest in a series of cascade reservoirs in the Araguari River, with a surface area of 443 km$^2$ and maximum accumulation volume of 12.8 billion m$^3$ of water (CEMIG 2015). Its hydroelectric power plant houses three power generating units with a total capacity of 510 Mw. Its dam wall has a maximum height of 142 meters and is 1600 meters long, and its residence time is ~507 days (ANA 2016).

### *2. Selection of sampling sites and sampling periods*

Sampling sites were defined according to a spatially balanced sampling design (Stevens & Olsen 2004), adapted to large tropical reservoirs (Macedo et al. 2014). Forty equidistant sampling sites were defined starting at a random point in the shore perimeter of Nova Ponte Reservoir. At each sampling site physical habitats were assessed, physical and chemical parameters of water column and sediment granulometry were measured, and benthic macroinvertebrate communities were sampled. Samplings were carried out in April 2010 (regular drought year) and in April 2014 (atypical drought year). In this month, the reservoir is expected to have its maximum volume, offering higher availability of physical habitats to the aquatic biota (Morais et al. 2017). The average volume in 2014 was below the historical average for the 14-year data (Figure 2).

### *3. Characterization of land uses*

Land uses were determined by identifying landscape characteristics in the influence areas (*buffers*) of 500 m surrounding each sampling site. *Buffers* were analyzed through satellite images (TM sensor onboard Landsat 5) captured in the same period as the samplings (April 2010 and 2014). Using the Kosmo 2.0 software and images available at Google Earth 6.0, images were interpreted and areas with different land uses were defined (e.g. agriculture, native vegetation, grass fields, pasture, constructions).

### *4. Field protocol*

The physical structure of habitats was characterized by applying the Physical Habitat Characterization Protocol (USEPA 2012). At each sampling site, 10 transects were set 15 meters equidistant from each other. In each transect, we assessed continuous sections of coastal zone (wetted

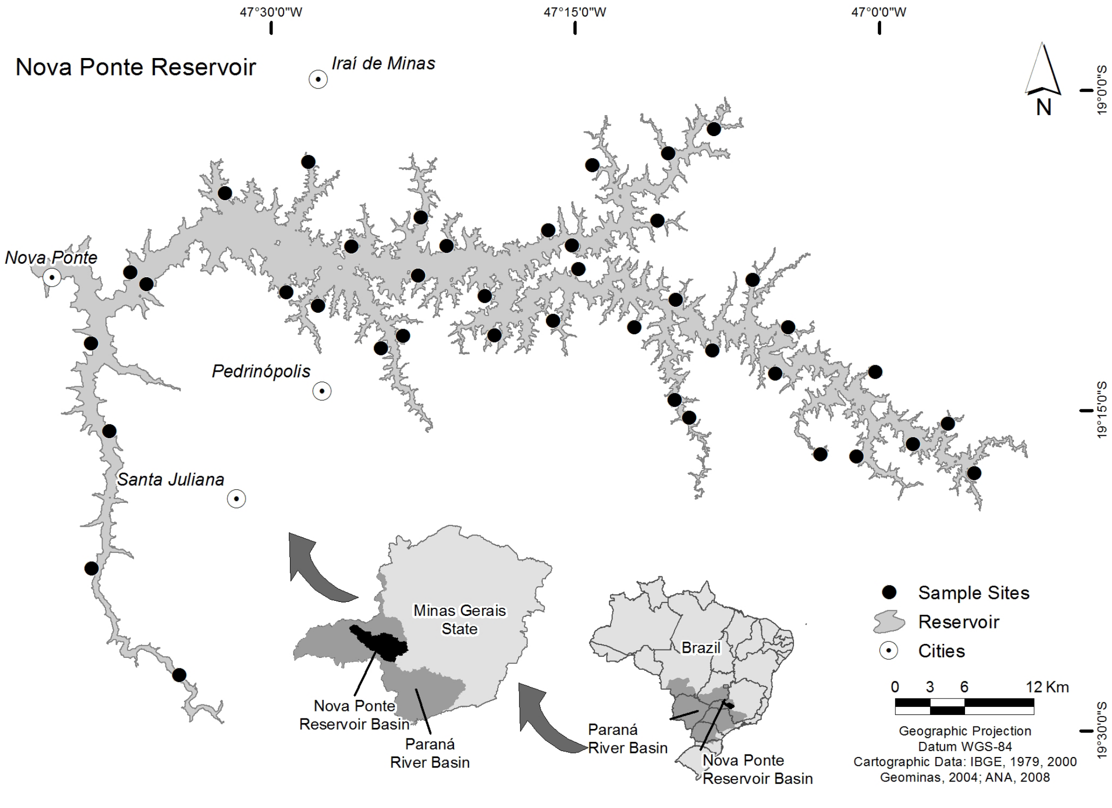

**Figure 1.** Sampling sites in the Nova Ponte reservoir, Araguari river basin, MG, Brazil.

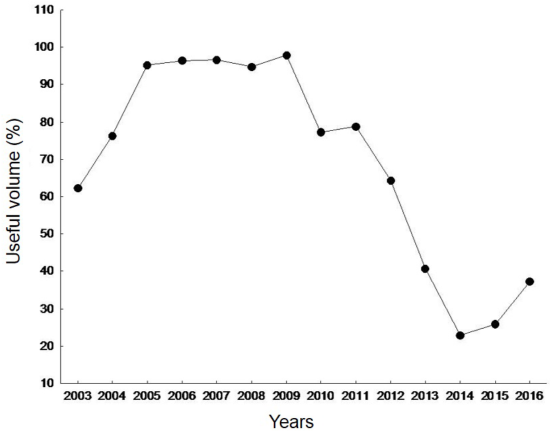

**Figure 2.** Historical water volume data of Nova Ponte reservoir, Araguari river basin, MG, regarding the month of April from the years of 2003 to 2016.

are next to margins, 15 x 10 m), flood zone (15 x Y m, where Y represents the flood zone length, which varies between transects according to the slope of margins at the sampling sites), and riparian zone (above flood zone, 15 x 15 m).

## *5. Evaluation of limnological parameters and sediment characterization*

Limnological parameters were evaluated at the 40 sampling sites based on measures taken in the subsurface. Water temperature (ºC), pH, and electric conductivity (µS $cm^{-1}$) were measured using a multi-analyzer YSI® 6600 model. Total depth was measured using a digital meter gauge and water transparency was measured using a Secchi (m) dish. Turbidity (NTU) was measured using a Digimed® turbidimeter. At the laboratory, chlorophyll-*a* contents (µg $L^{-1}$) were measured according to the methodology by Golterman et al. (1978) and dissolved oxygen contents (mg L) were measured using the Winkler method (1888). Total alkalinity (mEq $L^{-1}$ $CO_2$) was calculated according to Carmouze (1994). Organic matter contents in the sediment were determined using the gravimetric method, in which aliquots (0.3 ± 0.1g) were calcinated in a muffle furnace at 550°C for four hours and then weighed (Esteves et al. 1995). Granulometric composition was analyzed using the sieving method, according to Suguio (1973), modified by Callisto & Esteves (1996).

## *6. Characterization of anthropogenic disturbances*

In order to determine the level of disturbance at each sampling site, three indices were used, according to Ligeiro et al. (2013) and Martins et al. (2015): i) Buffer Disturbance Index (BDI), which reflects the disturbances in the *buffer* area; ii) Local Disturbance Index (LDI), which reflects disturbances at the local scale; and iii) Integrated Disturbance Index (IDI), which was calculated based on the two previous indices.

BDI was determined based on the percentages of land use inside each *buffer* (500 m), and different weights were attributed to each type of land use activity, according to the formula:

$$BDI = 4 \times \left(\%urban\ areas\right) + 2 \times \begin{pmatrix} \%agricultural\ areas + \\ \%bare\ soil\ area \end{pmatrix} + \%pasture\ areas \quad (1)$$

The SynRD*is_IX* index was used as a measure for the LDI. For compound this index we measured several metrics of physical habitat and human alterations along each site (Table 1), and calculations we made according to Kaufmann et al. (2014a, b).

Finally, a disturbance plane was built having the BDI and the LDI as the two axes, and the IDI was calculated as the Euclidian distance between the position of each site relative to the origin of the plane (zero values in both axes) (Ligeiro et al. 2013, Martins et al. 2015). Values farther from the origin represent higher departure from better ecological status, and consequently, higher human modifications. In other words, sampling sites located near the origin of the disturbance plane represent locations minimally changed by human activities, and can be considered as reference areas according to the Maximum Ecological Potential concept (Molozzi et al. 2013a).

## *7. Sampling of benthic macroinvertebrates*

Samplings of macroinvertebrate communities were performed at each sampling site using an Eckman-Birge drag (area 0.022 $m^2$). Samples were stored in plastic bags, fixated with 4% formaldehyde and transported to the Benthic Ecology Laboratory of the Federal University of Minas Gerais. At the laboratory, samples were rinsed individually through two sieves with mesh sizes 1.0 and 0.5 mm. After that, animals were sorted and identified using a stereoscope microscope with 40x magnification. Identification was performed at the family level with the help of specific taxonomic keys (Pérez 1988, Merritt & Cummins 1996, Carvalho & Calil 2000, Epler 2001, Fernández & Domínguez 2001, Costa & Simonka 2006, Mugnai et al. 2010). Oligochaeta, Hirudinea and Hydracarina were not identified at family. Individuals of the family Chironomidae (Diptera, Insecta) were identified at the genus level, using the taxonomic key by Trivinho-Strixino (2011). Exotic species were identified using specific taxonomic keys (Melo 2003, Pereira et al. 2012, Santos et al. 2012).

## *8. Biological metrics calculation*

Some biological metrics were calculated according to Silveira (2004) and Ferreira et al. (2011), namely: i) richness, ii) % richness, iii) abundance, and iv) % abundance, for the following data: (a) benthic *taxa*, (b) Ephemeroptera, Plecoptera and Trichoptera (EPT) (Leptohyphidae, Leptophlebiidae, Polymitarcyidae and Hydropsychidae) as sensitive *taxa*, (c) tolerant *taxa* (Staphylinidae, Chaoboridae, Ceratopogonidae, Naucoridae, Gomphidae, Libellulidae and Corixidae), (d) resistant *taxa* (Oligochaeta), (e) exotic species (*Corbicula fluminea* Müller 1974, *Melanoides tuberculatus* Müller 1974, and *Macrobrachium amazonicus* Heller 1862), (f) genera of Chironomidae.

## *9. Data analysis*

### *9.1. Assessing spatial correlation among macroinvertebrate communities*

To analyze spatial correlation of macroinvertebrate composition among sampling sites, the Mantel test (Mantel 1967) was performed at each sampling period using the '*vegan*' package (Oksanen et al. 2017) of the R program (R Core Team 2017). A Bray-Curtis dissimilarity matrix was built using macroinvertebrate abundance data (transformed in $Log_{10}$ (x+1)) and a spatial distance matrix was built applying an Euclidian distance in the geographical (lat/long) coordinates (UTM).

We also employed the Moran's I autocorrelation coefficient to evaluate spatial autocorrelation in taxonomic richness and abundance of macroinvertebrates at each sampling period. We used the inverse (1/x) of the Euclidean distances between pairs of sites as a measurement of distance weight. For these analyses we used the '*ape*' package (Paradis et al. 2004), also in R program (R Core Team 2017).

**Table 1.** Metrics used to calculate the Local Disturbance Index (LDI), after Kaufmann et al. (2014a; b).

| Metric | Description | Min | Med | Max |
|---|---|---|---|---|
| Pdraw | Ratio of horizontal drawdown distance divided by the field plot size (15m). | 1.0 | 1.9 | 6.1 |
| rviWoody | Summed coverage of woody vegetation in the canopy, understory and ground cover. | 0.1 | 0.4 | 0.8 |
| rvfcCanBig | Mean proportional areal cover of large diameter trees averaged over the 10 plots. | 0.0 | 0.3 | 0.8 |
| rvfcGrdBare | Mean proportional areal cover of bare ground (soil) averaged over the 10 plots. | 0.0 | 0.1 | 0.6 |
| hifpAnyCirca | Proportion of plots with at least one type of human activity. | 0.0 | 0.2 | 1.0 |
| hiiAg | Proportion of plots with agricultural activities. | 0.0 | 0.1 | 1.9 |
| hiiNonAg | Proportion of plots with non-agricultural activities. | 0.0 | 0.2 | 3.2 |
| hiiAll | Sum of the proportions of plots with agricultural and non-agricultural activities. | 0.0 | 0.3 | 5.1 |
| hiiAllCirca | Proportion between agricultural and non-agricultural activities. | 0.0 | 0.1 | 1.0 |

**Table 2.** Limnological and sediment variables measured in Nova Ponte reservoir, Araguari river basin, MG, in the years of 2010 and 2014. It is being presented the mean, the standard deviation and the results of the paired t-tests (d.f. = 39, * $p \leq 0,05$).

| Variables | 2010 | 2014 | *t* | p |
|---|---|---|---|---|
| % Cobbles (64 - 250 mm) | 0.26 ± 0.38 | 0.00 ± 0.00 | 4.294 | < 0.001 |
| % Gravel (2 - 63 mm) | 0.19 ± 0.24 | 0.07 ± 0.12 | 2.707 | 0.01 |
| % Fine sand (0.1 - 0.249 mm) | 0.33 ± 0.15 | 0.42 ± 0. 15 | -2.466 | 0.01 |
| % Very Fine Sand (0.125 - 0.062 mm) | 0.54 ± 0.24 | 0.71 ± 0.18 | -3.702 | < 0.001 |
| Secchi (m) | 3.13 ± 1.45 | 1.47 ± 1.10 | 7.994 | < 0.001 |
| pH | 7.56 ± 0.19 | 7.94 ± 0.52 | -3.683 | < 0.001 |
| Conductivity ($\mu S\ cm^{-1}$) | 22.80 ± 4.21 | 2.77 ± 1.47 | 36.919 | < 0.001 |
| Turbidity (UNT) | 2.53 ± 1.47 | 33.27 ± 49.24 | -3.947 | < 0.001 |
| Chlorophyll *a* ($\mu g\ L^{-1}$) | 0.86 ± 0.43 | 1.37 ± 1.28 | -2.233 | 0.031 |
| Total alkalinity (mEq $L^{-1}$ $CO_2$) | 155.35 ± 33.16 | 234.58 ± 83.74 | -6.437 | < 0.001 |

### *9.2. Comparisons of land uses and limnological variables between years*

Paired t-tests were used to analyze the differences of land uses in site *buffers* and limnological variables between the two sampling years. The percentage data first went through an arcsine square root transformation. BDI, LDI, and IDI values were also compared between sampling years in the same manner. These analyses were performed in the Statistica 6.0 program (Statsoft 2011).

### *9.3. Influence of anthropogenic disturbances on the benthic macroinvertebrate community*

Paired t-tests were used to check differences in taxonomic richness and abundance of individuals between sampling years. In order to assess the effects of anthropogenic influences on macroinvertebrate communities at different spatial scales, multiple linear regressions were performed between biological metrics and disturbance indices (BDI, LDI). These analyses were performed separately for each sampling year using the Statistica 6.0 program (Statsoft 2011).

## Results

Types of land use in areas surrounding the sampling sites in Nova Ponte Reservoir showed no striking changes between sampling years. In 2010, they were represented by grass fields (34.1%), native vegetation (33.6%), agriculture (21.7%), pasture (9.4%), bare soil (0.9%), and constructions (0.3%). This scenario was generally similar in 2014; fields (34.0%) (no change), native vegetation (33.6%) (no change), agriculture (22.2%) (t = -1.000, df = 39, p = 0.323), pasture (9.0%) (t = 1.000, df = 39; p = 0.323), bare soil (0.9%) (no change), and constructions (0.3%) (no change).

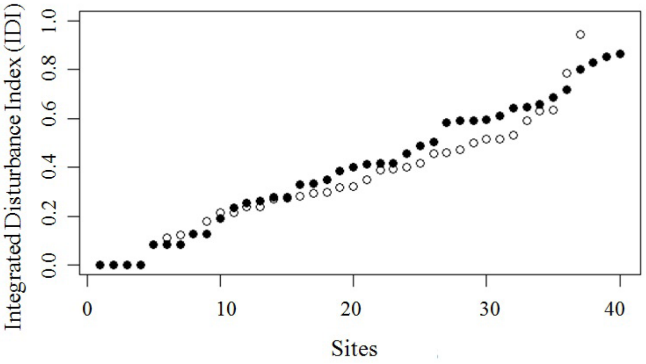

**Figure 3.** Ordered values of the Integrated Disturbance Index (IDI) of the sites in the years of 2010 (●) and 2014 (○).

Regarding limnological parameters, a quite different scenario was observed between the regular climatological year (2010) and the atypical drought year (2014) (Table 2). In 2010 we observed a higher water conductivity, while in 2014 almost all limnological parameters presented higher values, including pH, turbidity, Chlorophyll-a and total alkalinity. The analysis of granulometric composition in the shore sediment indicated larger particle sizes in 2010 (pebbles and gravels) compared to those obtained in 2014, when we observed a higher proportion of fine and very fine sand.

Disturbance indices results were similar between study years (LDI, t = 0.182, df = 39, p = 0.856; BDI, t = -1.000, df = 39, p = 0.323; IDI, t = 0.033, df = 39, p = 0.973) (Figure 3). This emphasizes that the atypical drought year did not influence anthropogenic stress intensity along the reservoir shoreline.

**Table 3.** List of *taxa* found in Nova Ponte reservoir, Araguari river basin, MG, in the years of 2010 and 2014.

| Taxa | Abundance | |
|---|---|---|
| | 2010 | 2014 |
| **Clitellata** | | |
| Oligochaeta | 470 | 92 |
| Hirudinea | 1 | 0 |
| **Mesogastropoda** | | |
| *Melanoides tuberculatus* | 14 | 0 |
| **Veneroida** | | |
| *Corbicula fluminea* | 12 | 13 |
| **Decapoda** | | |
| *Macrobrachium amazonicum* | 1 | 0 |
| **Trombidiformes** | | |
| Hydracarina | 4 | 0 |
| **Diptera** | | |
| Chironomidae | 515 | 390 |
| Chaoboridae | 47 | 439 |
| Ceratopogonidae | 7 | 2 |
| **Ephemeroptera** | | |
| Leptohyphidae | 16 | 2 |
| Caenidae | 9 | 0 |
| Baetidae | 3 | 0 |
| Leptophlebiidae | 0 | 5 |
| Polymitarcyidae | 0 | 1 |
| **Coleoptera** | | |
| Elmidae | 1 | 0 |
| Staphylinidae | 0 | 2 |
| **Odonata** | | |
| Gomphidae | 5 | 6 |
| Libellulidae | 5 | 1 |
| **Lepidoptera** | | |
| Pyralidae | 1 | 0 |
| **Trichoptera** | | |
| Leptoceridae | 2 | 0 |
| Polycentropodidae | 3 | 0 |
| Hydropsychidae | 0 | 1 |
| **Hemiptera** | | |
| Naucoridae | 0 | 1 |
| Corixidae | 0 | 1 |

A total of 1,116 individuals were identified in 2010, distributed in 18 *taxa*. The most abundant groups were Chironomidae (46%) and Oligochaeta (42%). The 456 Chironomidae were identified in 21 genera, with predominance of *Tanytarsus* (van der Wulp 1874), which had 45% of the sampled individuals, and *Polypedilum* (Kieffer 1912), with 15%. No significant correlation was observed between the distance between sites and the similarity of their species composition (R = 0.057, p = 0.22). Taxonomic richness and abundance of macroinvertebrates were weakly, but significantly, spatially autocorrelated during this year (Morans'I = 0.05, p = 0.03 in both cases).

In 2014, 956 individuals were collected and identified in 14 *taxa* (46% Chaoboridae and 41% Chironomidae) (Table 3). A total of 334 collected individuals of Chironomidae were identified in 22 genera, with predominance of *Polypedilum* (Kieffer 1912) and *Tanypus* (Meigen 1803) (each with 22% of the total) (Table 4). Again, no relationship was observed between spatial distances between sites and the similarity of their communities (R = -0.007, p = 0.51). Taxonomic richess and abundance of macroinvertebrates were not spatially autocorrelated during this year (respectively, Morans'I = 0.03, p = 0.22 and Morans'I = 0.03, p = 0.09).

**Table 4.** List of genera of Chironomidae found in Nova Ponte reservoir, Araguari river basin, MG, in the years of 2010 and 2014.

| Genera | Abundance | |
|---|---|---|
| | 2010 | 2014 |
| **Tanypodinae** | | |
| *Ablabesmyia* Johannsen, 1905 | 15 | 11 |
| *Clinotanypus* Kieffer, 1913 | 0 | 2 |
| *Coelotanypus* Kieffer, 1913 | 16 | 11 |
| *Djalmabatista* Fittkau, 1968 | 2 | 1 |
| *Labrundinia* Fittkau, 1962 | 2 | 0 |
| *Tanypus* Meigen, 1803 | 0 | 73 |
| **Orthocladiinae** | | |
| *Cricotopus* van der Vulp, 1874 | 36 | 0 |
| *Metriocnemus* van der Wulp, 1874 | 0 | 1 |
| **Chironominae** | | |
| *Aedokritus* Roback, 1958 | 13 | 10 |
| *Asheum* Sublette, 1964 | 5 | 7 |
| *Axarus* Roback, 1980 | 2 | 0 |
| *Caladomyia* Säwedal, 1981 | 5 | 0 |
| *Chironomus* Meigen, 1803 | 25 | 26 |
| *Cladopelma* Kieffer, 1921 | 14 | 21 |
| *Cryptochironomus* Kieffer, 1918 | 2 | 2 |
| *Dicrotendipes* Kieffer, 1913 | 0 | 3 |
| *Fissimentum* Cranston & Nolte, 1996 | 29 | 5 |
| *Goeldichironomus* Fittkau, 1965 | 5 | 37 |
| *Nilothauma* Kieffer, 1920 | 4 | 1 |
| *Paralauterborniella* Lenz, 1941 | 1 | 7 |
| *Pelomus* Reiss, 1990 | 2 | 9 |
| *Polypedilum* Kieffer, 1912 | 70 | 73 |
| *Saetheria* Jackson, 1977 | 1 | 7 |
| *Stempellinella* Brundin, 1947 | 0 | 1 |
| *Stenochironomus* Kieffer, 1919 | 3 | 1 |
| *Tanytarsus* van der Wulp, 1874 | 204 | 25 |

The richness of macroinvertebrates was significantly lower in the drier year (t = 2.882, d.f. = 39, p = 0.006), with 2.9 ± 1.7 (average ± standard deviation) *taxa* sampled in 2010 and 2.1 ± 0.9 *taxa* sampled in 2014. Macroinvertebrates did not show significant differences in abundance (t = 0.427, d.f. = 39, p = 0.671), with 27.9 ± 39.1 individuals collected in 2010 and 23.9 ± 41.7 individuals collected in 2014. On the other hand, there was no change in richness (t = -0.813, d.f. = 39, p = 0.420) and abundance (t = 0.727, d.f. = 39, p = 0.471) of genera of Chironomidae between years. Three exotic species were recorded in 2010: *Corbicula fluminea* (Müller 1974), *Melanoides tuberculatus* (Müller 1974), and *Macrobrachium amazonicus* (Heller 1862), whereas only *C. fluminea* was recorded in 2014.

No biological metric was related with BDI in neither of the two years (Table 5). In 2010, three biological metrics (exotic species abundance, percentage of individuals of exotic species, and percentage of exotic species richness) were significantly related to the LDI; whereas in 2014, only the metric exotic species abundance was significantly related to the LDI (Table 5).

**Table 5.** Multiple regression between the biological metrics and the disturbance indexes (IDB and IDL) in Nova Ponte reservoir, Araguari river basin, MG, in the years of 2010 and 2014. Only the response variables which rendered significant models (* $p \leq 0,05$) were presented.

| Biological Metrics | 2010 | | | | | | 2014 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | IDB | | IDL | | F(2,37) | p | IDB | | IDL | | F(2,37) | p |
| | p- level | B | p-level | B | | | p-level | B | p-level | B | | |
| Abundance of non-native species | 0.614 | 0.035 | 0.005* | 0.186 | 4.554 | 0.017 | 0.559 | 0.029 | 0.007* | 0.106 | 4.215 | 0.022 |
| Percent of non-native individuals | 0.870 | 0.674 | 0.011* | 10.014 | 3.610 | 0.036 | 0.876 | 0.571 | 0.066 | 5.204 | 1.793 | 0.180 |
| Percent non-native species richness | 0.465 | -0.025 | 0.017* | -0.076 | 3.423 | 0.043 | 0.979 | 0.083 | 0.127 | 3.818 | 1.214 | 0.308 |

## Discussion

The 2014 drought in southeastern Brazil was considered atypical for the region (IGAM 2014, ANA 2016). A water shortage crisis followed this episode in several parts of the country because of the low rainfall and also due to the poor management of water resources and the widespread environmental degradation related to anthropogenic activities (Dobrovolski & Rattis 2015). The total rain recorded over the previous two periods (2012/2013 and 2013/2014) were lower than the climatological normal, and these years were classified respectively as ‘slightly dry’ to ‘very dry’ (IGAM 2014, ANA 2016). Consequently, changes in the macroinvertebrate community, in the limnological parameters, and in the physical habitats of the Nova Ponte Reservoir were observed in 2014.

Macroinvertebrate taxonomic richness was lower in the atypical drought year (2014), but there was no change in the richness and abundance of genera of Chironomidae between years. Higher climatic unpredictability and the occurrence of extreme events have been seriously affecting aquatic biodiversity (Lake 2003). Hydrological disturbances might lead to changes in the characteristics of the environment, as observed in our study, since limnological parameters and habitat characteristics were strikingly different between the regular climatological year (2010) and the atypical drought year (2014). Water shortage led to decreased water level in the reservoir, and consequently, to increased pH, suspended solid contents, and chlorophyll-a, all of which are relevant factors to the structuring of benthic communities (Navarro et al. 2009). We also observed that decreased water volume led to changes in the granulometric composition of sediments, with predominance of finer particles in the drier year. This might be explained by shore retreat in the horizontal profile of the reservoir due to water level depletion. Therefore, the area which was a limnetic region in 2010 became a littoral region in 2014 due to water depletion, and this might have contributed to the lower macroinvertebrate diversity observed in this atypical drought year. Granulometric composition has been considered to be the factor with the highest influence on the distribution of benthic macroinvertebrates at a local scale in tropical reservoirs (Molozzi et al. 2013b). Hence, the more diversified the sediment, the higher the availability of shelters and protection for these organisms (Molozzi et al. 2011, Zerlin & Henry 2014).

Oligochaeta and larvae of Chironomidae and Chaoboridae were present and abundant in both sampling periods. In 2014, these organisms were the dominant *taxa*. This might be attributed to the high resistance of these groups to changes caused by water level depletion in the reservoir (Dollar et al. 2013, Morais et al. 2017). In addition, these organisms have high reproduction rates, and might adapt to sudden changes in water quality (Ledger et al. 2013). Chaoboridae are represented by cosmopolitan and voracious organisms which predate other invertebrates, especially zooplankton. They might be found in the sediment during the day and in the water column at night, and are common in reservoirs (Zerlin & Henry 2014). Many Chironomidae larvae inhabit harsh habitats, such as fine sediments, hot waters, and low oxygen contents (Ledger et al. 2012). The genus *Tanypus* was one of the most abundant in 2014. These larvae have preference for shallow places, and are adapted to fluctuations in environmental conditions. They are also known as organic pollution-tolerant organisms (Silva et al. 2009). On the other hand, the genera *Cricotopus*, *Fissimentum* and *Tanytarsus* presented a sharp decrease of abundance in the drought year, revealing the bioindicator potential of these genera (Morais et al. 2010). The decrease in the abundance of Oligochaeta in 2014 may indicate the preference of this group for littoral zones in reservoirs (Azêvedo et al. 2015), which were exposed during the water stress.

Our results showed that disturbance index values (Integrated Disturbance Index-IDI, Buffer Disturbance Index-BDI, and Local Disturbance Index-LDI) underwent minimum changes in Nova Ponte Reservoir when both study years were compared. Thus, the decrease observed in taxonomic richness was, in fact, due to the water stress event and not to increased human disturbance around the reservoir. Overall, Local Disturbance Index (LDI) better explained the variation in community structure than the *Buffer* Disturbance Index (BDI). This contrasts with the pattern usually observed in lotic ecosystems, such as streams, where disturbances acting in the drainage basin typically have higher influence on community structure (Martel et al. 2007, Kail et al. 2012, Ligeiro et al. 2013). Reservoirs are essentially artificial environments created for several different purposes, including electric power generation and water for human consumption (Tundisi & Matsumura-Tundisi 2008). Thus, this large-scale artificial condition is probably minimizing the importance of landscape elements operating in the area around sampling sites (*buffers*), and local-scale disturbance is more likely to have influence over the aquatic biota (Molozzi et al. 2013a). Therefore, our findings indicate that the management of artificial ecosystems must be based on premises other than those used for natural ecosystems. We encourage further studies to test the generality of this statement. Additionally, the effects of anthropogenic disturbance indices (LDI, BDI) on biological variables were more evident in 2010, which was within the climatological normal for that region. This suggests that the large-scale water stress which occurred in 2014 overrode the importance of both land uses and local habitat disturbances for the macroinvertebrate communities. In other words, large-scale climatic events negatively affect the ecological integrity of reservoirs, regardless of the conditions in their aquatic habitats and their surrounding areas. This corroborates findings of studies by international agencies, which emphasize the need for stopping and reversing severe global climate changes (IPCC 2016, Boersma et al. 2016). If that is not done, habitat management and conservation measures conducted at more limited scales will be of little use.

Exotic species were also negatively influenced by the water stress event. In 2014, these species presented quite decreased richness and abundance. *Corbicula fluminea* was the only exotic species found in 2014, although in lower numbers. This species has a remarkable capacity of re-colonizing and recovering its abundance after the occurrence of disturbances (Sousa et al. 2008). Some studies have demonstrated that increased turbidity might increase mollusk mortality (Avelar et al. 2014, Neves et al. 2014). Sediment type might also influence the mortality of these organisms, since very fine fractions require higher energy expenditure to keep the individuals in the sediment, and they might also clog the pallial cavity (Vianna & Avelar 2010). In addition, changes in several factors during drought, such as increased temperature, pH, and turbidity, might increase the mortality of benthic organisms, whether exotic or not (Sousa et al. 2008). The presence of exotic species can lead to a pauperization of macroinvertebrate communities (Linares et al., 2017). In this way, one can expect an amelioration of ecosystem integrity with the removal of those species. However, in this study the water stress impacted greatly both native and exotic species, so that any positive consequence resultant from this removal could not be detected. Therefore, if the patterns observed in this case study are confirmed, it is possible that water stress events might work as a barrier for the advance of exotic species distribution in reservoirs. On the other hand, metacommunity dynamics might also buffer local extinction events, keeping these species in the regional pool (Leibold et al. 2004, Brown et al. 2011).

## Conclusion

Although our temporal sampling effort was too short (normal versus atypical drought, one year each), our study provides important information about atypical drought conditions, creating unique opportunities to understand the ecological effect of climate changes in tropical reservoirs. The water level depletion caused in Nova Ponte Reservoir by an atypical drought event affected both limnological parameters of water and sediment size in the shore, thus influencing benthic macroinvertebrate communities. Nevertheless, the level of anthropogenic disturbances did not change between years, indicating that the drought *per se* did not influence the intensity of human intervention observed in local habitats and in the areas surrounding sampling sites (*buffers*). Our hypothesis that an extreme drought event is detrimental to macroinvertebrate communities was generally corroborated. However, our prediction that exotic species would benefit from the water stress event was not, as we observed a reduction in the richness and abundance of these organisms during that period. Although some genera of Chironomidae presented a decreased abundance due to the water stress, most genera tolerated well the drought conditions, confirming the high environmental plasticity of this group. Our results indicate that damaging effects caused by a large-scale water stress event might override the effects of habitat integrity in reservoirs and their surrounding landscapes, which has important implications for the management of these artificial environments in a setting of global climate changes.

## Acknowledgments

We thank the Peixe-Vivo Program of Companhia Energética de Minas Gerais, Pesquisa e Desenvolvimento/Agência Nacional de Energia Elétrica/Companhia Energética de Minas Gerais - P&D ANEEL/CEMIG (GT-487), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (PROCAD-CAPES), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq); Carlos Bernardo Mascarenhas Alves for his logistic support; and colleagues from the Benthic Ecology Laboratory of the Federal University of Minas Gerais, for helping with field samplings. MC was awarded research productivity CNPq (no. 303380/2015-2), research project CNPq (no. 446155/2014-4), and Minas Gerais research grant FAPEMIG PPM-IX - 00525-15. The State University of Paraíba Benthic Ecology Laboratory (UEPB) supported the senior author.

## Author Contributions

Raphael Ligeiro: Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intelectual content.

José Etham de L. Barbosa: Contribution to critical revision, adding intelectual content.

Joseline Molozzi: Contribution to data analysis and interpretation; Contribution to critical revision, adding intelectual content.

Marcos Callisto: Substantial contribution in the concept and design of the study; Contribution to data collection; Contribution to manuscript preparation; Contribution to critical revision, adding intelectual content.

## Conflicts of interest

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

## References

ANA. http://www2.ana.gov.br/reservatorios (the last access in 19/11/2016).

ÁRVA, D., SPECZIÁR, A., ERŐS, T. & TÓTH, M. 2015. Effects of habitat types and within lake environmental gradients on the diversity of chironomid assemblages. Limnologica. doi.org/10.1016/j.limno.2015.05.004.

AVELAR, W.E.P., NEVES, F.F. & LAVRADOR, M.A.S. 2014. Modelling the risk of mortality of *Corbicula fluminea* (Müller, 1774) (Bivalvia: Corbiculidae) exposed to different turbidity conditions. Braz. J. Biol. 74(2): 509-514.

AZEVÊDO, D.J.S., BARBOSA, J.E.L. GOMES, W.I.A., PORTO, D.E., MARQUES, J.C. & MOLOZZI, J. 2015. Diversity measures in macroinvertebrate and zooplankton communities related to the trophic status of subtropical reservoirs: Contradictory or complementary responses? Ecol. Indic. 50: 135-149.

AZEVÊDO, E.L., BARBOSA, J.E.L., VIDIGAL, T.H.A., MARQUES, J.C., CALLISTO, M. & MOLOZZI, J. 2016. Potential ecological distribution of alien mollusk *Corbicula largillierti* and its relationship with human disturbance in a semi-arid reservoir. Biota Neotrop. 16(1): e0109. http://dx.doi.org/10.1590/1676-0611-BN-2015-0109.

BOERSMA, K.S., NICKERSON, A., FRANCIS, C.D. & SIEPIELSKI, A.M. 2016. Climate extremes are associated with invertebrate taxonomic and functional composition in mountain lakes. Ecol. Evol. 6(22): 8094-8106.

BOND, N.R., LAKE, P.S. & ARTHINGTON, A.H. 2008. The impacts of drought on freshwater ecosystems: an Australian perspective. Hydrobiologia, 600: 3-16.

BORISOV, R.R., CHERTOPRUD, E.S. & KOVACHEVA, N.P. 2016. Water quality assessment in reservoirs: comparative analysis of bioindication systems based on macrobenthos characteristics. Water Resour. (43)5: 544-554.

BRANDIMARTE, A.L., ANAYA, M. & SHIMIZU, G.Y. 2016. Impact of damming on the Chironomidae of the upper zone of a tropical run-of-the-river reservoir. Braz. J. Biol. (76)2: 402-411.

BROWN, B.L., SWAN, C.M., AUERBACH, D.A., CAMPBELL GRANT, E.H., HITT, N.P., MALONEY, K.O. & PATRICK, C. 2011. Metacommunity theory as a multispecies, multiscale framework for studying the influence of river network structure on riverine communities and ecosystems. J. N. Am. Benthol. Soc. 30(1): 310-327.

CASTRO, D.M.P., DOLÉDEC, S. & CALLISTO, M. 2017. Landscape variables influence taxonomic and trait composition of insect assemblages in neotropical savanna streams. Freshwater Biol. 1-15. doi: 10.1111/fwb.12961

CALLISTO, M. & ESTEVES, F. 1996. Composição granulométrica do sedimento de um lago amazônico impactado por rejeito de bauxita e um lago natural. Acta Limnol. Bras. 8: 115-126.

CARPENTER, S.R., STANLEY, E.H. & ZANDEN, M.J.V. 2011. State of the world's freshwater ecosystems: physical, chemical, and biological changes. Annu. Rev. Env. Resour. 36: 75-99.

CARMOUZE, J.P. 1994. O metabolismo dos ecossistemas aquáticos: fundamentos teóricos, métodos de estudo e análises químicas. São Paulo: Ed. Edgard Blücher, FAPESP, p. 255.

CARVALHO, A.L. & CALIL, E.R. 2000. Chaves de identificação para famílias de Odonata (Insecta) ocorrentes no Brasil, adultos e larvas. Pap. Avulsos Zool. 41(15): 223-241.

CEMIG. Http://www.cemig.com.br/pt_br/a_cemig/Nossa_Historia/Paginas/Usinas_Hidreletricas (the last access in 18/03/2015).

CORBI, J.J. & TRIVINHO-STRIXINO, S. 2016. Chironomid species are sensitive to sugarcane cultivation. Hydrobiologia. doi:10.1007/s10750-016-2908-2.

COSTA, C.S. & SIMONKA, C.S. 2006. Insetos Imaturos Metamorfose e Identificação. RibeirãoPreto. Ed. Helos, p. 249.

DOBROVOLSKI, R. & RATTIS, L. 2015. Water collapse in Brasil: the danger of relying on what you neglect. Nat.Conservação. 13: 80-90.

DOLLAR, E., EDWARDS, F., STRATFORD, C., MAY, L., BIGGS, J., LAIZE, C., ACREMAN, M., BLAKE, J., CARVALHO, L., ELLIOTT, A., GUNN, I., HINSLEY, S., MOUNTFORD, O., NUNN, M., PRESTON, C., SAYER, E., SCHONROGGE, K., SPEARS, B., SPURGEON, D., WINFIELD, I. & WOOD, P. 2013. Monitoring and Assessment of Environmental Impacts of Droughts. Literature Synthesis, Report:SC120024/R1. Environment Agency, p. 24-29. https://www.environment-agency.gov.uk.

DURÃES, R., POMPEU, P.S. & GODINHO, A.L. 2001. Alimentação de quatro espécies de *Leporinus* (Characiformes, Anostomidae) durante a formação de um reservatório no sudeste do Brasil. Iheringia Ser. Zool. 90: 183-191.

EPLER, J.H. 2001. Identification manual for the larval Chironomidae (Diptera) of North and South Carolina. Department of Environmental and Natural Resources. Division of Water quality. Raleigh and St. Johns River Water Management District, Palatka, p. 526.

ESTEVES, F.A., SUZUKI, M.S., CALLISTO, M. & PERES-NETO, P.R. 1995. Teores de matéria orgânica, carbono orgânico, nitrogênio, fósforo e feopigmentos no sedimento de alguns ecossistemas lacustres do litoral do Estado do Espírito Santo. Oecologia Brasiliensis. 1: 407-417.

FERREIRA, W.R., HEPP, L.U., LIGEIRO, R., MACEDO, D.R., HUGHES, R.M., KAUFMANN, P.R., & CALLISTO, M. 2017. Partitioning taxonomic diversity of aquatic insect assemblages and funcional feeding groups in neotropical savanna headwater streams. Ecol. Indic. 72: 365-373.

FERREIRA, W.R., PAIVA, L.T. & CALLISTO, M. 2011. Development of a benthic multimetric index for biomonitoring of a neotropical watershed. Braz. J. Biol. 71(1): 15-25.

FERNÁNDEZ, H.R. & DOMÍNGUES, E. 2001. Guia para la determinación de los artrópodos bentônicos Sudamericanos. Universidad Nacional de Tucumán. Facultad de Ciencias Naturales e Instituto M. Lillo, Tucumán, p. 282.

GAETA, J.W., SASS, G.G. & CARPENTER, S.R. 2014. Drought-driven lake level decline: effects on coarse woody habitat and fishes. Can. J. Fish. Aquat. Sci. 71: 315-325.

GAMA, M., CRESPO, D., DOLBETH, M. & ANASTÁCIO, P.M. 2017. Ensemble forecasting of *Corbicula fluminea* worldwide distribution: projections of the impact of climate change. Aquatic Conserv: Mar Freshw Ecosyst. 27: 675-684.

GETIRANA, A. 2015. Extreme water deficit in Brazil detected from space. J. Hydrometeor. doi:10.1175/JHM-D-15-0096.1, in press.

GOLTERMAN, H.L., CLYMO, R.S. & OHNSTAD, M.A.M. 1978. Methods for physical and chemical analisys of fresh waters. Oxford: Blackwell Scientific, p. 214.

HOFMANN, H., LORKE, A. & PEETERS, F. 2008. Temporal scales of water-level fluctuations in lakes and their ecological implications. Hydrobiologia. 613: 85-96.

IGAM. 2014. Estudos de avaliação da precipitação em bacias do estado: Acordo de resultados 2014. http://www.igam.mg.gov.br/gestao-das-aguas (the last access 10/03/2015).

ILYASHUK, B.P. & ILYASHUK, E.A. 2007. Chironomid record of Late Quaternary climatic and environmental changes from two sites in Central Asia (Tuva Republic, Russia) local, regional or global causes? Quaternary Sci. Rev. 26: 705-731.

IPCC. 2016. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar5/wg1(the last access 24/08/2017).

KAIL, J., ARLEB, J. & JÄHNIG, S.C. 2012. Limiting factors and thresholds for macroinvertebrate assemblages in European rivers: empirical evidence from three datasets on water quality, catchment urbanization, and river restoration. Ecol. Indic. 18: 63-72.

KAUFMANN, P.R., HUGHES, R.M., SICKLE, J.V., WHITTIER, T.R., SEELIGER, C.W. & PAULSEN, S.G. 2014a. Lake shore andlittoral physical habitat structure: A field survey method and its precision. Lake Reserv. Manage. 30(2): 157-176.

KAUFMANN, P.R., HUGHES, R.M., WHITTIER, T.R., BRYCE, S.A. & PAULSEN, S.G. 2014b. Relevance of lake physical habitat indices to fish and riparian birds. Lake Reserv. Manage. 30(2): 177-19.

LAKE, P.S. 2000. Disturbance, patchiness, and diversity in streams. J. N. AM. Benthol. Soc. 19(4): 573-592.

LAKE, P.S. 2003. Ecological effects of perturbation by drought in flowing waters. Freshwater Biol. 48: 1161-1172.

LEDGER, M.E., HARRIS, R.M.L., ARMITAGE, P.D. & MILNER, A.M. 2012. Climate change impacts on community resilience: evidence from a drought disturbance experiment. Adv. Ecol. Res. 46: 211-258.

LEDGER, M.E., BROWN, L.E., EDWARDS, F.K., HUDSON, L.N., MILNER, A.M. & WOODWARD, G. 2013. Extreme climatic events alter aquatic food webs: asynthesis of evidence from a mesocosm drought experiment. Adv. Ecol. Res. 48: 343-395.

LEIBOLD, M.A., HOLYOAK, M., MOUQUET, N., AMARASEKARE, P., CHASE, J.M., HOOPES, M.F., & LOREAU, M. 2004. The metacommunity concept: a framework for multi-scale community ecology. Ecol. Lett. 7: 601-613.

LIGEIRO, R., HUGHES, R.M., KAUFMANN, P.R., MACEDO, D.R., FIRMIANO, K.R., FERREIRA, W., OLIVEIRA, D., MELO, A.S. & CALLISTO, M. 2013. Defining quantitative stream disturbance gradients and the additive role of habitat variation to explain macroinvertebrate *taxa* richness. Ecol. Indic. 25: 45-57.

LINARES, M.S., CALLISTO, M. & MARQUES, J.C. 2017. Invasive bivalves increase benthic communities complexity in neotropical reservoirs. Ecol. Indic. 75: 279-285.

MACEDO, D.R., POMPEU, P.S., MORAIS, L., CASTRO, M.A., ALVES, C.B.M., FRANÇA, J.S., SANCHES, B., UCHÔA, J. & CALLISTO, M. 2014. Sampling site selection, land use and cover, field reconnaissance, and sampling. *In:* Callisto, M., Hughes, R.M., Lopes, J.M., Castro, M.A. (eds.), Ecologicalconditions in hydropowerbasins. Belo Horizonte: Companhia Energética de Minas Gerais, (Série Peixe Vivo, 3), p. 61-83.

MACEDO, D.R., HUGHES, R.M., FERREIRA, W.R., FIRMIANO, K.R., SILVA, D.R.O., LIGEIRO, R., KAUFMANN, P.R. & CALLISTO, M. 2016. Development of benthic macroinvertebrate multimetric index (MMI) for Neotropical Savanna headwater streams. Ecol. Indic. 64: 132-141.

MACKAY, F., CYRUS, D. & RUSSELL, K.L. 2010. Macrobenthic invertebrate responses to prolonged drought in South Africa's largest estuarine lake complex. Estuarine, Coastal and Shelf Science. 86(4): 553-567.

MAGBANUA, F. S., MENDOZA, N. Y. B., UY, C. J. C., MATTHAEI, C. D. & ONG, P. S. 2015. Water physicochemistry and benthic macroinvertebrate communities in a tropical reservoir: the role of water level fluctuations and water depth. Limnologica. http://dx.doi.org/10.1016/j.limno.2015.10.002.

MANTEL, N.A. 1967. The detection of disease clustering and a generalized regression approach. Cancer Res. 27: 209-220.

MARENGO, J.A. 2009. Mudanças climáticas, condições meteorológicas extremas e eventos climáticos no Brasil. http://www.fbds.org.br/cop15/FBDS_MudancasClimaticas.pdf.

MARTEL, N., RODRIGUEZ, M.A. & BÉRUBÉ, P. 2007. Multi-scale analysis of responses of stream macrobenthos to forestry activities and environmental context. Freshwater Biol. 52: 85-97.

MARTINS, I., SANCHES, B., KAUFMANN, P.R., HUGHES, R.M., SANTOS, G.B., MOLOZZI, J. & CALLISTO, M. 2015. Ecological assessment of a southeastern Brazil reservoir. Biota Neotrop. 15(1): e20140061. http://dx.doi.org/10.1590/1676-06032015006114.

MCDOWELL, W.G., MCDOWELL, W.H. & BYERS, J.E. 2017. Mass mortality of a dominant invasive species in response to an extreme climate event: Implications for ecosystem function. Limnol. Oceanogr. 62: 177-188.

MELO, G.A.S. 2003. Manual de identificação dos crustacea decapoda de água doce do Brasil. Editora Loyola, São Paulo, p. 430.

MERRITT, R.W. & CUMMINS, K.W. 1996. An introduction to the aquatic insects of North America, 3rd ed. Kendall/Hunt Publishing Company, Dubuque, Iowa, v. 3, p. 862.

MOLOZZI, J., FRANÇA, J.S., ARAUJO, T.L.A., VIANA, T.H., HUGHES, R.M. & CALLISTO, M. 2011. Diversidade de habitats físicos e sua relação com macroinvertebrados bentônicos em reservatórios urbanos em Minas Gerais. Iheringia Ser. Zool. 101(3): 191-199.

MOLOZZI, J., FEIO, M.J., SALAS, F., MARQUES, J.C. & CALLISTO, M. 2013a. Maximum ecological potential of tropical reservoirs and benthic invertebrate communities. Environ. Monit. Assess. 185(8): 6591-6606.

MOLOZZI, J., HEPP, L.U., & CALLISTO, M. 2013b. The additive partitioning of macroinvertebrate diversity in tropical reservoirs. Mar. Freshwater Res. 64(7): 609-617. doi: 10.1071/MF12354.

MORAIS, L., DE OLIVEIRA SANCHES, B., SANTOS, G.B., KAUFMANN, P.R., HUGHES, R.M., MOLOZZI, J. & CALLISTO, M. 2017. Assessment of disturbance at three spatial scales in two large tropical reservoirs. J. Limnol. doi: http://dx.doi.org/10.4081/jlimnol.2016.1547.

MORAIS, S.S., MOLOZZI, J., VIANA, A.L., VIANA, T.H., & CALLISTO, M. 2010. Diversity of larvae of littoral Chironomidae (Diptera: Insecta) and their role as bioindicadors in urban reservoirs of different trophic levels. Braz. J. Biol. 70(4): 995-1004.

MUGNAI, R., NESSIMIAN, J.L. & BAPTISTA, D.F. 2010. Manual de identificação de macroinvertebrados aquáticos do Estado do Rio de Janeiro. Editora Technical Books, Rio de Janeiro, p. 176.

NAVARRO, E., CAPUTO, L., MARCÉ. R., CAROL, J., BENEJAM, L., GARCÍA-BERTHOU, E. & ARMENGOL, J. 2009. Ecological classification of a set of Mediterranean reservoirs applying the EU Water Framework Directive: A reasonable compromise between science and management. Lake and Reserv. Manage. 25: 364-376.

NEVES, F.F., LAVRADOR, M.A.S., COSTA, A.S. & AVELAR, W.E.P. 2014. The effect of exposure to suspended sediment in mortality of *Corbicula fluminea* (Müller, 1774) (Bivalvia: Corbiculidae). Am. J. Life Sci. 2(3): 150-154.

OKSANEN, J., BLANCHET, F.G., FRIENDLY, M., KINDT, R., LEGENDRE, P., MCGLINN, D., MINCHIN, P.R., O'HARA, R.B., SIMPSON, G.L., SOLYMOS, P., STEVENS, M.H.H., SZOECS, E. & WAGNER, H. 2017. Vegan: Community Ecology Package. R package version 2.4-3. https://CRAN.R-project.org/packege=vegan.

ONS, Operador Nacional do Sistema Elétrico. http://www.ons.org.br/tabela_reservatorios/conteudo.asp (the last access 17/03/2015).

PARADIS, E., CLAUDE, J. & STRIMMER, K. 2004. APE: analyses of phylogenetics and evolution in R language. Bioinformatics 20: 289-290.

PEREIRA, D., MANSUR, M.C.D. & PIMPÃO, D.M. 2012. Identificação e diferenciação dos bivalves límnicos invasores dos demais bivalves nativos do Brasil. *In*: Mansur, M.C.D., Santos, C.P., Pereira, D., Paz, I.C.P., Zurita, M.L.L., Rodriguez, M.T.R., Nehrke, M.V., Bergonci, P.E.A. (Org.), Moluscos límnicos invasores no Brasil: biologia, prevenção e controle. Redes Editora, Porto Alegre, p. 75-94.

PÉREZ, G.P. 1988. Guía para el studio de los macroinvertebrados acuáticos del departamento de Antioquia. Editorial Presencia Ltda. Bogotá, p. 217.

RAHEL, F.J. & OLDEN, J.D. 2008. Assessing the effects of climate change on aquatic invasive species. Conserv. Biol. 22(3): 521-533.

RESH, V. H., BÊCHE, L.A., LAWRENCE, J.E., MAJOR, R.D., MCELRAVY, E.P., O'DOWD, D., RUDNICK, D. & CARLSON, S.M. 2013. Long-term population and community patterns of benthic macroinvertebrates and fishes in Northerm California Mediterranean-climate streams. Hydrobiological. 719: 93-118.

ROCHA, O., ESPÍNDOLA, E.L., RIETZLER, A.C., FENERICH-VERANI, N. & VERANI, J.R. 2011. Animal invaders in São Paulo state reservoirs. Oecol. Aust. 15(3): 631-642. doi:10.4257/oeco.2011.1503.14.

ROMM, J. 2011. Desertification: The next dust bowl. Nature. 478: 450-451. doi:10.1038/478450a.

R Core Team 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, URL https: //www.R-project.org/.

SANTOS, S.B., THIENGO, S.C., FERNANDEZ, M.A., MIYAHIRA, I.C., GONÇALVES, I.C.B., XIMENES, R.D.F. & PEREIRA, D. 2012. Espécies de moluscos límnicos invasores no Brasil. *In*: MANSUR, M.C.D., SANTOS, C.P., PEREIRA, D., PAZ, I.C.P., ZURITA, M.L.L., RODRIGUEZ, M.T.R., NEHRKE, M.V., BERGONCI, P.E.A. (Org.), Moluscos límnicos invasores no Brasil: biologia, prevenção e controle. Redes Editora, Porto Alegre, p. 25-49.

SAULINO, H.H., LEITE-ROSSI L.A. & TRIVINHO-STRIXINO, S. 2017. The effect of small reservoirs on chironomid diversity and trait composition in Savanna streams: evidence for Serial Discontinuity Concept. Hydrobiologia. 793: 109-119.

SILVA, E.C. & BARROS, F. 2011. Macrofauna bentônica introduzida no Brasil: lista de espécies marinhas e dulcícolas e distribuição atual. Oecol. Aust. 15(2): 326-344.

SILVA, F.L. 2009. Functional trophic categorization of macroinvertebratecomumunities of two reservoirs in the midwestern region of São Paulo state. Brazil. Acta Sci. Biol. Sci. 31(1): 73-78.

SILVEIRA, M.P. 2004. Aplicação do biomonitoramento para avaliação da qualidade da água em rios. Embrapa Meio Ambiente, Jaguariúna, p. 68.

SOUSA, R., ANTUNES, C. & GUILHERMINO, L. 2008. Ecology of the invasive Asian clam *Corbicula fluminea* (Müller, 1774) in aquatic ecosystems: an overview. Ann. Limnol. Int. J. Lim. 44(2): 85-94.

STATSOFT. 2011. Statistica (data analysis software system). http://www.statsoft.com (the last access in 22/09/2014).

STEVENS, D.L. & OLSEN, A.R. 2004. Spatially balanced sampling of natural resources. J. Am. Stat. Assoc. 99: 262-278.

STRAYER, D.L. 2010. Alien species in fresh waters: ecological effects, interactions with other stressors, and prospects for the future. Freshwater Biol. 55: 152-174.

SUGUIO, K. 1973. Introdução à sedimentologia. Ed. Edgard Blucher, EDUSP, São Paulo, p. 317.

SUTELA, T., AROVIITA, J. & KETOC, A. 2013. Assessing ecological status of regulated lakes with littoral macrophyte, macroinvertebrate and fish assemblages. Ecol. Indic. 24: 185-192.

TANER, M.Ü., CARLETON, J.N. & WELLMAN, M. 2011. Integrated model projections of climate change impacts on a North American lake. Ecol. Model. 222: 3380-3393.

TANG, Q., BAO, Y., HE, X., FU, B., COLLINS, A.L. & ZHANG, X. 2016. Flow regulation manipulates contemporary seasonal sedimentary dynamics in the reservoir fluctuation zone of the Three Gorges Reservoir, China. Sci. Total Environ. 548(549): 410-420.

TRIVINHO-STRIXINO, S. 2011. Larvas de Chironomidae: Guia de identificação. São Carlos. Depto. Hidrobiologia/Lab. Entomologia Aquática/UFSCar, p. 371.

TUNDISI, J.G. & MATSUMURA-TUNDISI, T. 2008. Limnologia. São Paulo: Oficina de Textos, Capitulo 12, p. 313.

USEPA. 2012. Nacional Lakes Assessment. Field Operations Manual. EPA. 841-B-11-003. U.S. Environmental Protection Agency, Washington, DC.

VIANNA, M.P. & AVELAR, E.P.A. 2010. Ocorrência da espécie invasora *Corbicula fluminea* (Bivalvia, Corbiculidae) no rio Sapucaí (São Paulo, Brasil), Biotemas. 23(3): 59-66.

WILLIAMSON, C.E., SAROS, J.E. & SCHINDLER, D.W. 2009. Sentinels of Change. Science. 323: 887-888.

WINKLER, L.W. 1888. Die Bertimmung des imwassergelösten Sauer-stoffs. Ber. Dtsch. Chem. Ges. 21: 2843-2854.

ZERLIN, R.A. & HENRY, R. 2014. Does water level affect benthic macro-invertebrates of a marginal lake in a tropical river-reservoir transition zone? Braz. J. Biol. 74(2): 408-419.

*Received: 28/03/2017*
*Revised: 30/01/2018*
*Accepted: 06/02/2018*

Biota Neotropica 18(2): e20170470, 2018
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
Article

# Reproductive strategies of a population of a freshwater amphipod (Crustacea, Amhipoda, Hyalellidae) from southern Brazil

*Daniela da Silva Castiglioni*[1]*, *Morgana Taís Streck*[1], *Stella Gomes Rodrigues*[2] &

*Alessandra Angélica de Padua Bueno*[2]

[1] *Universidade Federal de Santa Maria, Departamento de Zootecnia e Ciências Biológicas, Avenida Independência, 3751, Vista Alegre, 97105-900, Palmeira das Missões, RS, Brasil*
[2] *Universidade Federal de Lavras, 37200-000, Lavras, MG, Brasil*
**Corresponding author: Daniela da Silva Castiglioni, e-mail: danielacastiglioni@yahoo.com.br*

CASTIGLIONI, D. S., STRECK, M. T., RODRIGUES, S. G., BUENO, A. A. P. **Reproductive strategies of a population of a freshwater amphipod (Crustacea, Amhipoda, Hyalellidae) from southern Brazil**. Biota Neotropica. 18(2): e20170470. http://dx.doi.org/10.1590/1676-0611-BN-2017-0470

***Abstract:*** The aim of this study was to characterize the reproductive strategies of a population of *Hyalella bonariensis* from southern Brazil. Pairing success, reproductive period of males and females, fecundity, and body size at the onset of reproduction were evaluated. Animals were sampled four times (August 2012, October 2012, January 2013, and April 2013) with the 250 µm-mesh dip net during 20 minutes by only one person. In the field, precopulatory pairs and ovigerous females were individualized. In the laboratory, cephalothorax length (CL) were measured and eggs and juveniles were removed from the females' marsupium and counted. The mean CL of paired males and females was significantly higher than that of non-paired males and females. A sexual dimorphism in body size was observed in the population - both paired and non-paired males were larger than females. Probably larger males have a higher probability of losing females during precopulatory behavior. A significant correlation was observed between the size of paired males and females - larger males often paired with larger females and smaller males paired with smaller females (r = 0.81). The pairing success of males increased with body size and we can assume that males from all size classes are able to find mates. The pairing success of females was independent of body size - paired and non-paired females had similar mean CL. The reproductive success increased with body size in males and females, and was more evident in males. Females from the largest size classes had null reproductive success. The idea that larger females can produce more eggs but might have a lower probability of finding a mate than smaller females was corroborated by our results. Therefore, smaller females have higher pairing success because they are capable of mating with a higher percentage of males. The estimated mean fecundity of *H. bonariensis* was 17.4 (± 3.89) eggs/juveniles. Our results are similar to those of other species of *Hyalella* from Brazil.

***Keywords:*** *fecundity, body size, Hyalella bonariensis, reproductive success, pairing success.*

# Estratégias reprodutivas de uma população de um anfípodo de água doce (Crustacea, Amhipoda, Hyalellidae) do sul do Brasil

***Resumo:*** Este trabalho teve por objetivo caracterizar as estratégias reprodutivas de uma população de *Hyalella bonariensis* no sul do Brasil, avaliando o sucesso de pareamento, o período reprodutivo de machos e fêmeas, a fecundidade e o tamanho corporal dos indivíduos durante a reprodução. Para isso foram realizadas quatro amostragens (Agosto/2012, Outubro/2012, Janeiro/2013 e Abril/2013) utilizando-se uma rede de mão, com malha de 250 µm, durante 20 minutos por um coletor. Em campo, os casais e as fêmeas ovígeras foram individualizados e em laboratório os mesmos foram mensurados quanto ao comprimento do cefalotórax (CC) (mm) e os ovos ou juvenis encontrados dentro do marsúpio foram contados. O CC médio dos machos e fêmeas pareados foi significativamente superior ao dos machos e fêmeas não pareados. Um dimorfismo sexual no tamanho corpóreo foi observado na população - ambos machos pareados e não pareados foram maiores do que as fêmeas. Aparentemente os machos maiores têm uma maior probabilidade de perder fêmeas durante o comportamento precopulatório. Foi observada correlação positiva entre o tamanho dos machos e fêmeas que foram encontrados formando casais - machos maiores geralmente pareiam com fêmeas maiores e machos menores com fêmeas menores (r=0,81). O sucesso de pareamento dos machos aumentou com o tamanho corpóreo e podemos assumir que os machos de todas as classes de tamanho são capazes de encontrar parceiras sexuais; entretanto, o sucesso de pareamento das fêmeas não depende do tamanho das mesmas, sendo que as fêmeas pareadas e não pareadas apresentaram CC médio semelhante. O sucesso reprodutivo da espécie aumentou com o tamanho corpóreo em machos e fêmeas, sendo mais pronunciado nos machos. As fêmeas pertencentes às maiores classes de tamanho apresentaram sucesso reprodutivo nulo. Os resultados suportam a ideia que as fêmeas grandes poderiam ter uma baixa probabilidade de encontrar parceiro para formar par pré-copulatório, quando comparada às fêmeas de tamanhos inferiores, apesar das fêmeas maiores serem mais fecundas. Neste sentido, as menores fêmeas possuem um sucesso de pareamento maior, pois elas são capazes de copular com uma elevada proporção de machos. A fecundidade média da espécie foi estimada em 17,4 (± 3,89) ovos/juvenis. Os resultados observados no presente trabalho assemelham-se aos encontrados para outras espécies do gênero já analisadas no sul do Brasil.

***Palavras-chave:*** *fecundidade, Hyalella, sucesso de pareamento, sucesso reprodutivo, tamanho corpóreo.*

## Introduction

In general, the reproduction of Amphipoda is well known (Strong 1973; Hartnoll 1982; Sastry 1983; Wellborn 1995; Cothran et al. 2015). The sequential events of reproduction can be summarized in four stages: stage I, location of a mate mediated by pheromones; stage II, pairing initiates through contact stimuli; stage III, male and female pairing persists until the female molts; and stage IV, end of mating shortly after the molt (Borowsky 1991).

The precopulatory behavior is a common feature in some amphipod species. Males carry females on their ventral surface during several days prior female's molting, which signals mating availability (Hynes 1955; Wellborn 1995; Castiglioni & Bond-Buckup 2007; Castiglioni & Bond-Buckup 2008b). The precopulatory behavior probably ensures that the male is near when female reaches its short sexual period (Strong 1973; Borowsky 1984). It is also likely that the male protects the female against predators and from other males during the precopulatory period (Strong 1973; Lewbel 1978; Borowsky 1984; Dick et al. 1990). After mating, the development of amphipod crustaceans occurs within the marsupium and can be divided into two stages: 1) from ovulation to hatching (embryonic period) and 2) from hatching to emergence of the litter juvenile) (Borowsky 1980). The amphipods present a direct development, with the pups hatching with the body shape similar to that of the adult (Strong 1972; Borowsky 1991; Steele & Steele 1991; Morrit & Spicer 1996; Aoki 1997; Thiel 1999).

*Hyalella* Smith, 187 is a genus of freshwater crustacean distributed throughout the American continent, and in this genus, pairing, i.e., precopulatory behavior, occurs before copulation and several factors influence its success. Male and female body size, mate selection, and intrinsic factors, such as water temperature, might influence the reproductive success and fecundity of *Hyalella* (Wellborn 1995; Castiglioni & Bond-Buckup 2008a).

In Brazil, the studies about reproduction concerning *Hyalella* are restrict to species from south and southeast regions. In southern Brazil, reproductive features of the sympatric species *H. castroi* Bond-Buckup, Araujo & Santos, 2008, and *H. pleoacuta* Bond-Buckup, Araujo & Santos, 2008 were described (Castiglioni & Bond-Buckup 2007; Castiglioni & Bond-Buckup 2008a). In southeastern Brazil, where dry and wet seasons are well-defined, reproduction and egg production of *H. carstica* Bastos-Pereira & Bueno, 2012 and *H. longistila* (Faxon 1876) were evaluated (Torres et al. 2015; Bastos-Pereira & Bueno 2016).

The species *Hyalella bonariensis* Bond-Buckup, Araujo & Santos, 2008 is often found among macrophytes in water courses from southern Brazil and Argentina (Santos et al. 2008; Bueno et al. 2014). Only one study was recently developed on the population dynamics of the species in the municipality of Silveira Martins, central region of the state of Rio Grande do Sul, and it was found that ovigerous females and couples in pre-copulatory behavior were more frequent in the winter (Castiglioni et al. 2016).

The aim of this study is to characterize the reproductive strategy of *H. bonariensis* from a headwater stream from southern Brazil. Pairing success, reproductive period of males and females, fecundity, and body size onset reproduction were evaluated.

## Material and Methods

The studied population is located in a headwater stream in a private rural property called Portal do Roio (29°39'25.14"S, 53°37'33.53"W), in Silveira Martins municipality, central region of state of Rio Grande do Sul, in the southernmost Brazil. Four samplings were conducted in August and October 2012 and January and April 2013. In this region, the weather is, as the Köppen classification system, subtropical "Cfa", with average annual relative humidity of the air 82% (Isaia 1992). The central region of the state of Rio Grande do Sul is located in the transition area of the geomorphological compartments called Depressão Central e Planalto. According to Moraes & Bezzi (2009) the Depressão Central is associated with sedimentary rocks such as sandstones, clays and river plains and displays altitude around 90 meters above sea level. The Planalto slope has irregular relief associated with basaltic rocks and the altitude ranges from 500 to 100 meters above sea level (Dantas et al. 2010).

Amphipods use macrophytes as shelters and food so plants from each sample site were collected with a 250 µm-mesh dip net during 20 minutes by only one person. Afterwards, the macrophytes were stored in plastic bags and transferred to the laboratory in thermic boxes. Ovigerous females and precopulatory pairs were individualized and stored into microtubes with 70% ethanol.

In the laboratory, all individuals were separated from the macrophytes, identified, separated into to four categories (juveniles, males, females and ovígerous females) (Borowsky 1991; Castiglioni et al. 2016) and measured (cephalothorax length, CL in mm) under the micrometer ocular of a stereomicroscope.

The mean body size (cephalothorax length in mm) of unpaired and paired males were compared with the mean body size of unpaired and paired females, by means of a *t* test, after checking for the normality and homoscedasticity of the data (α= 0.05) (Zar, 1996). Moreover, the mean body size of paired and unpaired amphipods was compared, to assess whether pairing success was influenced by body size (*t* test; α= 0.05) (Zar, 1996).

To evaluate if *H. bonariensis* have mate preferences, the correlation between CL of paired males and females was estimated with a Person correlation coefficient (r). To evaluate if pairing is influenced by mate size, the mean CL of paired and non-paired males and paired and non-paired females were compared by a t test (α= 0.05). The Pairing Success Index (PSI) was used to evaluate the relationship between pairing success and male and female size. The PSI was adapted by Wellborn (1995) from the relative feeding index (Manly 1974) and have already been used in other studies about *Hyalella* reproduction (Castiglioni & Bond-Buckup 2008b), and it is given by

$$\beta i = (ri/ni)/\sum\left(\frac{rj}{nj}\right) \text{ where,}$$

i is the relative pairing success in size class i; ri and ni are the proportion of paired and non-paired individuals, respectively. The denominator is the sum of the proportion of paired individuals from all size classes. The minimum CL used for the size classes was the size of the smaller male and female found in precopulatory behavior. The size class intervals were based on ¼ of the CL standard deviation value (Markus 1971). Considering that the reproductive success also depends on aspects such as the number of fertilized eggs, male reproductive success (RM,i) was estimated by the following formula:

$$RM,i = \beta iei/\sum \beta iei \text{ where,}$$

the number of eggs fertilized by males from size class i (ei) was estimated through the calculation of the expected fecundity of each paired female using the regression of the number of eggs versus the CL of ovigerous females (F = 40.668CL - 4.9461). The denominator refers to the sum of the fecundity of all size classes.

Female reproductive success (RF,i) was derived from egg production, as follows:

$$RF,i = fi/\sum fj \text{ where,}$$

fi is the observed mean egg production (number of eggs inside the marsupium) of ovigerous females from size class i, and the denominator refers to the sum of the fecundity of all size classes. The minimum CL of the size classes was the size of the smallest precopulatory pair.

To estimate fecundity, the marsupial content was categorized into three stages of embryonic development and one post-embryonic stage according to Hynes (1955), Dick et al. (1998), Castiglioni & Bond-Buckup (2007, 2009). The developmental stages were easily distinguished under stereomicroscope and were characterized as follows: stage I (initial) — orange eggs, completely filled with yolk, and with discrete or no cleavage; stage II (intermediary) — beginning of cell cleavage with well-defined body parts absent; stage III (final) — yolk completely absorbed and reduced to a small portion used for embryonic supply, body somites and eyes visible; and stage IV (juveniles) — newly hatched juveniles attached inside the marsupium.

All eggs and juveniles were removed from the marsupium and counted under a stereomicroscope. The minimum, maximum, and mean number of eggs (from each stage of embryonic development) and juveniles were estimated. The comparison between the mean number of eggs of each stage of embryonic development and juveniles was performed with an analysis of variance (ANOVA), complemented by a Bonferroni test (F; α= 0.05). The minimum, maximum, and mean fecundity of each season was estimated and compared among seasons with ANOVA, followed by a Bonferroni test (F; α = 0.05) (Zar 1996). All ANOVA tests were preceded by assessments of normality and homocedasticity of the data (Zar 1996).

The relationship between ovigerous females CL (x) and the number of eggs per embryonic stage and number of juveniles (y) was estimated through a regression analysis. Then, a Pearson correlation (r) was calculated for each relationship (α = 0.05) (Zar 1996).

## Results

A total of 5,269 individuals of *H. bonariensis* were captured, 1,315 juveniles, 1,879 males, 2,075 females (240 ovigerous females). Of that total, 54 pairs were found in precopulatory behavior.

The mean CL of paired males and females was significantly larger than of non-paired males and females (males t = 10.5; females t = 8.67; $p < 0.05$; Table 1). A sexual dimorphism in body size was observed in the population; both paired and non-paired males were larger than females (paired males t = 5.46; non-paired males t = 9.80; $p < 0.05$; Table 1).

A positive correlation between the size of males and females found in precopulatory behavior was observed: larger males often paired with larger females and smaller males paired with smaller females (r = 0.81; Figure 1). Male success in finding a mate increased with body size. Males in larger size classes were approximately 2.5 times more likely of finding a mate than males from smaller size classes (Figure 2). Pairing success also increased with female body size; females from smaller size classes had null pairing success (Figure 2). Additionally, the reproductive success also increased with body size increment in both males and females (Figure 3). However, it seemed that extremely large males had a decreased reproductive and pairing success when compared with intermediate size males (Figure 3).

The cephalothorax length of ovigerous females ranged from 0.32 to 0.74 mm (mean ± standard deviation = 0.55 ± 0.07 mm). Females bearing eggs in different stages of embryonic development and those bearing juveniles had similar mean CL ($p > 0.05$; Table 2).

Female egg/juvenile production ranged from 8 to 26 (17.4 ± 3.89 eggs/juveniles). The number of eggs produced in each stage of embryonic development and the number of juveniles found inside the marsupium are shown in Table 3. There was a decrease of egg production throughout the embryonic development; the mean number of eggs in stages I, II, and III was significantly higher than that of juveniles inside the marsupium ($p < 0.05$) (Table 3). In all stages of embryonic development, there was positive linear correlation between the number of eggs produced and the CL of ovigerous females ($p < 0.05$). The number of juveniles inside the marsupium also showed positive correlation with female size ($p < 0.05$) (Table 3).

**Table 1.** Minimum, maximum, and mean cephalothorax length (mm) (± standard deviation) of *Hyalella bonariensis* paired and unpaired males and females from Silveira Martins municipality, state of Rio Grande do Sul, Brazil.

| | **Males** | | **Females** | |
|---|---|---|---|---|
| | **Paired** | **Unpaired** | **Paired** | **Unpaired** |
| CL mín – max | 0.40 – 0.74 | 0.30 – 0.92 | 0.38 – 0.62 | 0.30 – 0.74 |
| CL mean ± sd | 0.63 ± 0.08 a | 0.49 ± 0.10 b | 0.54 ± 0.05 a | 0.46 ± 0.08 b |
| N | 54 | 1825 | 54 | 2021 |

Note: Different letters indicate significant difference (*t* test) between paired and non-paired animals of each sex ($p < 0.05$); min = minimum; max = maximum; sd = standard deviation; N = number of individuals.

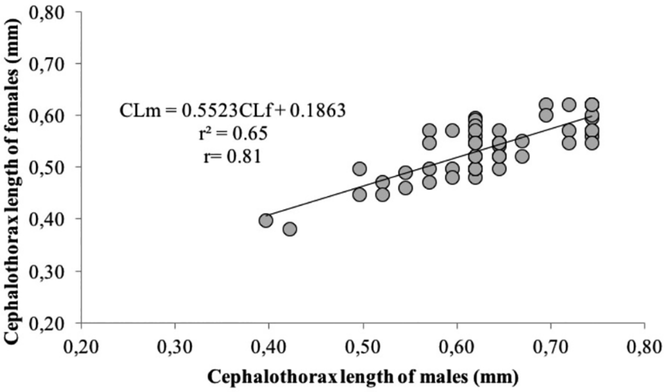

**Figure 1.** Assortative mating evaluated by Person's correlation between body size (cephalothorax length, in mm) of *Hyalella bonariensis* paired and non-paired males and females from Silveira Martins municipality, state of Rio Grande do Sul, Brazil.

**Figure 2.** Relationship between pairing success and size (cephalothorax length, in mm) of *Hyalella bonariensis* males from Silveira Martins municipality, state of Rio Grande do Sul, Brazil.

There was a significant reduction of the number of juveniles in the marsupium compared with the number of eggs ($p > 0.05$). Considering the seasonal mean fecundity, egg production was higher in winter and lower in autumn ($p < 0.05$; Table 4; juveniles were not included in this analysis). In all seasons, there was a positive correlation between female size and the number of eggs produced, meaning that egg production increased with female size ($p < 0.05$; Table 4).

## Discussion

Our observations revealed that paired males and females are larger than non-paired individuals. This finding is also true in populations of the *H. azteca* (Saussure, 1858) species complex from North America (Wellborn & Bartholf 2005) and in the Brazilian species *H. pleoacuta,*

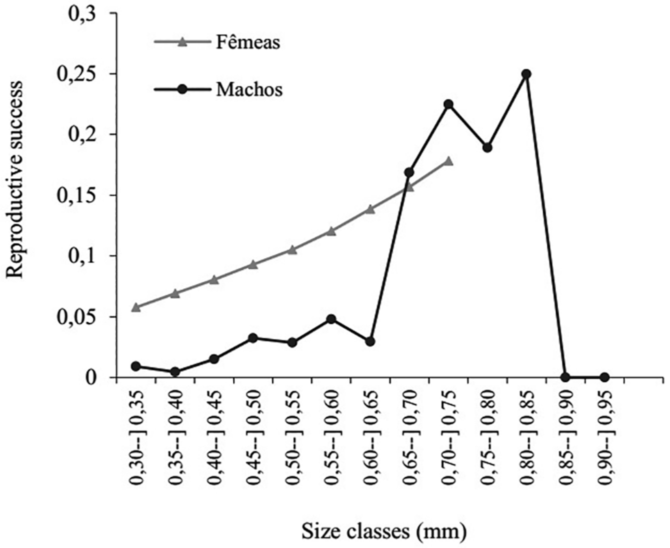

**Figure 3.** Reproductive success, based on size (cephalothorax length, in mm) of *Hyalella bonariensis* males (RM,i) and females (RF,i) from Silveira Martins municipality, state of Rio Grande do Sul, Brazil.

**Table 2.** Minimum, maximum, and mean cephalothorax length (mm) of *Hyalella bonariensis* females bearing eggs in different stages of embryonic development. Animals collected in Silveira Martins municipality, state of Rio Grande do Sul, Brazil.

| **Stage** | **N** | **Mean ± sd** | **Min – Max** |
|---|---|---|---|
| Initial | 57 | 0.54 ± 0.07 a | 0.32 – 0.75 |
| Intermediary | 49 | 0.55 ± 0.08 a | 0.32 – 0.74 |
| Final | 16 | 0.55 ± 0.09 a | 0.52 – 0.67 |
| Juvenile | 12 | 0.55 ± 0.09 a | 0.32 – 0.74 |

Note: N = number of females bearing eggs; min = minimum cephalothorax length; max = maximum cephalothorax length. Values with at least one letter in common are not significantly different (ANOVA and Bonferroni; $\alpha = 0.05$).

**Table 3.** Minimum, maximum, and mean (± standard deviation) number of eggs in each stage of embryonic development and juveniles found in the marsupium of *Hyalella bonariensis* females from Silveira Martins municipality, state of Rio Grande do Sul, Brazil.

| **Stage** | **N** | **Mean ± sd** | **Min - Max** | **$r^2$** |
|---|---|---|---|---|
| Initial | 57 | 16.8 ± 3.5 a | 8 – 26 | 0.75 |
| Intermediary | 49 | 17.4 ± 4.0 a | 9 – 25 | 0.79 |
| Final | 16 | 17.2 ± 4.9 a | 14 – 26 | 0.87 |
| Juvenile | 12 | 14.7 ± 0.09 b | 12 –17 | 0.80 |

Note: N = number of females bearing eggs; min = minimum number of eggs; max = maximum number of eggs. Values with at least one letter in common are not significantly different (ANOVA and Bonferroni, $\alpha = 0.05$).

**Table 4.** Minimum, maximum, and mean (± standard deviation) number of eggs inside the marsupium of *Hyalella bonariensis* females in each season in Silveira Martins municipality, state of Rio Grande do Sul, Brazil.

| Stage | N | Mean ± sd | Min – Max | $r^2$ |
|---|---|---|---|---|
| Autunm | 31 | 14.1 ± 2.6c | 9 – 20 | 0.74 |
| Winter | 41 | 19.3 ± 3.1a | 12 – 26 | 0.68 |
| Spring | 20 | 17.9 ± 4.6b | 8 – 23 | 0.90 |
| Summer | 24 | 17.1 ± 3.3b | 13 – 25 | 0.94 |

Note: N = number of females bearing eggs; min = minimum number of eggs; max = maximum number of eggs. Values with at least one letter in common are not significantly different (ANOVA and Bonferroni, α = 0.05).

*H. castroi* (Castiglioni & Bond-Buckup 2007, 2008b), and *H. longistila* (Bastos-Pereira & Bueno 2016). According to Ward (1983) and Dick & Elwood (1990), larger males have a lower probability of losing females during precopulatory behavior. This statement would explain why paired males were significantly larger than non-paired males in our study; similar results were also observed in populations of *H. pleoacuta* and *H. castroi* (Castiglioni & Bond-Buckup 2008b), and *H. longistila* (Bastos-Pereira & Bueno 2016).

The number of pairs in precopulatory behavior in the population of *H. bonariensis* was low, when compared to unpaired adults. The same result was observed in *H. castroi* and *H. pleoacuta* by Castiglioni & Bond-Buckup (2008b) and *H. carstica* by Torres et al. (2010). Probably the low occurrence of pairs can be related to the fact that the males and females stay in precopulatory behavior for approximately 3 days, a short time (personal observation), since this reproductive behavior can make individuals more vulnerable to predation (Wellborn, 1995). Moreover, the paired amphipods swim lower than unpaired ones (Cothran, 2004), or sampled methods may have led to the separation of males and females (Wellborn 1995; Castiglioni & Bond-Buckup 2008b).

The studied population of *H. bonariensis* reached sexual maturity at a quite small size. Individuals found in precopulatory behavior were relatively small (males: 0.40 mm of CL; females: 0.38 mm of CL) in comparison with the maximum size found in general population (male: 0.92 mm of CL; females: 0.74 mm of CL). Based on these results we can assume that *H. bonariensis* is able to reproduce early in life. Amphipod species which ensure progeny early in their life cycles may have developed a reproductive strategy aimed at reducing predation risk, since larger individuals are more easily seen by predators (Wellborn 1994, 1995, 2002). Species living in environments with unstable conditions, such as prolonged drought or floods can also reach early sexual maturity to ensure reproduction (Wellborn 1994, 1995, 2002; Appadoo & Myers 2004).

We observed that paired and non-paired males were larger than paired and non-paired females; similar results were found in populations of *H. pleoacuta* and *H. castroi* (Castiglioni & Bond-Buckup 2008a, b). Amphipod males often direct energy towards copulation, while females allocate time and energy to offspring care, especially in the production of large gametes. It is important to point out that females do not molt during incubation, creating a sexual dimorphism in body size (Wen 1992; Cardoso & Veloso 1996). As a consequence of this reproductive system, females reach a smaller body size compared with most amphipods - e.g., species of *Hyalella* such as *H. azteca* (Geisler 1944; Wen 1992; Othman & Pascoe 2001), *H. pleocuta* and *H. castroi* (Castiglioni & Bond-Buckup 2008a); and other amphipods such as *Gammarus pulex* (Linnaeus, 1758) (Adams & Greenwood 1983), *Pseudorchestoidea brasiliensis* (Dana, 1853) (Cardoso & Veloso 1996), *Gammarus leopoliensis* (Jazdzewski & Konopacka, 1989) (Zielinski 1998), *G. locusta* Linnaeus, 1758 (Costa & Costa 1999), and *Echinogammarus longisetosus* Pinkster, 1973 (Guerao 2003).

A positive size assortative mating was observed in the population of *H. bonariensis*, i.e., large males paired with large females. This size correlation was also observed in populations of *H. pleoacuta* and *H. castroi* (Castiglioni & Bond-Buckup 2009), *H. azteca* (Wellborn 1995), and *H. longistila* (Bastos-Pereira & Bueno 2016). Several hypotheses have been proposed to explain this size correlation in mating: loading constraint (Adams & Greenwood 1983); spatial segregation (Birkehead & Clarkson 1980); sexual selection (Ward 1984); guarding time (Elwood et al. 1987); microhabitat segregation (Ward & Porter 1993); and physical constraints (Adams & Greenwood 1987; Adams et al. 1989; Hatcher & Dunn 1997). The most accepted hypothesis is male-male competition, which postulates that large males have competitive advantages in pairing with larger and more fecund females (Ward 1983; Ward 1986; Ward 1988; Elwood et al. 1987; Crespi 1989; Dick & Elwood 1996; Bollache et al. 2000).

The pairing success of *H. bonariensis* increased with male body size and a similar pattern was also recorded in *H. pleoacuta*, *H. castroi* (Castiglioni & Bond-Buckup 2008b), *H. azteca* (Wellborn 1995), *H. longistila* (Bastos-Pereira & Bueno 2016), and *Gammarus pulex* (Ward 1988). Therefore, we can assume that males from all size classes are able to find mates. However, although larger females of *H. bonariensis* are more fecund than smaller females, they may have a lower probability of finding an available mate, because males have difficulty carrying them during pre-copulatory behavior. Because of that, larger females pair with less males, while smaller females can find more males to copulate with (Wellborn 1995). Wellborn (1995) observed that pairing and reproductive success of *H. azteca* is higher in females from intermediate size classes. These results demonstrate that the pairing system of *H. bonariensis* is explained by the loading constrain hypothesis, as observed for *H. pleoacuta* and *H. castroi* (Castiglioni & Bond-Buckup 2007).

In several crustacean's groups, eggs produced by females in a single brood have synchronized embryonic development, reinforcing the assumption that fertilization occurs in one unique event after pair separation (Green 1965; Kevrekidis 2005). This pattern was recorded here in *H. bonariensis* and in populations of *H. pleoacuta*, *H. castroi* (Castiglioni & Bond-Buckup 2007, 2009), *H. longistila* (Bastos-Pereira & Bueno 2016), *Gammarus duebeni* Lilljeborg, 1852 (Sheader 1983), *G. insensibilis* Stock, 1966 (Sheader 1996), *Pseudorchestoidea brasiliensis* (Cardoso & Veloso 2001), *Corophium insidiosum* (Crawford, 1937) (Kevrekidis 2004), and *C. orientale* Schellenberg, 1928 (Kevrekidis 2005).

During the embryonic development of amphipods, it is common to observe a reduction of the embryo number per brood (Moore 1981; Williams 1978; Dick et al. 1998; Dick et al. 2002; Kevrekidis 2004; Castiglioni & Bond-Buckup 2009; Bastos-Pereira & Bueno 2016); this was the case for *H. bonariensis*. According to Koch (1990), as the embryo volume increases, the space inside the marsupium decreases, leading to a premature loss of a few embryos. Apparently, this occurs due to a higher embryo production than the marsupium can hold during the final stages of development. Also, the reduction of eggs/juveniles may be a consequence of the presence of parasites (Sheader 1983; Kuris 1991) or maternal cannibalism, which may occur when food resources are scarce (Sheader 1983; Castiglioni & Bond-Buckup 2009).

A positive correlation between the female size and the number of eggs/juveniles was observed in *H. bonariensis*. Several authors observed an association between females' size/weight and the number of embryos in other *Hyalella* species (Strong 1972; Othman & Pascoe 2001; Alcocer et al. 2002; Castiglioni & Bond-Buckup 2007, 2009; Torres et al. 2015; Bastos-Pereira & Bueno 2016). According to Hines (1988), this association may be linked to the fact that the egg mass is restricted by the space available for energetic accumulation and gonadal development. In each species, the wide variability of the carapace shape may interfere with the volume available for gonadal development and, consequently, in brood size. Therefore, egg mass and body cavity volume have similar allometry (Hines 1982).

Production of many small eggs in the summer and few large eggs in the winter is a common amphipod reproductive strategy (Steele and Steele 1969; Sheader 1978; Kolding and Fenchel 1981; Powell 1992), reflecting both seasonal change in the reproductive investment of females that may be related to seasonal changes in food availability, and female and offspring mortality (Price 1974; Smith and Fretwell 1974). However, *H. bonariensis* showed a contrasting reproductive pattern to most species, producing fewer eggs during the summer and many in the winter. Probably, these fluctuations in number of eggs appear to be related to the macrophyte cover, which is much depleted during the warmer months (personal observation), reducing the food and shelter available for breeding females, but may also contributing to increased mortality of recruits. A similar reproductive strategy, characterized by the production of small broods during summer, has been observed in other species of amphipods, such as *H. pleocuta* and *H. castroi* (Castiglioni & Bond-Buckup 2009), *Bathyporeia pilosa* Lindström, 1855 (Powell 1992) and *Gammarus locusta* (Linnaeus, 1758 (Costa and Costa 1999).

The number of eggs produced by *H. bonariensis* is lower than in other *Hyalella* species from southern Brazil (*H. castroi* and *H. pleocuta*) (Table 5). *Hyalella castroi* and *H. pleocuta* are found in aquaculture trout pounds and have constant food availability, so females have sufficient energetic input to produce a high number of eggs (Castiglioni & Bond-Buckup 2009). However, *H. bonariensis* has a higher fecundity in comparison with other tropical species from southeast Brazil and with the North American species *H. azteca*. Distinct fecundities between species might be a consequence of differences in habitats and the microclimate in which they live, as it has been already observed in other amphipod species (Poweel 1992; Appadoo & Myers 2004). The high number of eggs produced by *H. bonariensis* might be an attempt to optimize juvenile survival since the mortality rate is elevated during this stage. However, fecundity data from species raised in laboratory would be needed to confirm this assumption.

**Table 5.** Comparative fecundity different species of *Hyalella* (data obtained from literature).

| Species | NE | Authors |
|---|---|---|
| *Hyalella azteca* | 1 - 50• | Cooper (1965) |
| *Hyalella* sp. | 1 - 6• | Sampaio (1988) |
| *Hyalella azteca* | 18.0* | Pennak (1953) |
| *Hyalella pernix (= H. curvispina)* | 13.0* | Severo (1997) |
| *Hyalella* sp. | 31.3* | Morelli (2001) |
| *Hyalella azteca* | 1 - 38• | Alcocer et al. (2002) |
| *Hyalella azteca* | 9.0* | Othman & Pascoe (2001) |
| *Hyalella azteca* | 5.2* | Wellborn et al. (2005) |
| *Hyalella azteca* | 5.3* | Wellborn et al. (2005) |
| *Hyalella azteca* | 6.2* | Wellborn et al. (2005) |
| *Hyalella azteca* | 5.2* | Wellborn et al. (2005) |
| *Hyalella azteca* | 19.2* | Wellborn et al. (2005) |
| *Hyalella azteca* | 14.7* | Wellborn et al. (2005) |
| *Hyalella azteca* | 10.3* | Wellborn et al. (2005) |
| *Hyalella pleoacuta* | 36.1* | Castiglioni and Bond-Buckup (2009) |
| *Hyalella castroi* | 31.4* | Castiglioni and Bond-Buckup (2009) |
| *Hyalella carstica* | 12.6* | Torres et al. (2015) |
| *Hyalella longistila* | 12.8* | Bastos-Pereira and Bueno (2016) |
| *Hyalella bonariensis* | 17.4* | Present study |

Note: NE = number of eggs; • indicates minimum and maximum fecundity; * indicates mean fecundity.

## Conclusions

The present paper demonstrated the importance of male body size as a determinant of reproductive success of *Hyalella bonariensis* similar to other species of genus. Understanding the interactive effects of partner selection, what stimuli are involved, and the evolution of these choices within the genre, including the formulation of predictive models, will be needed to complement studies on reproduction of this crustacean.

## Acknowledgements

This research was funded by Conselho Nacional de Desenvolvimento Científico e Tecnológico - Brasil (CNPq - Process Nº 477554/2011-3). DSC and MTS are grateful to the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and CNPq (Process nº 55.2597/2011-2) for the financial support.

## Author Contributions

Daniela da Silva Castiglioni: Contribution in the concept and design of the study.

Morgana Taís Streck: Contribution to data collection.

Stella Gomes Rodrigues: Contribution to manuscript preparation.

Alessandra Angélica de Padua Bueno: Contribution to critical revision, adding intelectual contente.

## Conflicts of interest

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

## References

ADAMS, J. & GREENWOOD, P.J. 1983. Why are males bigger than females in pre-copula pairs of *Gammarus pulex*? Behav. Ecol. Sociobiol. 13: 239-241. doi:10.1007/BF00299670.

ADAMS, J. & GREENWOOD, P.J. 1987. Loading constraints, sexual selection and assortative mating in peracarid Crustacea. J. Zool. 211: 35-46. doi: 10.1111/j.1469-7998.1987.tb07451.x.

ADAMS, J., WATT, P.J., NAYLOR, C.J. & GREENWOOD, P.J. 1989. Loading constraints, body size and mating preference in *Gammarus* species. Hydrobiologia. 183: 157-164. doi: 10.1007/BF00018720.

ALCOCER, J., ESCOBAR-BRIONES, E., PERALTA, L. & ÁLVAREZ, F. 2002. Population structure of the macrobenthic amphipod *Hyalella azteca* Saussure (Crustacea: Peracarida) on the littoral zone of six crater lakes. In Modern Approaches to the Study of Crustacea (E. Escobar-Briones & F. Álvarez, eds.). Kluwer Academic /Plenum Plublishers, New York, p.111-115.

ARNQVIST, G. & ROWE, L. 1995. Sexual conflict and arms races between the sexes - a morphological adaptation for control of mating in a female insect. Proc. R. Soc. Lond. B 261:123–127.

AOKI, N. 1997. Comparative study of mother-young association in caprellid amphipods: is maternal care effective? J. Crust. Biol. 17: 447-458.

APPADOO, C. & MYERS, A.A. 2004. Reproductive bionomics and life history traits of three gammaridean amphipods, *Cymadusa filosa* Savigny, *Ampithoe laxipodus* Appadoo and Myers and *Mallacoota schellenbergi* Ledoyer from tropical Indian Ocean (Mauritius). Acta Oecol. 26: 227-238. doi:10.1016/j.actao.2004.06.002.

BASTOS-PEREIRA, R. & BUENO, A.A.P. 2016. Reproductive biology and egg production of *Hyalella longistyla* (Faxon, 1876) (Amphipoda: Hyalellidae), a freshwater amphipod in southeastern Brazil. J. Crust. Biol. 36(5): 724-730. doi: 10.1163/1937240X-00002465.

BIRKHEAD, T.R. & CLARKSONV, K. 1980. Mate selection and precopulatory guarding in *Gammarus pulex*. Z. Tierpsychol. 52: 365-380.

BOLLACHE, L., GAMBADE, G. & CÉZILLYC, F. 2000. The influence of microhabitat segregation on size-assortative pairing in *Gammarus pulex* (L.) (Crustacea: Amphipoda). Arch. Hydrobiol. 147: 547-558. doi: 10.1127/archiv-hydrobiol/147/2000/547.

BOROWSKY, B. 1980. Reproductive patterns of three intertidal salt-marsh gammaridean amphipods. Mar. Biol.55: 327-334.

BOROWSKY, B. 1984. Effects of receptive females's secretions on some male reproductive behaviors in the amphipods *Microdeutopus gryllotalpa*. Mar. Biol. 84: 183-187 doi:10.1007/BF00393003.

BOROWSKY, B. 1991. Patterns of reproduction of some amphipod crustaceans and insights into the nature of their stimuli. In Crustacean Sexual Biology (R.T. Bauer & W. Martin, eds). Columbia University Press, New York, pp33-66.

BUENO, A.A.P., RODRIGUES, S.G. & ARAUJO, P.B. 2014. O estado da arte do gênero *Hyalella* Smith, 1874 (Crustacea, Amphipoda, Senticaudata, Hyalellidae) no Brasil. In Tópicos de Atualização em Ciências Aquáticas (C. Hayashi, ed.) UFTM, Uberaba, p. 57-88.

CARDOSO, R.S. & VELOSO, V.G. 1996. Population biology and secondary production of the sandhopper *Pseudorchestoidea brasiliensis* (Amphipoda: Talitridae) at Prainha Beach, Brazil. Mar. Ecol. Prog. Ser. 142: 111-119.

CARDOSO, R.S. & VELOSO, V.G. 2001. Embryonic development and reproductive strategy of *Pseudorchestoidea brasiliensis* (Amphipoda: Talitridae) at Prainha Beach, Brazil. J. Nat. Hist. 35: 201-211. doi: 10.1080/00222930150215332.

CASTIGLIONI, D.S. & BOND-BUCKUP, G. 2007. Reproductive strategies of two sympatric species of *Hyalella* Smith, 1874 (Amphipoda, Dogielinotidae) in laboratory conditions. J. Nat. Hist. 41(25-28): 1571-1584. doi: 10.1080/00222930701464604.

CASTIGLIONI, D.S. & BOND-BUCKUP, G. 2008a. Ecological traits of two sympatric species of *Hyalella* Smith, 1874 (Crustacea, Amphipoda, Dogielinotidae) from southern Brazil. Acta Oecol. 33: 36-48.

CASTIGLIONI, D.S. & BOND-BUCKUP, G. 2008b. Pairing and reproductive success in two sympatric species of *Hyalella* Smith, 1874 (Crustacea, Amphipoda, Dogielinotidae) from southern Brazil. Acta Oecol. 33: 49-55.

CASTIGLIONI, D.S. & BOND-BUCKUP, G. 2009. Egg production of two sympatric species of *Hyalella* Smith, 1874 (Crustacea, Amphipoda, Dogielinotidae) in aquaculture ponds in southern Brazil. J. Nat. Hist. 43(21-24): 1273-1289. doi: 10.1080/00222930902903756.

COSTA, F.O. & COSTA, M.H. 1999. Life history of the amphipod *Gammarus locusta* in the Sado estuary (Portugal). Acta Oecol. 20(4): 305-314. doi: 10.1016/S1146-609X(99)00136-8.

COTHRAN, R.D., FRENCH, B.J. & RELYEA, R.A. 2015. An assessment of Putative Sexually Antagonistic Traits in a Freshwater Amphipod Species. Ethology 121: 740-748. doi: 10.1111/eth.12389.

CRESPI, B.J. 1989. Causes of assortative mating in arthropods. Anim. Behav. 38: 980-1000.

DANTAS, M.E., VIEIRO, A.C. & SILVA, D.R.A. 2010. Origem das paisagens. Pp. 35-50. *In*: VIEIRO, A.C. & Da SILVA, D.R.A. (Eds). Geodiversidade do estado do Rio Grande do Sul. CPRM, Porto Alegre, 250 p.

DICK, J.T.A. & ELWOOD, R.W. 1990. Symmetrical assessment of females quality by male *Gammarus pulex* (Amphipoda) during struggles over precopula females. Anim. Behav. 40: 877-883.

DICK, J.T.A. & ELWOOD, R.W. 1996. Effects of natural variation in sex ratio and habitat structure on mate-guarding decisions in amphipods (Crustacea). Behaviour 133: 985-996.

DICK, J.T.A., IRVINE, D.E. & ELWOOD, R.W. 1990. Differential predation by males on moulted females may explain the competitive displacement of *Gammarus duebeni* by *G. pulex* (Amphipoda). Behav. Ecol. Sociobiol. 26: 41-45. doi: 10.1007/BF00174023.

DICK, J.T.A., BAILEY, R.J.E. & ELWOOD, R.W. 2002. Maternal care in the rockpool amphipod *Apherusa jurinei*: developmental and environmental cues. Anim. Behav. 63: 707-713. doi: 10.1006/anbe.2001.1958.

DICK, J.T.A., FALOON, S.E. & ELWOOD, R.W. 1998. Active brood care in an amphipod: influences of embryonic development, temperature and oxygen. Anim. Behav. 56: 663-672.

ELWOOD, R.W., GIBSON, J. & NEIL, S. 1987. The amorous *Gammarus*: size assortative mating in *G. pulex*. Anim. Behav. 35: 1-6.

GEISLER, S.S.J. 1944. Studies on the postembryonic development of *Hyalella azteca* (Saussure). Biol. Bull. 86: 6-22.

GREEN, J. 1965. Chemical embryology of the Crustacea. Biol. Rev. Camb. Philos. Soc. 40: 580-600.

GUERAO, G. 2003. Some observations on the life history of the freshwater amphipod *Echinogammarus longisetosus* Pinkter, 1973 (Gammaridae) from Catalonia (Spain, N Iberian Peninsula). Anim. Biodivers. Conserv. 26(1): 31-39.

HARTNOLL, R.G. 1982. Growth. In The biology of Crustacea: morphology and genetics (D.E. Bliss, ed.). London Academic Press, London, p. 111-196.

HATCHER, M.J. & DUNN, A.M. 1997. Size and pairing success in *Gammarus duebeni*: can females be too big? Anim. Behav. 54: 1301-1308. doi: 0003–3472/97/111301+08 $25.00/0/ar970534.

HINES, A.H. 1982. Allometric constraints and variables of reproductive effort in Brachyuran crabs. Mar. Biol. 69: 309-320. doi: 10.1007/BF00397496.

HINES, A.H. 1988. Fecundity and reproductive output in two species of deep-sea crabs, *Geryon fenneri* and *Geryon quinquedens* (Decapoda: Brachyura). J. Crust. Biol. 8(4): 557-562.

HYNES, H.B.N. 1955. The reproductive cycle of some British freshwater gammaridae. J. Anim. Ecol. 24(2): 352-387.

ISAÍA, T. 1992. Planejamento de uso da terra para o município de Santa Maria-RS, através do diagnóstico físico conservacionista das microbacias hidrográficas. UFSM, Santa Maria, 60 p.

KEVREKIDIS, T. 2004. Population dynamics, growth and reproduction of *Corophium insidiosum* (Crustacea: Amphipoda) at low salinities in Monolimni lagoon (Evros Delta, north Aegean Sea). Hydrobiologia 522: 117-132. doi: 10.1023/B:HYDR.0000029971.11713.41.

KEVREKIDIS, T. 2005. Life history, aspects of reproductive biology and production of *Corophium orientale* (Crustacea: Amphipoda) in Monolimni lagoon (Evros Delta, north Aegean Sea). Hydrobiologia 537-53-70. doi:10.1007/s10750-004-1713-5.

KOCH, H. 1990. Aspects of the population biology of *Traskorchestia traskiana* (Stimpson, 1857) (Amphipoda, Talitridae) in the Pacific Northwest, USA. Crustaceana 59: 35-52 doi: 10.1163/156854090X00273.

KOLDING, S. & FENCHEL, T.M. 1981. Patterns of reproduction in different populations of five species of the amphipod genus *Gammarus*. Oikos 37: 167-172.

KURIS, A.M. 1991. A review of patterns and causes of crustacean brood mortality. In Crustacean Issues 7: Crustacean Egg Production (A. Wenner & A. Kuris, eds) Balkema Academic, Rotterdam, p.117-141.

LEWBEL, G.S. 1978. Sexual dimorphism and intraspecific aggression, and their relationship to sex ratios in *Caprella gorgonia* Laubitz & Lewbel (Crustacea: Amphipoda: Caprellidae). J. Exp. Mar. Biol. Ecol. 33: 133-151. doi: 10.1016/0022-0981(78)90004-7.

MANLY, B.F.J 1974. A model for certain types of selection experiments. Biometrics 30: 281-294. doi: 10.2307/2529649.

MARKUS, R. 1971. Elementos de estatística aplicada. Faculdade de Agronomia e Veterinária da UFRGS: Centro Acadêmico Leopoldo Cortez, Porto Alegre.

MOORE, P.G. 1981. The life histories of the amphipods *Lembos websteri* Bate and *Corophium bonnellii* Milne Edwards in Kelp holdfasts. J. Exp. Mar. Biol. Ecol. 49: 1-50.

MORAES, F. D. & BEZZI, M. L. 2009. A organização do estado agrário de Mata/RS: a cadeia produtiva da pecuária. Geografia: Ensino & Pesquisa, 3(2): 21-32.

MORRIT, D. & J.I. SPICER. 1996. The culture of eggs and embryos of amphipod crustaceans: implications for brood pouch physiology. J. mar. biol. Ass. U.K. 76: 361-376.

POWELL, R. 1992. Biometry of brooding in seven species of amphipods (Crustacea) from the Clyde sea area. J. Nat. Hist. 26: 353-371.

OTHMAN, M.S. & PASCOE, D. 2001. Growth, development and reproduction of *Hyalella azteca* (Saussure, 1858) in laboratory culture. Crustaceana 74(2): 171-181. doi: 10.1163/156854001750096274.

PENNAK, R.N. 1953. Freshwater invertebrates of the United States. Ronald Press Company, New York.

PRICE, P.W. 1974. Strategies for eggs production. Evolution 28: 76-84.

SASTRY, A.N. 1983. Ecological aspects of reproduction. In The biology of Crustacea: enviromental adaptations (F.J. Vernberg & W.B. Vernberg eds.). Academic Press, New York, p. 179–269.

SANTOS, A.L.F., ARAUJO, P.B. & BOND-BUCKUP, G. 2008. New species and new reports of *Hyalella* (Crustacea, Amphipoda, Dogielinotidae) from Argentina. Zootaxa, 1760, 24–36.

SHEADER, M. 1978. Distribution and reproductive biology of *Corophium insidiosum* (Amphipoda) on the north-east coast of England. J. Mar. Biol. Assoc. U. K. 58: 585-596.

SHEADER, M. 1983. The reproductive biology and ecology of *Gammarus duebeni* (Crustacea: Amphipoda) in southern England. J. Mar. Biol. Assoc. U.K. 63: 517-540 doi: 10.1017/S0025315400070855.

SHEADER, M. 1996. Factors influencing egg size in the gammarid amphipod *Gammarus insensibilis*. Mar. Biol. 124: 519-526. doi: 10.1007/BF00351033.

SMITH, C.C. & FRETWELL, S.D. 1974. The optimal balance between size and number of offspring. Am. Nat. 108: 499-506.

STEELE, D.H. & STEELE, V.J. 1969. The biology of *Gammarus* (Crustacea, Amphipoda) in the North-western Atlantic. I. *Gammarus duebeni* Lillj. Can. J. Zool. 47: 235-244.

STEELE, D.H. & V.J. STEELE. 1991. Morphological and environmental restraints on egg production in amphipods. *In:* BAUER, R.T. & W.J. MARTIN. J. Crust. Sex. Biol. 157-170.

STRONG, D.R. 1972. Life history variation among populations of an amphipod (*Hyalella azteca*). Ecology 53(6): 1103-1111. doi: 10.2307/1935422.

STRONG, D.R. 1973. Amphipod amplexus, the significance of ecotypic variation. Ecology. 5: 1383-1388. doi: 10.2307/1934203.

THIEL, M. 1999. Extended parental care behavior I crustaceans – a comparative overview. Crustacean Issues 12: 211-226.

TORRES, S.H.S., BASTOS-PEREIRA, R. & BUENO, A.P.P. 2015. Reproductive aspects of *Hyalella carstica* (Amphipoda: Hyalellidae) in a natural environment in southeastern Brazil. Nauplius 23 (2): 159-165. doi: 10.1590/S0104-64972015002325.

WARD, P.I. & PORTER, A.H. 1993. The relative roles of habitat structure and male-male competition in the mating system of *Gammarus pulex* (Crustacea, Amphipoda): a simulation study. Anim. Behav. 45: 119-133. doi: 10.1006/anbe.1993.1011.

WARD, P.I. 1983. Advantages and a disadvantage of large size for male *Gammarus pulex* (Crustacea: Amphipoda). Behav. Ecol. Sociobiol. 14: 69-76. doi: 10.1007/BF00366658.

WARD, P.I. 1984. The effects of size on the mating decision of *Gammarus pulex* (Crustacea: Amphipoda). Z. Tierpsychol. 64: 174-184. doi: 10.1111/j.1439-0310.1984.tb00358.x.

WARD, P.I. 1986. A comparative study of the breeding behaviour of a stream and a pond of *Gammarus pulex* (Amphipoda). Oikos 46: 29-36. doi: 10.2307/3565376.

WARD, P.I. 1988. Sexual selection, natural selection and body size in *Gammarus pulex* (Amphipoda). Am. Nat. 131: 348-359.

WELLBORN, G.A. 1994. Size-biased predation and prey life histories: a comparative study of freshwater amphipod populations. Ecology 75(7): 2104-2117 doi: 10.2307/1941614.

WELLBORN, G.A. 1995. Determinants of reproductive success in freshwater amphipod species that experience different mortality regimes. Anim. Behav. 50: 353-363. doi: 10.1006/anbe.1995.0251.

WELLBORN, G.A. 2002. Trade-off between competitive ability and antipredator adaptation in a freshwater amphipod species complex. Ecology 83(1): 129-136.

WELLBORN, G.A. & BARTHOLF, S.E. 2005. Ecological context and the importance of body and gnathopod size for pairing in two amphipod ecomorphs. Oecologia 143: 308-316. doi: 10.1007/s00442-004-1786-x.

WEN, Y.H. 1992. Sexual dimorphism and mate choice in *Hyalella azteca* (Amphipoda). Am. Midl. Nat. 129: 153-160.

WILLIAMS, J.A. 1978. The annual pattern of reproduction of *Talitrus saltator* (Crustacea: Amphipoda: Talitridae). J. Zool. 184: 213-244.

ZAR, J.H. 1996. Biostatistical analysis. Prentice Hall, Upper Saddle River.

ZIELINSKI, D. 1998. Life cycle and altitude range of *Gammarus leopoliensis* Jazdzewski & Konopacka, 1989 (Amphipoda) in south-eastern Poland. Crustaceana 71(2): 129-143. doi: 10.1163/156854098X00112.

*Received: 23/10/2017*
*Revised: 02/04/2018*
*Accepted: 02/04/2018*
*Published online: 23/04/2018*

Biota Neotropica 18(2): e20170423, 2018
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
Article

# Effectiveness of abundance and biomass curves in detecting environmental alterations in semi-arid region reservoirs

*Carlinda Raílly Medeiros[1]*; Evaldo de Lira Azevêdo[2]; José Etham de Lucena Barbosa[3] & Joseline Molozzi[3]*

*[1]Universidade Federal do Pará, Programa de Pós-Graduação em Ecologia, Belém, PA, Brasil*
*[2]Universidade Federal Rural de Pernambuco, Programa de Pós-Graduação em Etnobiologia e Conservação da Natureza, Recife, Brasil*
*[3]Universidade Estadual da Paraiba, Programa de Pós-Graduação em Ecologia e Conservação, Campina Grande, PB, Brasil*
**Corresponding author: Carlinda Raílly Medeiros, e-mail: carlindarailly@gmail.com*

MEDEIROS, C.; AZEVÊDO, E.; BARBOSA, E.; MOLOZZI, J. **Effectiveness of abundance and biomass curves in detecting environmental alterations in semi-arid region reservoirs**. Biota Neotropica. 18(2): e20170423. http://dx.doi.org/10.1590/1676-0611-BN-2017-0423

**Abstract*:*** For mitigation of environmental problems generated by bad water resource management, the first step is to develop methods for effective diagnosis. The potential bioindicator, mainly in the benthic community, in the evaluation of water quality is the structure of the community, associated with magnitude of environmental impact. The aim of the present study was to evaluate the effectiveness of abundance biomass curves (ABC) as tools to estimate ecological quality in reservoirs in the Brazilian semi-arid region. Two reservoirs, Epitácio Pessoa and Argemiro de Figueiredo were selected. These reservoirs are located in the watershed of the Paraíba River, in Northeast Brazil. Sampling was done at 40 sites in the littoral region of each reservoir, during the periods of higher and lower water volume in the reservoirs. ABC for semi-arid region reservoirs showed disparate results for biological and environmental indicators, because they had a better relationship with momentary variables (physical and chemical parameters). This may be related to the high occurrence of exotic species, principally *Corbicula largillierti*, which has a high biomass, in association with a severe drought period. ABC must thus be used with parsimony and combined with other indicators, for an accurate and coherent characterization.

***Keywords:*** *Benthic Macroinvertebrates, Environmental Impact, Biomonitoring, Exotic Species.*

# Eficácia das curvas de abundância e biomassa na detecção de alterações ambientais em reservatórios do semiárido

**Resumo**: Para mitigação de problemas ambientais gerados pela má gestão de recursos hídricos, o primeiro passo é o desenvolvimento metodologias de diagnósticos eficientes. O potencial bioindicador, principalmente da comunidade bentônica, na avaliação da qualidade da água deve-se aos aspectos estruturais dessa comunidade, associado com a magnitude de impactos ambientais. O objetivo do presente estudo foi avaliar a eficiência das curvas de biomassa e abundância (ABC) como ferramentas para estimar a qualidade ecológica em reservatórios na região do semi-árido brasileiro. Dois reservatórios, Epitácio Pessoa e Argemiro de Figueiredo foram selecionados. Estes reservatórios estão localizados na bacia do rio Paraíba, no nordeste do Brasil. As coletas foram realizadas em 40 locais na região litorânea de cada reservatório, durante os períodos de maior e menor volume de hídrico. As curvas ABC, quando plotadas em reservatórios do semiárido, apresentaram resultados diferentes aos indicadores biológicos e ambientais, tendo uma relação melhor com as variáveis momentâneas (parâmetros físicos e químicos). Isso pode estar relacionado à alta ocorrência de espécies exóticas, principalmente *Corbicula largillierti*, o que reflete uma elevada biomassa, combinada com um período severo de seca. O método ABC devem ser utilizadas com parcimônia e associada a outros indicadores, para uma caraterização coerente e precisa.

***Palavras-chave:*** *Macroinvertebrados bentônicos, Impacto ambiental, Biomonitoramento, Espécies exóticas.*

## Introduction

Reservoirs are used for various purposes, such as electrical power generation, irrigation, navigation, leisure, and water supply (Tundisi et al. 2008). The various uses of these ecosystems can end up negatively affecting water quality of aquatic systems (Thorne & Williams 1997, Bednarek 2001, Abellán et al. 2006). Ecological quality depends on the functional characteristics of an ecosystem, such as the physical and chemical quality of the water, morphometry quality, and functional and structural features of the biological communities (Molozzi et al. 2013).

Aquatic ecosystems in semi-arid regions have particularities related to low rainfall levels, rain irregularity and high rates of evaporation (Barbosa et al. 2012). In this case, barring rivers and other environmental features of semi-arid regions, such as high salt concentrations, long periods of water retention (about 3 to 5 years) and habitat homogenization, cause biological integrity loss and trophic imbalance and thus alterations in the structure and composition of biological communities (Rocha et al. 2012).

For mitigation of environmental problems generated by inadequate water resource management, the first step is to develop methods for effective diagnosis (Buss 2003). Although water physical and chemical parameters are good estimators of the pollution level of aquatic ecosystems, they overlook the biological communities (Thompson et al. 2008, Camargo et al. 2011). This results in a momentary assessment, which is insufficient to diagnose the ecological quality of aquatic ecosystems (Baptista 2008, Molozzi et al. 2012).

Ecological quality evaluation of aquatic ecosystems has incorporated benthic macroinvertebrates as a biological tool to measure stress factors in continental water ecosystems (Statzner & Bêche 2010, Pope et al. 2013). Benthic macroinvertebrates exhibit biological traits that reflect ecological integrity in aquatic ecosystems, considering the effects of pollutants over a period of time and including all the dimensions of the ecosystem (Otermin et al. 2002, Sharma & Rawat 2009). The abundance and biomass of the benthic community are considered important biological attributes for the evaluation of ecological quality. Preserved freshwater ecosystems usually show a lower biomass in the benthic macroinvertebrates community, and an abundance equally distributed, due to low concentrations of dissolved nutrients, and consequently, lower productivity compared to impacted ecosystems (Ahrens & Peter 1991, Jørgensen et al. 1992, Takahashi et al. 2008, Molozzi et al. 2013).

The use of abundance biomass curves (ABC) as tools for biomonitoring was proposed by Warwick (1986), through the comparison of the curves. This method was first used for the marine macrobenthic community, founded on the evolutionary strategy theories “k” and “r”, comparing dominance curves in terms of abundance and biomass (Clarke & Warwick 2001), according to the perspective that the distribution of the numerical abundance of organisms and total biomass do not show the same pattern in ecosystems subject to different levels of pollution (Marques et al. 2009). The theory founded on the evolutionary strategies “k” and “r” suggests that in environments under stable conditions, with less disturbance, it is expected that the biomass curve rises above the abundance curve, classifying the environment as non-polluted. In such scenario, the community is likely dominated by “k” strategist species with one or two species at high biomass levels, but showing low abundance of species (Yemane et al. 2005). These species are characterized as having slow growth, late maturation, and large body size, and being rarely dominant in terms of abundance, although they are dominant in terms of biomass (Yemane et al. 2005). On the other hand, curves can also tend to overlap, identifying a moderately disturbed environment, when the community shows “k” species being replaced by “r” species, which show fast growth and are dominant in terms of biomass and number (Yemane et al. 2005, Puente & Diaz 2008, Carvalho et al. 2013). When the abundance curve rises above the biomass curve, the environment is classified as severely polluted, because the community is theoretically dominated by “r” species, with smaller body size, but with high numerical abundance (Carvalho et al. 2013).

In evaluating the ecological quality of aquatic ecosystems, several aspects must be incorporated for a comparative and complementary classification (Molozzi et al. 2013). The aim of this study was to evaluate the effectiveness of biomass abundance curves (ABC) as tools to estimate ecological quality in reservoirs in the Brazilian semi-arid region. The study comparing ABC with other ecological and environmental indicators is important to evaluate the concordance of such curves with the description of ecological conditions in semi-arid region reservoirs.

## Material and Methods

Two reservoirs, Epitácio Pessoa and Argemiro de Figueiredo were selected. These reservoirs are located in the watershed of the Paraíba River, in Northeast Brazil (Figure 1). Minimum air temperature is in July and

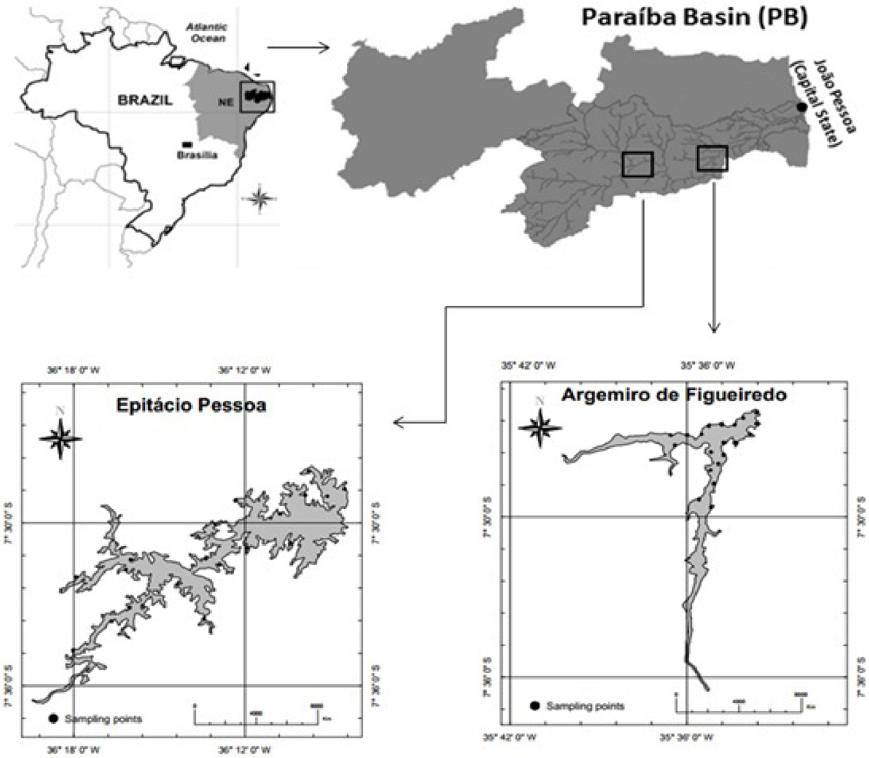

**Figure 1.** Geographical location of Epitácio Pessoa and Argemiro de Figueiredo reservoirs in the watershed of the Paraíba River, in Brazil. The points in the figure indicate the sampling sites.

August (18-22ºC), and maximum in November and December (28-31ºC). The climate of the region is BSh semi-arid hot (Köppen-Geiger 1936), with average rainfall of 400 mm/year (AESA 2013). The watershed of the Paraiba River is the second largest in Paraiba State. It is composed of the sub-watershed of the Taperoá River and regions of the upper, middle and lower course of the Paraiba River. It includes a 20.072 km$^2$ area, with maximum capacity of 1.078.104.307 km$^3$ of accumulated water and about 1.828.178 inhabitants in its coverage area (AESA 2013).

The Epitácio Pessoa Reservoir (7º27.5'3"S; 35º35'52.6"W) was constructed in 1956, and is located in the division between the upper and middle course of the Paraiba River with drainage basin of 26.784 ha, accumulation capacity of 418 million m$^3$ and hydraulic retention time of 3 to 5 years. Argemiro de Figueiredo Reservoir (7º29'20"S; 36º17'3"W) was constructed in 2001, located in the middle and lower course of the Paraiba River, with drainage basin of 2.300 ha, accumulation capacity of 253 million m$^3$ and hydraulic retention time of 3 to 5 years. The main use of the reservoirs is for water supply, but they are also used for other activities such as fishing, leisure, regional tourism and irrigation.

In each reservoir, sampling was conducted at twenty sites in the littoral region in periods of higher and lower water volume, representing variations in the benthic macroinvertebrates community between seasonal periods. The higher water volume in the reservoirs was observed in December (2011), when we recorded in the Epitácio Pessoa Reservoir 373.957.565 m$^3$ of water (90.8% of its maximum capacity), and in the Argemiro de Figueiredo Reservoir 206.397.908 m$^3$ of water (81.6% of its maximum capacity). Meanwhile, in July (2012), we recorded the lower volume in the reservoirs, i.e., 308.826.158 m$^3$ for Epitácio Pessoa (75% of maximum) and 143.367.467 m$^3$ for Argemiro de Figueiredo (56.7% of maximum) (AESA 2014).

The macroinvertebrates were sampled using a Van Veen dredge (500 cm$^2$ area). The sediment samples were fixed *in situ* in 4% formaldehyde. In the laboratory, the samples were washed with overlapping sieves (1.00 – 0.50 mm), preserved in alcohol (70%) and identified to the family level (Mugnai et al. 2010), except for the family Chironomidae, in which identification was to the genus level (Trivinho-Strixino 2011).

After taxonomic identification, the organisms were dried in an oven at 60°C for 72 hours and weighed (accuracy of $10^{-5}$ mg) for biomass determination. The individuals of the phylum Mollusca were burned in a muffle furnace at 450°C for 4 hours to estimate the ash free dry weight (Azevêdo et al. 2015).

In each sampling period and at each sampling site, physical and chemical variables were measured *in situ* using a multiparameter probe (Horiba/U-50): dissolved oxygen (mg/L), electrical conductivity (mS/cm), turbidity (NTU) and pH. Water samples were collected in the sub-surface with a Van Dorn type bottle for subsequent analysis of total nitrogen (TN), total phosphorus (TP), nitrite ($NO_2^-$), nitrate ($NO_3^-$), ammonium ion ($NH_3^-$) and reactive soluble phosphate ($PO_4^-$), in accordance with the "Standard Methods for the Examination of Water and Wastewater" (APHA 2005). The concentration of chlorophyll-*a* (Chla) was determined according to Lorezen (1967). Transparency was estimated using a Secchi disk, and water column depth was estimated using a portable sonar (Laylin Associates SM5 SM-5).

For the characterization of the physical aspects of the habitat and anthropic disturbance in the reservoirs, ten protocols of physical habitat characterization were applied at each sampling site, totaling 200 protocols applied for each study reservoir according to methods determined by the US Environmental Protection Agency (USEPA 2012). The protocol was applied only in the period of higher water volume in the reservoirs. Observations were taken from three areas: littoral zone (10 m wide and 15 m length), floodplain (15 m width and variable length), and riparian zone (15 m width and 15 m long).

The protocol evaluates physical features of habitats such as the bottom substrate from the littoral zone, presence and types of macrophytes, potential shelters for fish, riparian and flooding zone dossal, and type of ground vegetation, along with the assessment of human influences such as construction, trade, transmission lines or trash, and grain crops. For this study, information was used about human disturbance around the reservoirs, and disturbance metrics were established for the flooding zone (Kaufmann et al. 2014, Azevêdo et al. 2017).

Metrics of anthropic disturbance in the flooding zones were determined according to the methods developed by the Environmental Protection Agency of the USA (USEPA, 2012; Kaufmann et al. 2014).

In this work, the intensity and extension indices of human disturbance were used, considering 12 types of human disturbance activities. Four activities are related to agriculture (grain crop fields, pastures, orchards, grass/parks) and eight activities are related to other types of disturbances (constructions, trade, artificial beaches, docks/boats, walls/dikes, trash, roads, railroads, transmission lines). The disturbance metric was determined as the absence of disturbance corresponding to weight 0, the disturbance inside of the parcel with weight 1, and disturbances adjacent to the analyzed parcel with weight 0.5. The values were then used for final metric calculation. The index of the final metric included values varying from 0 to 1. Values closest to 0 indicated smaller degrees of disturbance, and values closest to 1 indicated more intense disturbances. The metric values were characterized as follows: from 0 to 0.30 was a smaller disturbance degree, 0.31 to 0.6 was a moderate disturbance degree and 0.61 to 1 was more intense disturbance degree (Kaufmann et al. 2014).

The Shannon-Wiener diversity index (Shannon & Weaver 1963) and taxonomic richness were used as comparative parameters with ABC method, to improve explicability of the overlapping of the curves in the periods of higher and lower water volume, and between reservoirs.

The disturbance degree in the reservoirs was estimated using the ABC method proposed by Warwick (1986), based on ABC tendencies. In impacted environments, abundance curve is above biomass curve; in moderately disturbed environments, abundance and biomass curves tend to overlap; and in low level disturbance systems, biomass curve is above abundance curve.

The W index is the numerical summarization of the ABC, measuring differences in the overlap of the curves, assuming the values: +1, indicating undisturbed systems; -1, indicating disturbed systems; and 0, indicating moderately disturbed systems. The values were generated in combination with the ABC for classification of the reservoirs (Marques et al. 2009).

The index is given by Eq. 1:

$$W = \Sigma\left(Bi - Ai\right) / \left[50\left(S - 1\right)\right] \qquad \text{(Eq. 1)}$$

where *Bi* is the biomass of species *i*, *Ai* the abundance of species *i* and *S* the number of species (Warwick & Clarke, 1994).

Permutational multivariate analysis of variance (PERMANOVA) was used to assess the differences between the environmental parameters biomass and abundance, where $p \leq 0.05$ was considered statistically significant (Anderson et al. 2008). The factors established were: reservoirs (two levels: Epitácio Pessoa and Argemiro de Figueiredo) and seasonal periods (two levels: higher and lower water volumes). Euclidean distance was used as the dissimilarity measure for environmental parameters. The Bray Curtis similarity matrix was calculated and used to generate a two-dimensional plot using the non-metric multidimensional scaling (NMDS) analysis (Clarke & Warwick 2001, Clarke & Gorley 2006). The biological data (species abundance and biomass) were square-root transformed and environmental data $\log_{(x+1)}$ transformed. The software used was PERMANOVA + for PRIMER, 2006 (Systat Software, Cranes Software International Ltd. 2008).

The influence of exotic species on taxonomic richness and Shannon-Wiener diversity was assessed using simple regression (Spearman rank correlation), with the aim of better understanding the pattern of the curves due to the high abundance of exotic species observed. Statistic 7.0 software was used to determine correlations.

## Results

The waters in the Argemiro de Figueiredo Reservoir was slightly more alkaline in the two seasonal periods when compared to the waters of the Epitácio Pessoa Reservoir (Table 1). Epitácio Pessoa showed higher concentrations of total phosphorus (1043 µgL$^{-1}$) in the period of higher water volume and of organic nitrogen (53.42 µgL$^{-1}$) in the period of lower water volume (Table 1). The physical and chemical variables were significantly different between Argemiro de Figueiredo and Epitácio Pessoa (PERMANOVA: Pseudo-$F_{1.79}$ =52.481; p=0.001) and between the periods of higher and lower water volume (PERMANOVA: Pseudo-$F_{1.79}$ =47.601; p=0.001).

The metrics established from the protocol of physical habitat characterization, related to human disturbance, showed that Argemiro de Figueiredo included 60% of the sites classified as having good environmental quality, with metrics varying from 0 to 0.30 (Figure 2). In 30% of sampling sites, the disturbance metrics varied from 0.31 to 0.6, demonstrating moderate disturbance levels and 10% with metrics from 0.61 to 0.80, classified as impacted (Figure 2). The more elevated disturbance metrics were related to construction, trash presence and pasture. For Epitácio Pessoa, 30% of the sites had metrics of anthropic disturbance of 0 to 0.30, classifying them as having good environmental quality, 60% of the metrics varied from 0.31 to 0.60, classifying those sites as moderately disturbed, and 10% varied from 0.61 to 0.90 classifying those sites as impacted (Figure 2). The sites with the most elevated metrics were associated with pastures, transmission lines, construction, trade, and trash, which reflects use and occupation around the reservoir.

At Argemiro de Figueiredo reservoir there was overlap in the ABC during the lower (Figure 3A) and higher water volume (Figure 3B) classifying it as moderately disturbed. This result was supported by the W index during the lower (Figure 3A) and higher (Figure 3B) water volume (W=0.009 and 0.024, respectively), classifying also the reservoir as moderately perturbed for both periods. In Epitácio Pessoa, the biomass curve was above of the abundance curve during the lower water volume (Figure 4A). In the period of higher water volume, the ABC classified the reservoir as moderately disturbed through the overlapping of the ABC (Figure 4B). The W index classified the Epitácio Pessoa reservoir as moderately disturbed in the period of lower water volume (W=0.207) and also in the period of higher water volume (W=0.046).

The macroinvertebrates community were represented by 17.573 individuals distributed in 14 taxa (3 Mollusca, 2 Annelida, 6 Diptera, 2 Odonata and 1 Crustacea) (Table 2). Argemiro de Figueiredo was more representative in terms of abundance (14.536 individuals) compared to Epitácio Pessoa (3.037 individuals) (Figure 5A). In terms of the biomass of organisms, Argemiro de Figueiredo showed 112.6 mg/m$^2$ and Epitácio Pessoa 49.67 mg/m$^2$ (Table 2; Figure 5B).

In the period of lower water volume, Argemiro Figueiredo had high abundance of the exotic species *Melanoides tuberculatus* (MÜLLER, 1774) (96%), followed by *Goeldichironomus* (0.56%) and Oligochaeta (0.31%) (Figure 6A). In terms of biomass, the most common benthic macroinvertebrates were *M. tuberculatus* (93%), Planorbidae (4%) and Oligochaeta (1.9%) (Figure 6C). In the period of higher water volume in Argemiro de Figueiredo, *M. tuberculatus* represented the community with proportions of 98% of total abundance, followed by Hirudinea (0.9%) and *Fissimentum* (0.6%) (Figure 6A). The biomass of the benthic macrofauna was represented by larger proportions of *M. tuberculatus* (90%), followed by *Parachironomus* (4%) and *Fissimentum* (1%) (Figure 6C).

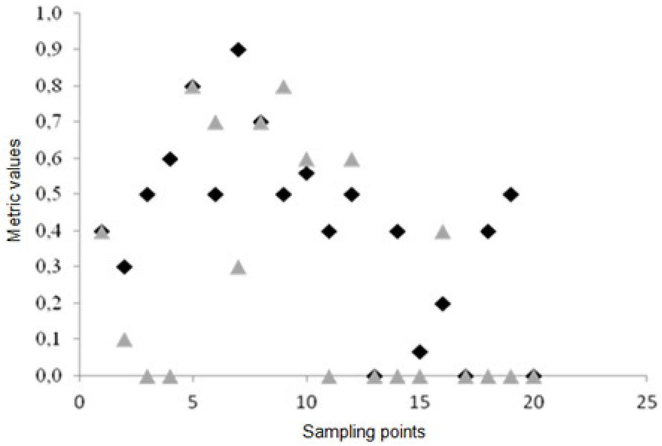

**Figure 2.** Dispersion of the metrics - characterization protocol of physical habitat for inundation zone in the Argemiro de Figueiredo and Epitácio Pessoa reservoirs. The gray symbols represent the Argemiro de Figueiredo reservoir and black symbols represents the Epitácio Pessoa reservoir.

**Table 1.** Mean and standard deviation of the physical and chemical variables in the Argemiro de Figueiredo and Epitácio Pessoa reservoirs, between periods of lower and higher water volume, sampled in the years 2011/2012. The (*) indicates the variables that show differences between the reservoirs.

| Reservoir | Argemiro de Figueiredo | | Epitácio Pessoa | |
|---|---|---|---|---|
| Estation | Lower volume | Higher volume | Lower volume | Higher volume |
| Water temperature (°C) | 28.84 ± 0.86 | 29.07 ± 0.61 | 26.52 ± 0.80 | 28.09 ± 2.55 |
| pH | 9.31 ± 0.25 | 7.97 ± 0.26 | 9.21 ± 0.66 | 7.98 ± 0.57 |
| Orthophosphate (mV) | 127.15 ± 8.84 | 202.55 ± 12.68 | 108.25 ± 23.74 | 199.90 ± 23.15 |
| Electrical Conductivity (µS/cm$^{-1}$) | 1.23 ± 0.00 | 1.11 ± 0.00 | 0.86 ± 0.02 | 0.76 ± 0.04 |
| Turbidity (NTU) | 60.86 ± 26.87 | 96.17 ± 84.23 | 40.49 ± 74.83 | 123.19 ± 181.48 |
| Dissolved Oxygen (mg/L$^{-1}$) | 8.68 ± 1.35 | 9.83 ± 0.68 | 8.41 ± 1.29 | 7.94 ± 1.84 |
| Total Dissolved Solids (mg/L$^{-1}$) | 0.79 ± 0.00 | 0.71 ± 0.00 | 0.55 ± 0.01 | 0.49 ± 0.02 |
| Salinity (%) | 0.06 ± 0.00 | 0.05 ± 0.00 | 0.04 ± 0.00 | 0.04 ± 0.00 |
| *Alkalinity (mg) | 23.50 ± 2.41 | 22.25 ± 1.33 | 16.35 ± 1.92 | 15.35 ± 4.94 |
| * Total Phosphorus (µg/L$^{-1}$) | 543.70 ± 105.70 | 366 ± 62.39 | 448.52 ± 89.73 | 1043 ± 187 |
| Phosphates (µg/L$^{-1}$) | 184.62 ± 8.14 | 38.50 ± 19.92 | 196.24 ± 241.95 | 53.75 ± 79.81 |
| * Organic Nitrogen (µg/L$^{-1}$) | 43.31 ± 342.43 | 30.97 ± 467.23 | 66.73 ± 267.41 | 53.42 ± 161.69 |

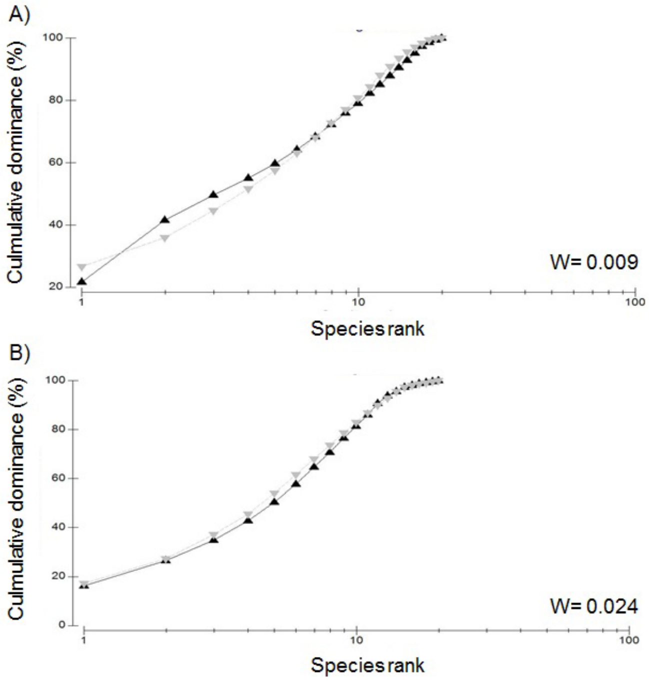

**Figure 3.** Trends in abundance (black symbols) and biomass (gray symbols) curves in the Argemiro de Figueiredo Reservoir in the periods of lower (A) and higher water volume (B).

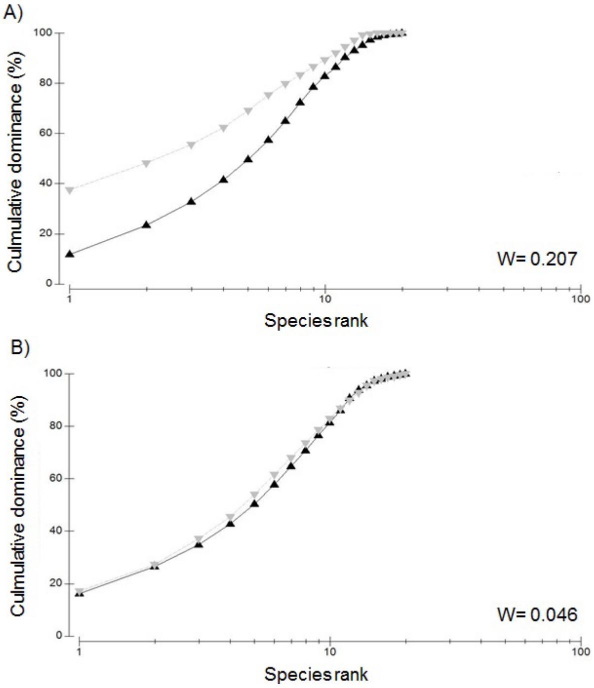

**Figure 4.** Trends in abundance (black symbols) and biomass (gray symbols) curves in the Epitácio Pessoa Reservoir in the periods of lower (A) and higher water volume (B).

**Table 2.** Mean and standard deviation for the abundance (total number of individuals), biomass (mg-2), richness (number of species) and Shannon-Winner diversity of benthic community of the Argemiro de Figueiredo and Epitácio Pessoa reservoirs during periods of lower and higher water volume. The (*) indicates no occurrence.

| | **Argemiro de Figueiredo** | | | | **Epitácio Pessoa** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Lower volume** | | **Higher volume** | | **Lower volume** | | **Higher volume** | |
| | **Abundance** | **Biomass** | **Abundance** | **Biomass** | **Abundance** | **Biomass** | **Abundance** | **Biomass** |
| **MOLLUSCA** | | | | | | | | |
| *Melanoide tuberculatus,* Müller, 1774 | 506 ± 604.03 | 1.11 ± 60.53 | 195 ±160.99 | 4.52 ± 3.96 | 35 ± 31.45 | 8.62 ± 994.57 | 107 ± 105.10 | 4.90 ± 2.29 |
| *Corbicula largilierti,* Philippi, 1844 | * | * | * | * | 1 ± 0.99 | 481,55 ± 491.46 | * | * |
| Planorbidae | 2 ± 4.12 | 708.60 ± 99.70 | * | * | * | * | 1 ± 0.78 | * |
| **ANÉLIDA** | | | | | | | | |
| Oligochaeta | 16 ± 50.69 | 0.18 ± 0.01 | 1 ± 0.22 | * | 4 ± 8.82 | 0.01 ± 0.04 | 4 ± 15.60 | 0.01 ± 0.06 |
| Hirudínea | * | * | 2 ± 7.13 | * | * | * | 1 ± 0.22 | 2.07 ± 2.23 |
| **DIPTERA** | | | | | | | | |
| Ceratopogonidae | * | * | 1 ± 1.43 | 0.09 ± 0.02 | 1 ± 0.67 | 3.30 ± 0.22 | * | * |
| *Goeldichironomus,* Fittkau, 1965 | 3 ± 11.85 | 0.10 ± 0.45 | * | * | * | * | 1 ± 0.30 | 0.08 ± 0.26 |
| *Fissimentum,* Cranston; Nolte, 1996 | * | * | 1 ± 2.03 | 0.32 ± 0.06 | 1 ± 0.22 | 4.10 ± 0.07 | 1 ± 1.34 | 3.53 ± 1.11 |
| *Parachironomus,* Lenz, 1921 | * | * | 1 ± 0.22 | 1.90 ± 0.09 | * | * | 1 ± 0.30 | 1.5 ± 6.70 |
| *Aedokritus,* Roback, 1958 | * | * | * | * | 1 ± 0.31 | 1.40 ± 0.12 | * | * |
| *Coelotanypus,* Kieffer, 1913 | * | * | * | * | 1 ± 0.22 | 8.90 ± 0.10 | * | * |
| **ODONATA** | | | | | | | | |
| Libellulidae | * | * | * | * | 1 ± 0.22 | 0.20 ± 0.09 | 1 ± 0.22 | 0.19 ± 0.02 |
| Corixidae | * | * | 1 ± 0.67 | 0.10 ± 0.03 | * | * | * | * |
| **CRUSTACEA** | | | | | | | | |
| Decápode | * | * | * | * | 2 ± 5.23 | 0.19 ± 0.63 | * | * |
| **Abundance (number of individuals)** | 10541 | * | 3995 | * | 814 | * | 2223 | * |
| **Richness (number of species)** | 4 | * | 8 | * | 9 | * | 8 | * |
| **Diversity of Shannon** | 0.09 | * | 0.11 | * | 0.31 | * | 0.11 | * |

Abundance in Epitácio Pessoa in the period of lower water volume was represented by the exotic gastropod *M. tuberculatus* with proportions of 84% for the benthic community, followed by Oligochaeta (9.1%) and Decapoda (4.67%) (Figure 6B). The biomass of the benthic macrofauna was represented in larger proportions by the two exotic species *Corbicula largillierti* (Philippi, 1844) (67%) and *M. tuberculatus* (35%), followed by *Coelotanypus* (Diptera) (1.5%) (Figure 6D). In the higher water volume period of Epitácio Pessoa, the abundance and biomass of the community

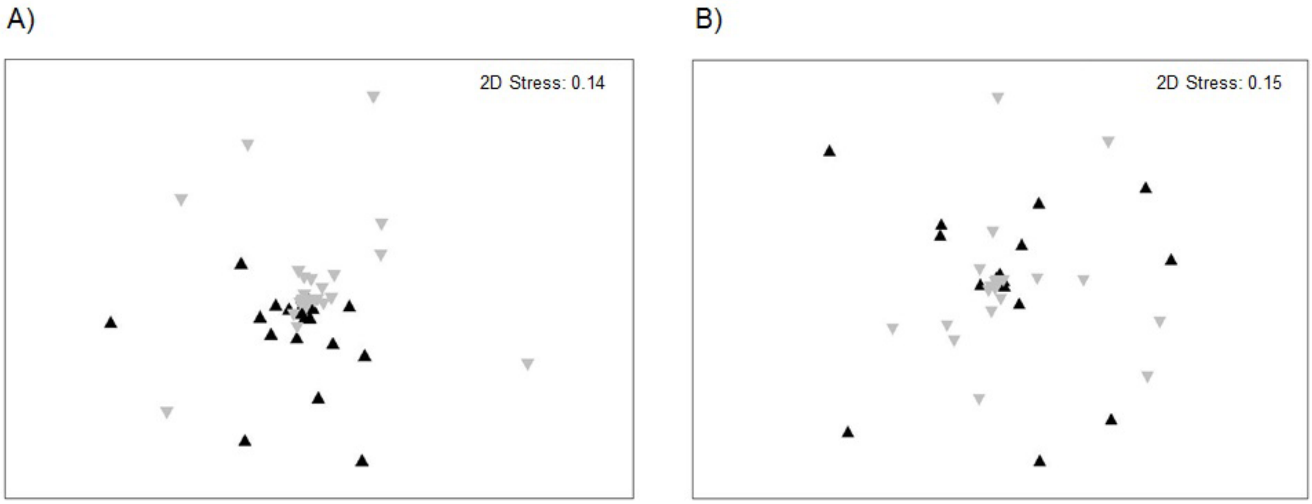

**Figure 5.** Non-metric multidimensional scaling (NMDS) analysis showing the spatial distribution of abundance (A) and biomass (B) of the benthic macroinvertebrates community. The gray symbols represent the Argemiro de Figueiredo reservoir and black symbols represents the Epitácio Pessoa reservoir.

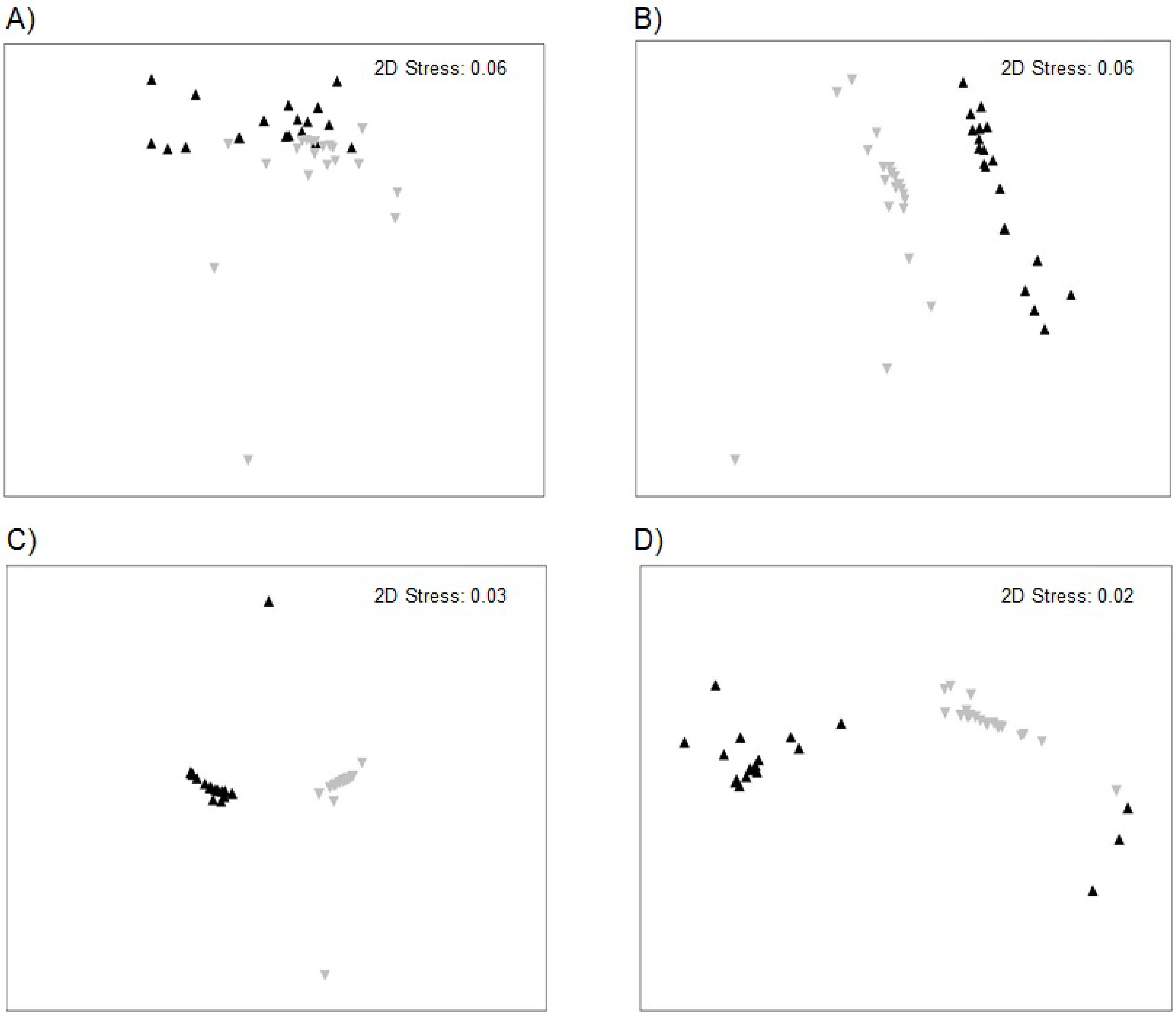

**Figure 6.** Non-metric multidimensional scaling (NMDS) analysis showing the spatial distribution in the periods at lower (black symbols) and higher water volume (gray symbols), for abundance (A and B) and biomass (C and D) of the benthic macroinvertebrates community of the Argemiro de Figueiredo (A and C) and Epitácio Pessoa (B and D) reservoirs, in the Paraíba River, Paraíba, Brazil.

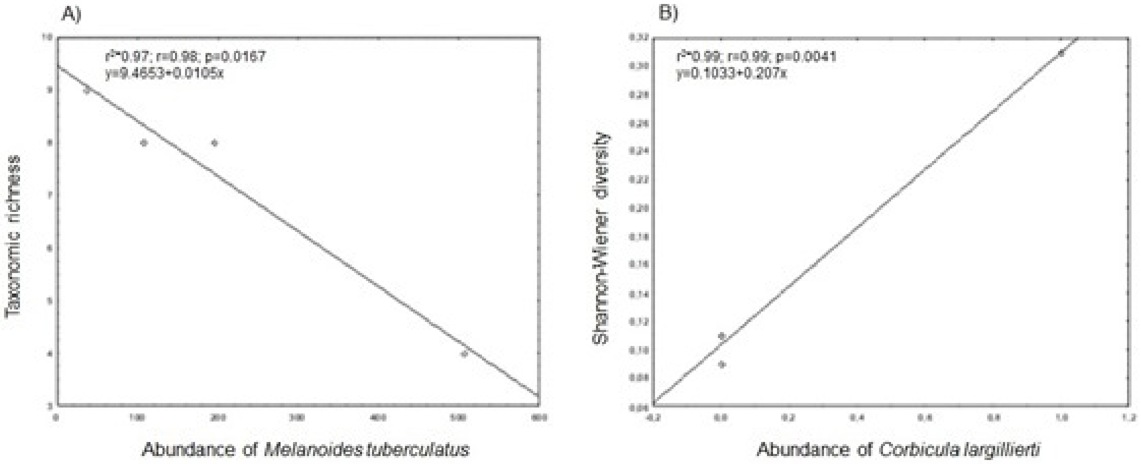

**Figure 7. 7A** Correlation between abundance of *Melanoides tuberculatus* and taxonomic richness in the Argemiro Figueiredo and Epitácio Pessoa reservoirs. 7B Correlation between abundance of *Corbicula largillierti* and Shannon-Wiener diversity in the Argemiro Figueiredo and Epitácio Pessoa reservoirs. Spearman coefficient is shown in each graph.

were represented in equal proportions by *M. tuberculatus,* (95%), followed by Oligochaeta (3%), and Planorbidae mollusks (0.27%) for abundance (Figure 6B), and in terms of biomass, Hirudinea (2%) and *Fissimentum* (1%) (Figure 6D).

The taxonomic richness of the macroinvertebrates in the Epitácio Pessoa reservoir was more representative in the period of lower volume in the reservoir (9 taxa), followed by the period of higher hydric volume (8 taxa). The opposite occurred in the Argemiro de Figueiredo reservoir, where richness was more elevated in the period of higher water volume in the reservoir (8 taxa) when compared to the period of lower water volume (4 taxa) (Table 2). The correlation suggests that as *M. tuberculatus* abundance increases, taxonomic richness decreases ($r^2 = 0.97$; p=0.016) (Figure 7A); however, a significant correlation with *C. largillierti* ($r^2 = 0.99$; p=0.0041) was observed.

The Shannon-Wiener diversity was greater in Epitácio Pessoa, with values of 0.31 at lower water volume and 0.11 bits at higher water volume (Table 2). The index represented the diversity in Argemiro de Figueiredo, with values of 0.11 at higher water volume and 0.09 at lower water volume (Table 2). Significant differences occurred between the reservoirs in diversity (PERMANOVA: Pseudo-$F_{3,1}$=1.2777; p=0.654) and richness (PERMANOVA: Pseudo-$F_{3,1}$=1.2912; =0.659). Linear regression did not show a significant correlation between Shannon-Wiener diversity and abundance of *M. tuberculatus* ($r^2 = 0.40$; $p>0.05$), but rather a correlation between Shannon-Wiener diversity and *C. largillierti* ($r^2 = 0.99$; $p<0.004$) (Figure 7B).

## Discussion

Our results suggest that the ABC method shows variation opposite to the theory proposed by Warwick (1986) for semi-arid reservoirs. According to the theory, impacted environments there are species with high numbers of individuals and with small body size, which results in the positioning of the abundance curve above the biomass curve. Our results showed the opposite. In this study, the biomass curve over the abundance curve classified the Epitácio Pessoa Reservoir in the lower water volume period of the reservoir as being impacted. The inverse ABC classification was associated with the presence of the exotic species *C. largillerti,* abundant in terms of biomass. This classification was confirmed by the W index, which was also high when compared to the index values that classified the Argemiro de Figueiredo Reservoir as moderately disturbed. The increase in W index when impact levels increase was also identified by Reizopoulou et al. (1996).

Environments with greater organic enrichment provide a larger biomass of exotic species, as observed by other authors (Callisto et al. 2005, Velho et al. 2005, Elkarmi & Ismail 2007, Peso et al. 2011, Molozzi et al. 2013), which is often determined by anthropic actions (Borja et al. 2009, Tafangenyasha & Dube 2008). This is associated with an increase in productivity in those ecosystems, which makes the rise in metabolic rates and lifespan possible, allowing the dominance of some opportunist species.

Both reservoirs harbored the exotic species *M. tuberculatus*, which might have influenced the proximity between abundance and biomass curves, in both seasonal periods for the Argemiro de Figueiredo Reservoir, and in the higher water volume period for the Epitácio Pessoa Reservoir. *M. tuberculatus* is an exotic species that, in a disturbed environment, shows a larger size in relation to other species of the benthic community (Molozzi et al. 2013). The proximity between the curves is explained by other authors as the elimination of specialist species, allowing the existence of "r" strategist species, abundant in terms of number of individuals, increasing the tendency of the abundance curve, and consequently, causing the curves to be closer (Clarke 1990, Carvalho et al. 2013, Magurran 2013).

The ecological indicators, based on the richness and diversity of the community of benthic macroinvertebrates in the reservoirs studied displayed a response at odds with the ABC. Opportunist and exotic species cause changes in the structure of macrobenthic communities because of their high capacity for invasion and competition (Harkantra & Rodrigues 2014). We believe that in cases where the two exotic species *M. tuberculatus* and *C. largilliert* both occurred, there was competition between them, which caused a decrease in the occurrence of *M. tuberculatus* and increase in the diversity of the benthic community.

Santos and Eskinazi-Sant'Anna (2010) investigated the introduction of *M. tuberculatus* in reservoirs in the semi-arid region and found that exotic species caused a decline in native species, decreasing their abundance, whereas opportunist species benefited and often became dominant in terms of biomass, leading to alterations in biological communities, which, in general, put the biodiversity and ecological balance of water ecosystems at risk. This could be seen in the reservoirs studied, where the exotic gastropod *M. tuberculatus*, considered an exotic "r" species, with high ecological and tolerant plasticity to different pollution gradients (Abílio et al.

2007, Molozzi et al. 2012, Azevêdo et al. 2014), negatively affected the abundance, richness, and diversity of native species, as indicated by the low representativeness of those species in the study.

When the environmental indicators for Argemiro de Figueiredo were analyzed, the metrics of physical habitat characterization were discordant in most periods, classifying the reservoir as having good environmental quality. This discordance in classification is due to the morphological characteristics of the reservoir, with a great declivity of its margins, a fact that hinders anthropogenic influences. For Epitácio Pessoa, the disturbance metrics confirmed the curve plotted for the higher water volume, where the sites with the higher metrics were associated with the presence of pastures, transmission lines, construction, trade, and trash, reflecting use and occupation around that reservoir.

Our results showed that abundance and biomass curves have the potential to be used as assessment tools for ecological quality in reservoirs in semi-arid regions, showing major relationships with physical and chemical variables, but with information discordant with ecological indicators and disturbance metrics. The ABC method has been applied in temperate and tropical regions (Beukema 1988, Clarke 1990, Reizopoulou et al. 1996, Carvalho et al. 2013); however, as seen in this study, its use has been questioned (Beukema 1988, Reizopoulou et al. 1996). Despite that the curves use abundance and biomass data, and even though they are easy to interpret (Clarke 1990), it is necessary to have knowledge of the ecological aspects of the species that form the community, because when they are not considered, there may be possible errors in the interpretation of curves (Warwick & Clarke 1990, Reizopoulou et al. 1996). Accordingly, the abundant species in terms of biomass may not always indicate low impact areas, and abundant species based on number of individuals may indicate disturbance sites (Dauer et al. 1993) as occurred in our study. ABC may be used cautiously and combined with other indicators, for a coherent and accurate characterization of the quality of reservoirs.

## Acknowledgments

The authors thank the Universidade Estadual da Paraíba (UEPB/PROPESQ) for financial support and Laboratório de Ecologia de Bentos and the Laboratório de Ecologia Aquática (UEPB) for their technical support. JM is grateful to project CNPq / MCT/ Universal process n 379 446721/2014 and for research productivity scholarships (process 302393/2017-0). JELB for is grateful to productivity research scholarships (process 302393/2017-0).

## Author Contributions:

Carlinda Raílly Medeiros, Evaldo de Lira Azevêdo, José Etham de Lucena Barbosa and Joseline Molozzi: Substantial contribution in the concept and design of the study.

Carlinda Raílly Medeiros and Evaldo de Lira Azevêdo: Contribution to data collection.

Carlinda Raílly Medeiros and Joseline Molozzi: Contribution to data analysis and interpretation.

Carlinda Raílly Medeiros, Evaldo de Lira Azevêdo and Joseline Molozzi: Contribution to manuscript preparation.

Carlinda Raílly Medeiros, Evaldo de Lira Azevêdo, José Etham de Lucena Barbosa and Joseline Molozzi: Contribution to critical revision, adding intelectual content.

## Conflicts of interest

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

## References

ABELLÁN, P., SANCHÉZ-FERNÁNDEZ, D., MILLÁN, A., BOTELLA, B. SÁNCHEZ-ZAPATA, J.A. & GIMÉNEZ, A. 2006. Irrigation pools as macroinvertebrate habitat in a semi-arid agricultural landscape (SE Spain). Journal of Arid Environments, 67(2): 255-269, https://doi.org/10.1016/j.jaridenv.2006.02.009.

ABÍLIO, F.J.P., RUFFO, T.L.M., SOUZA, A.H.F.F., FLORENTINO, S.H., JUNIOR, E.T.O., MEIRELES, B.N. & SANTANA, A.C.D. 2007. Macroinvertebrados bentônicos como bioindicadores de qualidade ambiental de corpos aquáticos da Caatinga. Oecologia Brasiliensis, 11(3): 397-409.

AGÊNCIA EXECUTIVA DE GESTÃO DAS ÁGUAS DO ESTADO DA PARAÍBA. 2013. Comitê Rio do Paraíba. http://www.aesa.pb.gov.br/comites/paraiba/. Accessed 10 July 2013.

AHRENS, M.A. & PETER, R.H. 1991. Patterns and limitations in limnoplankton size spectra. Canadian Journal of Fisheries and Aquatic Sciences, 48(10):1967-1978, https://doi.org/10.1139/f91-234.

ANDERSON, M.J., GORLEY, R.N. & CLARKE, K.R. 2008. PERMANOVA + for PRIMER: Guide to software and statistical methods, PRIMER-E. Plymouth.

APHA, Awwa. WEF. 2005. Standard methods for the examination of water and wastewater. American Public Health Association, American Water Works Association, and Water Environment Federation.

AZEVÊDO, D.J.S., BARBOSA, J.E.L., GOMES, W.I.A., PORTO, D.E., MARQUES, J.C. & MOLOZZI, J. 2015. Diversity measures in macroinvertebrate and zooplankton communities related to the trophic status of subtropical reservoirs: Contradictory or complementary responses?. Ecological Indicators, 50:135-149, https://doi.org/10.1016/j.ecolind.2014.10.010.

AZEVÊDO, E.L., BARBOSA, J.E.L., VIANA, L.G., ANACLETO, M.J.P., CALLISTO, M. & MOLOZZI, J. 2017. Application of a statistical model for the assessment of environmental quality in neotropical semi-arid reservoirs. Environmental Monitoring and Assessment, 189(2): 65, https://link.springer.com/article/10.1007/s10661-016-5723-3.

AZEVÊDO, E.L., BARBOSA, J.E.L., VIDIGAL, T.H.D.A., CALLISTO, M. & MOLOZZI, J. 2014. First record of *Corbicula largillierti* (Philippi 1844) in the Paraíba River Basin and potential implications from water diversion of the São Francisco River. Biota Neotropica, 14(4): 1-4, http://dx.doi.org/10.1590/1676-0603003614

BAPTISTA, D.F. 2008. Uso de macroinvertebrados em procedimentos de biomonitoramento em ecossistemas aquáticos. Oecologia Brasiliensis, 12(3): 425-441.

BARBOSA, J.E.L., MEDEIROS, E.S.F., BRASIL, J., CORDEIRO, R.D.S., CRISPIM, M.C.B. & SILVA, G.H.G.D. 2012. Aquatic systems in semi-arid Brazil: limnology and management. Acta Limnologica Brasiliensia, 24(1): 103-118, http://dx.doi.org/10.1590/S2179-975X2012005000030.

BEDNAREK, A.T. 2001. Undamming rivers: a review of the ecological impacts of dam removal. Environmental Management, 27(6): 803-814, https://link.springer.com/article/10.1007%2Fs002670010189?LI=true.

BEUKEMA, J.J. 1998. An evaluation of the ABC-method (abundance/biomass comparison) as applied to macrozoobenthic communities living on tidal flats in the Dutch Wadden Sea. Marine Biology, 99(3): 425-433.

BORJA, A., MILES, A., OCCHIPINTI-AMBROGI, A. & BERG, T. 2009. Current status of macroinvertebrate methods used for assessing the quality of European marine waters: implementing the Water Framework Directive. Hydrobiologia, 633(1): 181-196, https://link.springer.com/article/10.1007/s10750-009-9881-y.

BUSS, D.F., BAPTISTA, D.F. & NESSIMIAN, J.L. 2003. Conceptual basis for the application of biomonitoring on stream water quality programs. Cadernos de Saúde Pública, 19(2): 465-473, http://dx.doi.org/10.1590/S0102-311X2003000200013.

CALLISTO, M., GOULART, M., BARBOSA, F.A.R. & ROCHA, O. 2005, Biodiversity assessment of benthic macroinvertebrates along a reservoir cascade in the lower São Francisco river (northeastern Brazil). Brazilian Journal of Biology, 65(5): 229-240, http://dx.doi.org/10.1590/S1519-69842005000200006.

CAMARGO, J.A., GONZALO, C. & ALONSA, Á. 2011. Assessing trout farm pollution by biological metrics and indices based on aquatic macrophytes and benthic macroinvertebrates: A case study. Ecological Indicators, 11(3): 911-917, https://doi.org/10.1016/j.ecolind.2010.10.001.

CARVALHO, F.G., JUNIOR, J.M.B.O., FARIAS, A.P.J. & JUEN, L. 2013. Uso da curva ABC como método para detectar o efeito de modificação antropogênica sobre assembleia de Odonata (insecta). Interciencia, 38(7): 516-522.

CLARKE, K.R. Comparisons of dominance curves. 1990. Journal of Experimental Marine Biology and Ecology, 138(1): 143-157.

CLARKE, K.R. & GORLEY, R.N. 2006. Primer v6: USER manual. PRIMER-E Ltd. Plymouth Marine Laboratory, 192.

CLARKE, K.R. & WARWICK, R.M. 2001. Change in marine communities: An approach to statistical analysis and interpretation. 2nd Ed. PRIMER-E Ltd, Plymouth Marine Laboratory, 172.

DAUER, D.M., LUCKENBACH, M.W. & RODI-JR. A.J. 1993. Abundance biomass comparison (ABC method): effects of an estuarine gradient, anoxic/hypoxic events and contaminated sediments. Marine Biology, 116(3): 507-518, https://link.springer.com/article/10.1007%2FBF00350068?LI=true.

ELKARMI, A.Z. & ISMAIL, N.S. 2007. Growth models and shell morphometrics of two populations of *Melanoides tuberculata* (Thiaridae) living in hot springs and freshwater pools. Journal of Limnology, 66(2): 90-96, https://doi.org/10.4081/jlimnol.2007.90.

GOLTERMAN, H.L., CLYMO, R.S. & OHNSTAD, M. 1978. Methods for physical and chemical analysis of freshwaters. 2 Ed. Oxford: Blackwell Scientific Publications Ib.

HARKANTRA, S.N. & RODRIGUES, N.R. 2004. Numerical analyses of soft bottom macroinvertebrates to diagnose the pollution in tropical coastal waters. Environmental Monitoring and Assessment, 93(1-3): 251-275, https://link.springer.com/article/10.1023/B:EMAS.0000016800.86679.62.

JØRGENSEN, P.E., ERIKSEN, T. & JENSEN, B.K. 1992. Estimation of viable biomass in wastewater and activated sludge by determination of ATP, oxygen utilization rate and FDA hydrolysis. Water Research, 26(11): 1495-1501, https://doi.org/10.1016/0043-1354(92)90069-G.

KAUFMANN, P.R., PECK, D.V., PAULSEN, S.G., SEELIGER, C.W., HUGHES, R.M., WHITTIER, T.R. & KAMMAN, N.C. 2014. Lakeshore and littoral physical habitat structure in a national lakes assessment. Lake and Reservoir Management, 2014, 30(2): 192-215.

KÖPPEN, W. & GEIGER, R. 1936. Handbuch der Klimatologie. Berlin: Gebrüder Bornträger.

LORENZEN, C.J. 1967. Determination of chlorophyll and pheo□pigments: spectrophotometric equations. Limnology and oceanography, 12(2): 343-346, http://onlinelibrary.wiley.com/doi/10.4319/lo.1967.12.2.0343/full.

MAGURRAN, A.E. 2013. Medindo a diversidade biológica. Curitiba: Editora UFPR.

MARQUES, J., SALAS, F., PATRÍCIO, J., TEIXEIRA, H. & NETO, J.M. 2009. Ecological indicators for coastal and estuarine environmental assessment. Boston: Wit Press.

MOLOZZI, J., FEIO, M.J., SALAS, F., MARQUES, J.C. & CALLISTO, M. 2013. Maximum ecological potential of tropical reservoirs and benthic invertebrate communities. Environmental Monitoring and Assessment, 185(8): 6591-6606, https://link.springer.com/article/10.1007/s10661-012-3049-3.

MUGNAI, R., NESSIMIAN, J.L. & BAPTISTA, D.F. 2010. Manual de identificação de macroinvertebrados aquáticos do Estado do Rio de Janeiro. Rio de Janeiro: Technical Books Editora.

OTERMIN, A., BASAGUREN, A. & POZO, J. 2002. Re-colonization by the macroinvertebrate community after a drought period in a first-order stream (Agüera Basin, Northern Spain). Limnetica, 21(2): 117-128.

PESO, J.G., PÉREZ, D.C. & VOGLER, R.E. 2011. The invasive snail *Melanoides tuberculata* in Argentina and Paraguay. Limnologica Ecology and Management of Inland Waters, 41(4): 281-284, https://doi.org/10.1016/j.limno.2010.12.001.

POPE, K.L. & HANNELLY, E.C. 2013. Response of benthic macroinvertebrates to whole-lake, non-native fish treatments in mid-elevation lakes of the Trinity Alps, California. Hydrobiologia, 714(1): 201-215, https://link.springer.com/article/10.1007/s10750-013-1537-2.

PUENTE, A. & DIAZ, R.J. 2008. Is it possible to assess the ecological status of highly stressed natural estuarine environments using macroinvertebrates indices?. Marine Pollution Bulletin, 56(11): 1880-1889, https://doi.org/10.1016/j.marpolbul.2008.07.016.

REIZOPOULOU, S., THESSALOU-LEGAKI, M. & NICOLAIDOU, A. 1996. Assessment of disturbance in Mediterranean lagoons: An evaluation of methods. Marine Biology, 125(1), 189-197.

ROCHA, L.G., MEDEIROS, E.S.F. & ANDRADE, H.T.A. 2012. Influence of flow variability on macroinvertebrate assemblages in an intermittent stream of semi-arid Brazil. Journal of Arid Environments, 85, 33-40, https://doi.org/10.1016/j.jaridenv.2012.04.001.

SANTOS, C.M. & ESKINAZI-SANT'ANNA, E.M. 2010. The introduced snail Melanoides tuberculatus (Muller, 1774) (Mollusca: Thiaridae) in aquatic ecosystems of the Brazilian Semiarid Northeast (Piranhas-Assu River basin, State of Rio Grande do Norte). Brazilian Journal of Biology, 70(1): 1-7, http://dx.doi.org/10.1590/S1519-69842010000100003.

SHARMA, R.C. & RAWAT, J.S. 2009. Monitoring of aquatic macroinvertebrates as bioindicator for assessing the health of wetlands: A case study in the Central Himalayas, India. Ecological Indicators, 9(1): 118-128, https://doi.org/10.1016/j.ecolind.2008.02.004.

SHANNON, C.E. & WEAVER, W. 1963. The mathematical theory of communication. Chicago: University of Illinois Press.

STATZNER, B. & BÊCHE, L.A. 2010. Can biological invertebrate traits resolve effects of multiple stressors on running water ecosystems? Freshwater Biology, 55(1): 80-119, http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2427.2009.02369.x/full.

TAFANGENYASHA, C. & DUBE, L.T. 2008. An investigation of the impacts of agricultural runoff on the water quality and aquatic organisms in a Lowveld Sand river system in Southeast Zimbabwe. Water Resources Management, 22(1): 119-130, https://link.springer.com/article/10.1007%2Fs11269-006-9147-7?LI=true.

TAKAHASHI, M.A., HIGUTI, J., BAGATINI, Y.M., ZVIEJKOVSKI, I.P. & VELHO, L.F.M. Composition and biomass of larval Chironomidae (Insecta, Diptera) as potential indicator of trophic conditions in southern Brazil Reservoirs. Acta Limnologica Brasiliensia, 2008, 20(1): 5-13, http://www.ablimno.org.br/acta/pdf/acta20_vol1_02.pdf.

THORNE, R. & WILLIAMS, P. 1997. The response of benthic macroinvertebrates to pollution in developing countries: a multimetric system of bioassessment. Freshwater Biology, 37(3): 671-686, http://onlinelibrary.wiley.com/doi/10.1046/j.1365-2427.1997.00181.x/full.

THOMPSON, S.A., THOMPSON, G.G. & WITHERS, P.C. 2008. Rehabilitation index for evaluating restoration of terrestrial ecosystems using the reptile assemblage as the bio-indicator. Ecological Indicators, 8(5): 530-549, https://doi.org/10.1016/j.ecolind.2007.07.001.

TRIVINHO-STRIXINO, S. & STRIXINO, G. 1995. Larvas de Chironomidae (Diptera) do Estado de São Paulo: Guia de Identificação e Diagnose dos Gêneros. São Carlos-SP: PPG-ERN/UFSCAR.

TRIVINHO-STRIXINO, S. 2011. Larvas de Chironomidae, Guia de Identificação. Departamento Hidrologia Entomologia Aquática/UFSCAR, São Carlos.

TUNDISI, J.G., MATSUMURA-TUNDISI, T. & TUNDISI, J.E.M. 2008. Reservoirs and human well being: new challenges for evaluating impacts and benefits in the neotropics. Brazilian Journal of Biology, 68(4), 1133-1135, http://dx.doi.org/10.1590/S1519-69842008000500020.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY. 2012. National lakes assessment field operations manual EPA 841-B-11-003. Washington. DC: U.S. Environmental Protection Agency.

VARNOSFADERANY, M.N., EBRAHIMI, E., MIRGHAFFARY, N. & SAFYANIAN, A. 2010. Biological assessment of the Zayandeh Rud River, Iran, using benthic macroinvertebrates. Limnologica-Ecology and Management of Inland Waters, 40(3): 226-232, https://doi.org/10.1016/j.limno.2009.10.002.

VELHO, L.F.M., PEREIRA, D.G., PAGIORO, T.A., SANTOS, V.D., PERENHA, M.C.Z. & LANSAC-TÔHA, F.A. 2005. Abundance, biomass and size structure of planktonic ciliates in reservoirs with distinct trophic states. Acta Limnologica Brasiliensia, 17(4): 361-371, http://ablimno.org.br/acta/pdf/acta_limnologica_contents1704E_files/17_2(4).pdf.

WARWICK, R.M. & CLARKE, K.R. 1994. Relearning the ABC: taxonomic changes and abundance/biomass relationships in disturbed benthic communities. Marine Biology, 118: 739-744, https://link.springer.com/article/10.1007%2FBF00347523?LI=true.

WARWICK, R. 1986. A new method for detecting pollution effects on marine macrobenthic communities. Marine Biology, 92(4): 557-562, https://link.springer.com/article/10.1007/BF00392515.

YEMANE, D., FIELD, J.G. & LESLIE, R.W. 2005. Exploring the effects of fishing on fish assemblages using Abundance Biomass Comparison (ABC) curves. ICES Journal of Marine Science: Journal du Conseil, 62(3): 374-379, https://doi.org/10.1016/j.icesjms.2005.01.009.

*Received: 09/08/2017*
*Revised: 08/01/2018*
*Accepted: 16/01/2018*
*Published online: 01/03/2018*

Biota Neotropica 18(2): e20180515, 2018
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
Article

# Soil macrofauna in organic and conventional coffee plantations in Brazil

*Janaina Biral dos Santos*[1], *Alessandro Coutinho Ramos*[2], *Romildo Azevedo Júnior*[1],

*Luís Carlos Iuñes de Oliveira Filho*[3], *Dilmar Baretta*[4] *& Elke Jurandy Bran Nogueira Cardoso*[5]*

[1]*Universidade de Vila Velha, Laboratório de Microbiologia Ambiental e Biotecnologia, Vila Velha, ES, Brasil*
[2]*Universidade Estadual do Norte Fluminense, Laboratório de Fisiologia e Bioquímica, Campos dos Goytacazes, RJ, Brasil*
[3]*Universidade do Estado de Santa Catarina, Centro de Ciências Agroveterinárias, Lages, SC, Brasil*
[4]*Universidade do Estado de Santa Catarina, Centro de Educação Superior do Oeste, Chapecó, SC, Brasil*
[5]*Universidade de São Paulo, Escola Superior de Agricultura "Luiz de Queiroz", Departamento de Ciência do Solo, Piracicaba, SP, Brasil*
**Corresponding author: Elke Jurandy Bran Nogueira Cardoso, e-mail: ejbncard@usp.br*

SANTOS, J. B., RAMOS, A. C., AZEVEDO JÚNIOR, R., OLIVEIRA FILHO, L. C. I., BARETTA, D., CARDOSO, E. J. B. N. **Soil macrofauna in organic and conventional coffe plantations in Brazil**. Biota Neotropica. 18(2): e20180515. http://dx.doi.org/10.1590/1676-0611-BN-2018-0515

***Abstract:*** Brazil has always been one of the most important coffee producing countries. Lately, there has equally been a renewed interest in alternative coffee production systems. The state of Espírito Santo is the second greatest coffee producer in Brazil; so, we used local coffee plantations to evaluate the relations between soil macrofauna and chemical and microbiological soil properties to identify which of these properties discriminate more effectively between the organic management system (OS) and the conventional management system (CS) of coffee plantations. For each of these two cultivation systems we chose three coffee farms who employed both cultivation systems and picked out the most similar fields from each property. At each site, first we sampled the litter at the soil surface. Afterwards, we sampled nine soil monoliths to evaluate the macrofauna, in summer and winter. We also collected nine supplemental soil samples, taken at a few centimeters from the soil monoliths, for chemical and microbiological analyses. Macrofauna density was evaluated by ANOVA and multivariate analysis. The chemical and microbiological properties are environmental variables, while the data on macrofauna are the explanatory variables. The total number of individuals recovered in this study was 3,354, and the climate, identified by the sampling season, was a great modulator of macrofauna, with higher numbers in winter. The principal components analysis showed that soil moisture, organic matter, nitrogen, phosphorus, boron, copper, pH, acid and alkaline phosphatases and microbial biomass carbon, were the most outstanding ones to discriminate both cultivation systems. We found no statistical significant differences in macrofauna density between OS and CS, probably due to a general great variability, since there was a tendency for much greater values in OS. We detected the interference of chemical and microbiological soil properties on the macrofauna community in both systems of coffee cultivation, and some results clearly correlated much better with climate data than with other factors. To our knowledge, this is the first time in which the data point to a clear separation between the more numerous and diversified soil macrofauna in coffee with organic cultivation from that with a conventional cultivation system.
***Keywords:*** *bioindicators, soil biology, soil ecology, soil fauna, climate.*

# Macrofauna do solo em plantações de café orgânico e convencional no Brasil

***Resumo:*** O Brasil sempre foi um dos mais importantes países produtores de café. Ultimamente, houve um renovado interesse pelos sistemas alternativos de produção de café. O Estado do Espírito Santo é o segundo maior produtor de café do Brasil; então, utilizaram-se plantações locais de café para avaliar as relações entre a macrofauna do solo e as propriedades químicas e microbiológicas do solo para identificar quais dessas propriedades discriminam mais efetivamente entre o sistema de manejo orgânico (SO) e o sistema de manejo convencional (SC) das plantações de café. Para cada um desses dois sistemas de cultivo, escolheu-se três fazendas de café que empregaram ambos os sistemas de cultivo e selecionaram os campos mais similares de cada propriedade. Em cada local, primeiro amostrou-se a serrapilheira do solo. Posteriormente, amostraram-se nove monólitos de solo para avaliar a macrofauna, tanto no verão como no inverno. Também, foram coletadas nove amostras suplementares de solo, a alguns centímetros dos monólitos de solo, para análises químicas e microbiológicas. A densidade da macrofauna foi avaliada por ANOVA e análise multivariada. As propriedades químicas e microbiológicas são variáveis ambientais, enquanto os dados sobre a macrofauna são as variáveis explicativas. O número total de indivíduos recuperados neste estudo foi de 3.354 e o clima, identificado pela época de amostragem, foi um ótimo modulador da macrofauna, com maiores números no inverno. A análise dos componentes principais mostrou que a umidade do solo, matéria orgânica, nitrogênio, fósforo, boro, cobre, pH, fosfatases ácido e alcalina e carbono da biomassa microbiana, foram os mais destacados para discriminar ambos os sistemas de cultivo. Encontraram-se diferenças significativas na densidade da macrofauna entre SO e SC, provavelmente devido a uma grande variabilidade geral, uma vez que houve uma tendência para valores muito maiores no SO. Detectou-se a interferência das propriedades químicas e microbiológicas do solo na comunidade de macrofauna em ambos os sistemas de cultivo de café, e alguns resultados claramente correlacionados muito melhor com os dados climáticos do que com outros fatores. A nosso conhecimento, esta é a primeira vez em que os dados apontam para uma clara separação entre a macrofauna do solo mais numerosa e diversificada em café com cultivo orgânico de que com um sistema de cultivo convencional.

***Palavras-chave:*** *bioindicadores, biologia do solo, ecologia do solo, fauna do solo, clima.*

## Introduction

In Brazil, most of the *Coffea* sp. is cultivated on conventional systems. However, in recent years, the organic system has emerged and is creating a new market niche for organic products (Partelli et al. 2012). In the state of Espírito Santo, coffee (*Coffea arabica* L) is one of the most important agricultural products and affects social and economic scenarios (Frederico 2013). Coffee plantations are normally planted in monocultures and consequently may present a smaller biological diversity in the soil (Scherr & McNeely 2008). Conventional agriculture requires high inputs of fossil energy and large amounts of fertilizers and chemical pesticides (Gündoğmuş 2006). This inputs often have a negative effect on soil quality, with a higher tendency to soil compaction, loss of mineral nutrients, and reduction of soil biota (Vasconcellos et al. 2013), which affect soil quality and ecological functions (Albrecht et al. 2010) and causes degradation of soil and environment. A more sustainable method of agriculture, that includes adoption of conservational practices, represents a feasible alternative for minimization of such effects (Partelli et al. 2016). Many biological processes are favored in organically managed farms (Glover et al. 2000), as higher root colonization by mycorrhizal fungi (Lamine & Bellon 2009), constant transformation of organic materials, resulting in a greater stock of mineral nutrients and microbial activity (Scherr & McNeely 2008). As reported by Bartz et al. (2009), in Brazil, few studies have been carried out to assess and compare the impact of organic and conventional systems on soil fauna populations under coffee plantations.

To evaluate the sustainability of a cultivation system, it is important to utilize good indicators of soil quality (Antunes et al. 2013, Cardoso et al. 2013, Azevedo Junior et al. 2017). These indicators must be sensitive to soil modifications, be part of the ecosystem functions, be easy to determine, easily understandable, and must be comparable with other indicators (Swift et al. 2004, Rousseau et al. 2013). Soil macrofauna complies with these characteristics in ecosystem functions, besides being part of different trophic levels, and show interactions with many environmental components, especially with plant residues, which constitute their major food resource and habitat (Swift et al. 2004). Macrofauna are sensitive to modifications of the environment and rapidly respond to many different impacts on the ecosystem (Hole et al. 2005), while they are also important instruments to evaluate, organize and even modify soil (Rousseau et al. 2013).

Thus, one of the most important groups of soil macrofauna are earthworms (Oligochaeta). They affect soil structure, fertility and nutrient cycling with important consequences on plant growth (Lavelle & Spain 2001, Bityutskii et al. 2016). They promote the distribution of particles and organic matter on the surface and in the soil profile, catalyzing microbial activity and consequently creating better conditions for colonization by other biotic components (Lavelle et al. 1999, Brown et al., 2000, Baretta et al. 2007). In agroecosystems, earthworms have positive impacts on plant production with an average increase in yield of 25–35%, as reported in meta-analyses (Brown et al. 1999, van Groenigen et al. 2014). Since soil biodiversity is influenced by the cultivation systems adopted, information of the soil macrofauna and earthworms are important for success of agricultural activity and for sustainability.

There are physical and chemical soil properties that interact with macrofaunal groups by influencing their metabolism, while, at the same time, responding to the behavior of soil invertebrates. The most cited physical properties are soil texture, porosity, and water retention capacity, which normally are not susceptible to rapid responses, while the chemical ones are linked to soil fertility and nutrient availability (Effgen et al. 2008, 2012), and may have a great impact on soil macrofauna. Among the most responsive ones, we cite the microbiological properties, which describe the microbial activity in soils (Maluche-Baretta et al. 2006, Kaschuk et al. 2010). Partelli et al. (2016) and Azevedo Junior et al. (2017) highlight the positive effect of organic farming on physical attributes of soils. In coffee cultivation systems, according to Partelli et al. (2016), the physical properties, as soil resistance to penetration, macroporosity, density and total porosity in soil under organic management provides this system with a higher similarity to the Atlantic forest than the conventional system. Azevedo Junior et al. (2017) report that microbiological and chemical soil properties are effective in discriminating the two cultivation systems and most important as sensitive indicators were calcium, boron, microbial biomass carbon and acid phosphatase.

Up to now, in the State of Espírito Santo, there have been no reports or surveys on physical, chemical or biological indicators of soil health in organic or conventional coffee farms. Such studies are of importance to determine the sustainability of organic cultivation in relation to the conventional system. In this study, we focus on soil macrofauna for evaluating impacts of the agroecosystem management and on their use as potential biological indicators of soil quality. Equally, we focus too on earthworms as indicators of environmental quality, as they are sensitive to various soil and environmental modifications. We hypothesize that organic coffee cultivation systems provide chemical, physical and microbiological improvements of the soil, differentiating it from the conventionally cultivated soils, presenting greater sustainability and a greater abundance and diversity of soil organisms, especially of earthworms. Therefore, this study was set up in coffee plantations to identify which of the surveyed soil macrofauna groups and earthworms discriminate more effectively organic and conventional coffee plantations and to evaluate the relations between soil macrofaunal, as earthworms, indicators and chemical, physical and microbiological soil properties.

## Material and Methods

### 1. *Characterization of the study site*

We conducted this research on indicators of soil quality at six sites with coffee farms, in the municipalities of Marechal Floriano (20º 26' 761" S and 40 º45' 780" W), Domingos Martins (20º 21' 572" S and 41° 03' 063" W), and Santa Maria de Jetibá (20° 0' 267" S and 40° 47' 010" W), Espírito Santo State, Brazil. The three coffee plantations were 1 to 5 kilometers apart, and each farm presented plots under organic (OS) and conventional management (CS). Each plot was at least 1 ha in extension. Soils of these sites present a silty clay loam texture and are of lateritic origin, classified as Ferralsols (IUSS Working Group WRB 2015), with very similar nutrient availability, and an altitude between 700 and 1.000 m, presenting conventional and organic coffee plantations closely together.

The climate of Marechal Floriano and Domingos Martins is subtropical of altitude, most of the time with average temperatures between 10°C and 18°C (Cwb, according to Köppen), typical of mountain ranges in tropical regions. During summer (in January 2013), the mean temperature was 23ºC and the rainfall was 257 mm a month. In winter (in July 2013), the medium temperature was 18.5ºC and the precipitation was 60 mm (registered at the Meteorological Experimental Station in Santa Maria (20º 26' 761" S and 40º 45' 780" W). Santa Maria de Jetibá presented a humid subtropical climate (Cwa). During summer, the mean rainfall is about 260 mm a month and, in winter, it varies from 60 to 80 mm a month. In this region we used the data of the Agro-climatic Station of Santa Teresa (19º 98' 86" S and 40º 57' 94" W), with average temperature of 21.2ºC and average rainfall of 270 mm a month in summer. In winter the medium values were, respectively, 16.7ºC and 81 mm.

Each one of the chosen sites is a true repetition, as all of them were lying on similarly inclined slopes, at the western site, and the plantations were in the productive phase, over four years of age, planted with the variety Catuaí (IAC44). In OS, organic compost produced on the farm with chicken, cow or swine manure, mixed with fibrous plant material is applied at a rate of 3 to 4 kg of compost per plant once a year, in November or December. The farmers use 4% cow urine for pest control during winter. Herbicides are replaced by hoeing, and productivity is low, about 23 at 60 kg bags ha$^{-1}$. In CS, plants are fertilized with N-P-K (19-04-19), based on nitrate or ammonia, applying 200 kg per plant, three times a year. A foliar fertilizer composed of 4% B, 12% Cu, 5% Mn, 5% Zn, 1% K and 11% is sprayed on the shoots once a year, in November. *Hemileia vastatrix* Berkeley & Broome 1869 (the pathogen of coffee rust) and *Leucoptera coffeella* (Guérin-Mèneville & Perrottet 1842) (the leaf borer) are controlled with the fungicide Cyproconazole and the insecticide Thiamethoxan, while Glyphosate is the herbicide used. Productivity reaches 60 at 75 kg bags ha$^{-1}$.

### 2. *Experimental design and soil sampling*

We sampled soil monoliths in summer (January 2013), and in winter (July 2013). For each system, we catalogued nine points in a grid sampling (centered in a 1 ha area), with a minimum distance of 30 m between them, to avoid autocorrelation, and leaving a border region of 20 m (Bartz et al. 2014). Sampling depth was always from 0 to 20 cm, directly below the canopy of the coffee tree. Evaluation of the macrofaunal soil community was according to the methodology recommended by the "Tropical Soil Biology and Fertility" Program (TSBF) (Anderson & Ingram 1993), which consists of sampling nine to ten soil monoliths measuring 625 cm$^2$ and 20 cm deep per area studied. Previously, we sampled litter (including all plant residues on the soil surface) in an area of 1 m$^2$. To obtain a representative soil sample for chemical, physical and microbiological analyses, at each of the nine points, directly at the sites where the soil monoliths were gathered, we also collected 0 to 20 cm deep soil subsamples, later mixed to provide a composite sample (Embrapa 1997, Tomé Jr. 1997). For physical (granulometry) and chemical analyses, soil samples were air-dried and sieved (2 mesh). To determine soil moisture, undisturbed samples were collected with the help of a volumetric ring, and stored inside a closed container. For microbiological analyses, soil samples were sieved (2 mesh) and stored in the refrigerator at 4°C for analytical procedures.

### 3. *Soil Macrofauna Sampling*

The total of 27 soil monoliths were collected per system in each sample collection period. We define soil macrofauna as measuring 2 to 20 mm, which includes more than 20 groups of invertebrates: Araneae, Blattodea, Coleoptera, Chilopoda, Diplopoda, Dermaptera, Formicidae (Hymenoptera), Gastropoda, Hemiptera, Isopoda, Isoptera, Oligochaeta, Opiliones, Orthoptera, Pseudoscorpionida, among others (sum of other less common groups, such as Homoptera, Lepidoptera, and some unidentified individuals) (Baretta et al. 2011). The macrofauna were hand-sorted from the monoliths and were stored in 70% ethanol, except for the earthworms, stored in absolute alcohol. For identification, we visualized the macrofauna with a stereomicroscope, when necessary, and the taxonomical macrofaunal groups, defined at the level of class, order or family, were registered. Such higher level of arthropod taxonomy, and others invertebrates, is considered to provide benefits for rapid biodiversity surveys (Cotes et al. 2010, Gkisakis et al. 2016). It is mentioned as a particularly useful tool in the first phases of investigation for biodiversity assessments, at least at a local scale, comparing different land uses and agricultural management practices, when rapid results are required and financial resources are limited (Biaggini et al. 2007, Gkisakis et al. 2016). For earthworms, taxonomic classification was at the family level, and sometimes up to genus and species. All macrofaunal densities were assessed by counting individuals per square meter (ind. $m^{-2}$) and by Shannon's Diversity index (Odum 1983, Santorufo et al. 2012) and earthworm diversity by richness (number of families, genera or species).

Specimens of this survey are housed at the Collection of the University of Vila Velha (UVV), Boa Vista, Vila Velha, Brazil.

## 4. *Chemical and physical soil analyses*

For the chemical analyses (pH, organic matter, N, P, K, Ca, Mg, S, Al, H+Al, Na, CEC at pH 7.0, Fe, Cu, Zn, Mn, B) and physical analyses (granulometry, moisture) we followed the methodology of van Raij et al. (2001) (Table 1). We quantified soil moisture twice, during summer and winter, while soil granulometrywas analyzed only once, in January 2013.

## 5. *Microbiological Soil Analyses*

Microbial biomass carbon (MBC) evaluation followed Vance et al. (1987), and $CO_2$ evolution was according to Alef (1995) (Table 2). We calculated the metabolic quotient ($qCO_2$) according to Anderson & Domsch (1993). The enzymes studied are involved in the biogeochemical cycles of phosphorus [acid (ACP) and alkaline (ALP) phosphatases] and were evaluated following Tabatabai & Bremner (1969) (Table 2).

## 6. *Statistical analyses*

Prior to statistical analyses, total numbers of individuals for each taxonomic group were determined, and this value was the estimate of density (ind. $m^{-2}$). Data (without outliers) were transformed ($\sqrt{x+1}$) to comply with the requirements of analysis of variance (ANOVA; normal distribution and homoscedasticity of error variances). The normality of data (density) was checked with Kolmogorov–Smirnov's and homogeneity of variances was tested using Bartlett's test. ANOVA was the base to compare density of macrofauna community and Shannon's Diversity index in OS and CS in summer and winter, using SAS (SAS Institute 1999). Analyses were conducted at the farming system level, using the nine soil samples per municipality as replicates (n = 27 in each farming system). Means presented in the text and figures were calculated using non-transformed data (± standard deviation). Comparisons of means were according to Tukey's HSD test ($p < 0.05$). The same procedures were applied to OS earthworm specimens.

For multivariate analysis of the total number of individuals for each taxonomic group we obtained the length of the gradient in a detrended Correspondence Analysis and, as this was less than three (linear response), we opted for the Principal Components Analyses (PCA) using the software CANOCO 4.5 (ter Braak & Šmilauer 2002). The collinear

**Table 1.** Chemical and physical characterization of the soils at a depth of 0-20 cm in the organic (OS) and conventional farming systems (CS), in the state of Espírito Santo, Brazil. (n = 27, means ± standard deviation).

| Soil properties | Cultivation systems | | | |
|---|---|---|---|---|
| | Organic system | | Conventional system | |
| | Summer | Winter | Summer | Winter |
| pH ($H_2O$) | 6.00 ± 0.16 | 6.13 ± 0.16 | 5.70 ± 0.13 | 6.11 ± 0.11 |
| Organic matter (g $dm^{-3}$) | 50.77 ± 3.75 | 48.25 ± 3.45 | 42.56 ± 1.80 | 41.39 ± 1.76 |
| N (%) | 0.45 ± 0.03 | 0.49 ± 0.03 | 0.40 ± 0.03 | 0.40 ± 0.03 |
| P-resin (mg $dm^{-3}$) | 225.67 ± 47.7 | 324.00 ± 81.06 | 99.22 ± 17.7 | 121.52 ± 29.1 |
| K (mmol $dm^{-3}$) | 4.92 ± 0.47 | 5.61 ± 0.48 | 4.97 ± 0.25 | 5.09 ± 0.28 |
| Ca (mmol $dm^{-3}$) | 65.04 ± 6.46 | 57.07 ± 5.58 | 45.67 ± 3.22 | 41.11 ± 2.54 |
| Mg (mmol $dm^{-3}$) | 16.52 ± 0.89 | 14.81 ± 0.85 | 12.627 ± 1.04 | 11.70 ± 0.97 |
| S (mg $dm^{-3}$) | 33.63 ± 2.71 | 33.40 ± 3.00 | 33.77 ± 2.22 | 39.23 ± 3.69 |
| Al (mmol $dm^{-3}$) | 1.85 ± 0.52 | 1.37 ± 0.50 | 2.41 ± 0.78 | 1.19 ± 0.43 |
| H+Al (mmol $dm^{-3}$) | 73.85 ± 10.24 | 61.11 ± 8.41 | 77.52 ± 6.24 | 58.89 ± 8.31 |
| Na (mmol $dm^{-3}$) | 0.92 ± 0.12 | 1.16 ± 0.16 | 0.50 ± 0.06 | 0.37 ± 0.05 |
| CEC pH7.0 (mmol $dm^{-3}$)[1] | 161.24 ± 7.32 | 139.67 ± 6.16 | 141.30 ± 4.52 | 117.15 ± 3.47 |
| Fe (mg $dm^{-3}$) | 33.81 ± 4.95 | 35.09 ± 5.39 | 57.17 ± 3.51 | 48.58 ± 4.05 |
| Cu (mg $dm^{-3}$) | 2.86 ± 0.47 | 1.79 ± 0.39 | 3.03 ± 0.58 | 2.19 ± 0.38 |
| Zn (mg $dm^{-3}$) | 20.59 ± 3.36 | 23.59 ± 3.98 | 13.04 ± 0.90 | 11.74 ± 0.96 |
| Mn (mg $dm^{-3}$) | 27.24 ± 2.98 | 26.94 ± 2.45 | 10.47 ± 0.88 | 8.77 ± 0.79 |
| B (mg $dm^{-3}$) | 0.36 ± 0.03 | 0.39 ± 0.03 | 0.54 ± 0.02 | 0.50 ± 0.03 |
| Moisture (%) | 22.71 ± 0.90 | 20.41 ± 0.60 | 20.61 ± 0.35 | 20.41 ± 0.35 |
| Sand (g $kg^{-1}$) | 120.6 ± 1.05 | | 132.0 ± 1.25 | |
| Silt (g $kg^{-1}$) | 505.7 ± 3.78 | | 537.2 ± 4.42 | |
| Clay (g $kg^{-1}$) | 373.6 ± 3.99 | | 330.7 ± 3.57 | |

[1] CEC – Cation Exchange Capacity.

**Table 2.** Microbiological characterization of the soils at 0-20 cm in organic (OS) and conventional farming system (CS), in the state Espírito Santo, Brazil. (n = 27, means ± standard deviation).

| Microbiological soil properties | Cultivation systems | | | |
|---|---|---|---|---|
| | Organic system (OS) | | Conventional system (CS) | |
| | Summer | Winter | Summer | Winter |
| Alkaline phosphatase activity (mg PNF $g^{-1}$ $h^{-1}$)[1] | 3.55 ± 0.34 | 6.04 ± 0.44 | 1.88 ± 0.08 | 4.67 ± 0.30 |
| Acid phosphatase activity (mg PNF $g^{-1}$ $h^{-1}$) | 5.41 ± 0.24 | 5.56 ± 0.27 | 4.27 ± 0.12 | 4.71 ± 0.20 |
| MBC (mg C $g^{-1}$ dry soil)[2] | 0.62 ± 0.02 | 0.60 ± 0.04 | 0.46 ± 0.01 | 0.37 ± 0.02 |
| $CO_2$-C (mg $g^{-1}$ dry soil)[3] | 0.06 ± 0.00 | 0.07 ± 0.01 | 0.03 ± 0.00 | 0.04 ± 0.00 |
| $qCO_2$ (µg $CO_2$-C $mg^{-1}$ MBC $g^{-1}$ dry soil $h^{-1}$)[4] | 3.84 ± 0.20 | 5.17 ± 0.43 | 2.97 ± 0.32 | 4.17 ± 0.36 |

[1] PNF – Phosphonitrophenol. [2] MBC – Microbial biomass carbon. [3] $CO_2$-C – Basal respiration. [4] $qCO_2$ – Metabolic coefficient.

and significant environmental attributes ($p \leq 0.05$) were identified by Redundancy Analysis (RDA), using Monte Carlos permutations, were subsequently used in the PCA as explanatory variables for changes in groups of soil macrofauna, comprehending soil moisture, pH, N, P, S, Cu, B, OM (organic matter), acid phosphatase (ACP), alkaline phosphatase (ALP), and microbial biomass carbon (MBC). This procedure guarantees a robust analysis (Baretta et al. 2010). The same procedures were followed for earthworms.

Afterwards, the environmental variables and macrofaunal groups were inserted into a Canonical Discriminant Analysis (CDA), to learn which of them was relevant in discriminating the cultivation systems (Baretta et al. 2005, 2010). Standardized canonical coefficients (SCC), correlation coefficients (*r*), and parallel discrimination rates (PDR = *r*×SCC) were determined. PDR values indicate weight of each variable or property in discriminating the studied systems. Thus, values below 0.03 (class I) express a very low weight, from 0.04 to 0.09 (class II) a medium weight, between 0.10 and 0.20 (class III) they are considered good indicators, 0.21 to 0.41 (class IV) are very good, 0.42 to 0.80 (class V) are superior, while 0.81 and above (class VI) are excellent (Baretta et al. 2010). The *r* coefficients reflect the individual role for each variable and the standardized canonical coefficient explains separation between the areas according to a multivariate point of view. Generally, PDR is the best one for identification of the weight for each property to discriminate the studied systems. If we find a significant difference of the systems by means of the CDA, we should use a comparison test of means of the SCC values in the canonical function I, using the LSD test ($p < 0.05$).

## Results

### 1. *Density and Shannon's Diversity index*

In total, 3,354 individuals were obtained in this study, and the most representative taxa were Oligochaeta, Coleoptera, Gastropoda, Hymenoptera, Isoptera and Chilopoda, regardless of cultivation system and season (Table 3).

Mean density of the organisms showed no significant variation between cultivation systems (Figure 1A). However, there was a significant difference between seasons in the organic system ($p = 0.009$), with a mean of 344 ± 96 ind. $m^{-2}$ in summer and 1,323 ± 707 ind. $m^{-2}$ in winter. In CS, averages were 3.1 times smaller in summer (300 ± 117 ind. $m^{-2}$) than in winter (916 ± 859 ind. $m^{-2}$). On the other hand, in both seasons, there were over 50% more individuals in OS than in CS, although there was no statistical significance. Nevertheless, this is an indication of a strong tendency of OS to maintain greater numbers of macrofauna individuals, although a relatively great variation between replicates resulted in a lack of mathematical categorization.

Shannon's Diversity index of the organisms showed significant variation between cultivation systems in summer and winter and differences between seasons in the conventional system (Figure 1B).

### 2. *Principal Components Analysis (PCA) (macrofauna)*

The PCA on TSBF sampled macrofauna, in summer, showed that the two first principal components (PC1 and PC2) explain 64.4% of total variability of data, with 36.3% explained by PC1 and 28.1% by PC2.

For OS, in summer, there is greater diversity of organisms of the soil macrofauna than for conventional systems, as can be seen at the left of Figure 2A. One perceives a greater abundance of the different taxonomic groups associated with OS, especially due to higher values of chemical and microbiological properties and OS.

Oligochaeta correlated strongly with acid phosphatase (ACP) and nitrogen (N). Dermaptera and Chilopoda correlated with organic matter, moisture and MBC. Isoptera, Coleoptera, Orthoptera, and some other groups correlate with alkaline phosphatase (ALP). Araneae, Hymenoptera, Hemiptera, Blattodea and Opiliones correlated with S, P and pH. Finally, Gastropoda did not reveal any strong association with any chemical property (Figure 2A).

The organic system correlated with OM, N, P, S, pH and moisture, as well as with MBC, ACP and ALP. This seems to indicate that OS is a friendlier environment for a great many soil macrofaunal groups (Figure 2A). During summer, Diplopoda correlated with B and Cu in CS, where we found smaller numbers of macrofauna (at the right in Figure 2A).

In winter, we also detected a greater diversity of soil macrofaunal groups in OS, when PCA explained 67.6% of total variability of data, with 43.9% for PC1 and 23.7% for PC2 (Figure 2B). Chemical soil properties OM, N, P, S, pH, moisture and microbiological properties MBC, ACP and ALP correlated with OS.

In winter, in OS, Isopoda, Diplopoda, Hemiptera and "others" (non-classified) correlated with P and pH, while Gastropoda, Chilopoda, Blattodea, Hymenoptera, Oligochaeta, Isopoda, and Coleoptera correlated with MBC, ACP, ALP, N, OM and moisture. In CS, however, there was less correlation between macrofaunal groups and chemical properties. We only found some correlation between Araneae, Pseudoscorpionida and Opiliones with Cu, S and B (Figure 2B).

**Table 3.** Soil macrofauna (ind. $m^{-2}$) sampled by TSBF in organic (OS) and conventional (CS) farming system in summer and winter, in Espírito Santo, Brazil.

| Soil macrofauna | Summer | | Winter | |
|---|---|---|---|---|
| | OS | CS | OS | CS |
| Araneae | 32 | 160 | 64 | 112 |
| Blattodea | 112 | 48 | 96 | 0 |
| Chilopoda | 112 | 32 | 1,232 | 128 |
| Coleoptera | 544 | 176 | 672 | 384 |
| Dermaptera | 48 | 0 | 0 | 0 |
| Diplopoda | 0 | 16 | 16 | 0 |
| Gastropoda | 96 | 64 | 2,336 | 256 |
| Hemiptera | 80 | 80 | 16 | 0 |
| Hymenoptera | 1,072 | 800 | 13,376 | 16,032 |
| Isopoda | 0 | 0 | 192 | 32 |
| Isoptera | 304 | 32 | 8,432 | 432 |
| Oligochaeta | 512 | 464 | 1,056 | 336 |
| Opiliones | 16 | 16 | 0 | 368 |
| Orthoptera | 32 | 0 | 0 | 0 |
| Others[1] | 288 | 176 | 2,128 | 496 |
| Pseudoscorpionida | 0 | 0 | 48 | 112 |
| Total | 3,248 | 2,064 | 29,664 | 18,688 |

[1] Others – Sum of other less common groups.

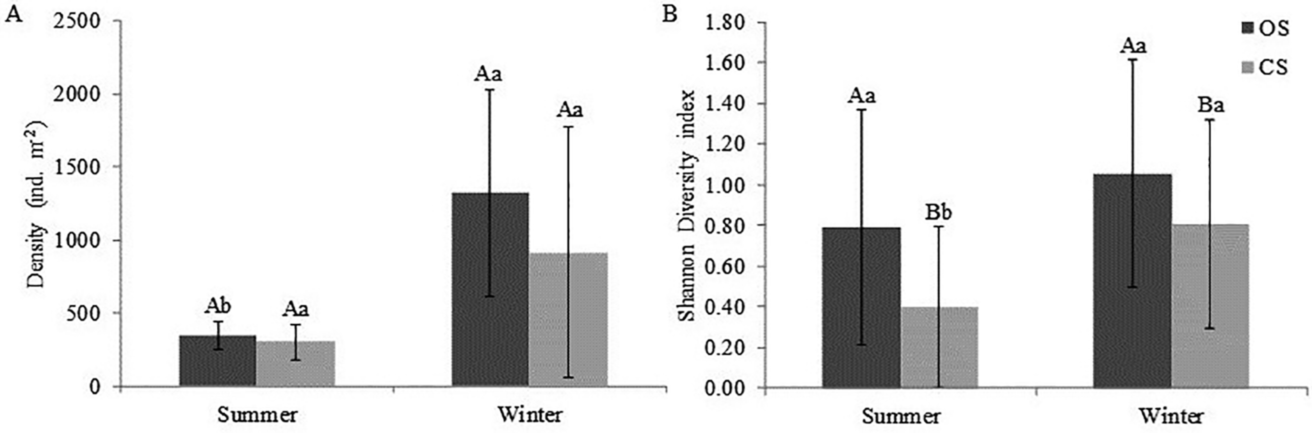

**Figure 1.** Average density and Shannon's Diversity index of the invertebrate macrofauna community in organic (OS) and conventional farming systems (CS) in two seasons, summer and winter, in Espírito Santo, Brazil. Means followed by the same capital letter for different farming systems, in the same season, do not differ by Tukey's test ($p < 0.05$). Means followed by the same lower-case letter, comparing seasons in the same cropping system, do not differ by Tukey's test ($p < 0.05$). (┬) Standard deviation ($n = 27$).

### *3. Canonical Discriminant Analysis (CDA) (Macrofauna)*

The Wilks'*lambda* test for macrofaunal richness and diversity revealed significant differences between management systems and between the seasons. We found high canonical correlations for summer (0.66) and winter (0.73) ($p < 0.0001$) of canonical discriminant functions 1 (CDF1) and 2 (CDF2); therefore, we performed a CDA for each sampling period.

The CDA explained part of the variability present in these cultivation systems regarding macrofauna. High correlation values indicate strong association between abundance of macrofaunal groups and cultivation systems. Standardized canonical coefficients (SCC) for CDF1 and for CDF2 explain the multivariate behavior of different soil macrofaunal groups, which discriminate between OS and CS as response to the independent variables, when analyzed together. CDF1 separated OS from CS (Figures 3A and 3B), and the differences between the SCC values and the centroids were smaller in winter. However, in both, summer and winter, there was no coincidence of the centroids for OS and CS. This polarized distribution of both cultivation systems indicates great dissimilarity regarding numbers of individuals for each soil macrofaunal group in OS and CS.

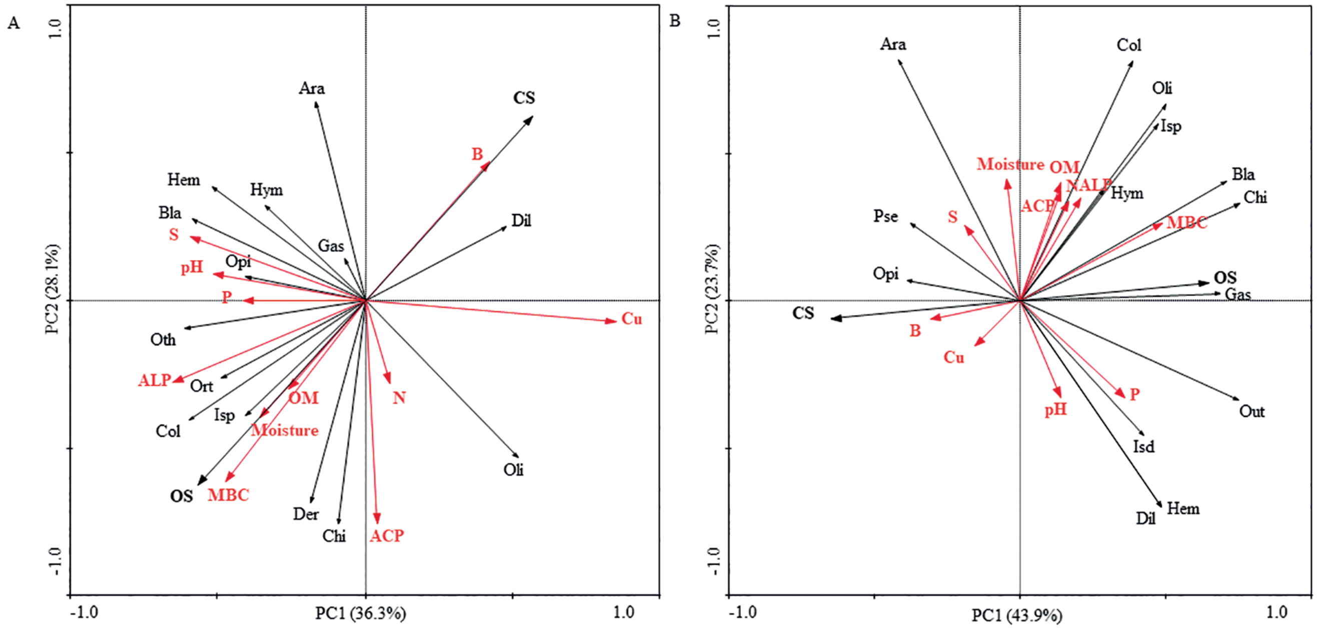

**Figure 2.** Relationship between the principal component 1 (PC1) and the principal component 2 (PC2), taking into account the organic (OS) and conventional farming system (CS), the invertebrate macrofauna community (black arrows) and the selected explicative environmental properties (red arrows) in summer (A) and winter (B), in Espírito Santo, Brazil. Oli: Oligochaeta, Dil: Diplopoda Ara: Araneae, Hym: Hymenoptera, Hem: Hemiptera, Bla: Blattodea, Gas: Gastropoda, Opi: Opiliones, Col: Coleoptera, Isd: Isopoda, Isp: Isoptera, Ort: Orthoptera, Pse: Pseudoscorpionida, Oth: Other, Der: Dermaptera, Chi: Chilopoda. Cu: copper, N: nitrogen, B: boron, S: sulfur, pH: hydrogen potential, P: phosphorus, ALP: alkaline phosphatase, ACP: acid phosphatase, OM: organic matter, MBC: microbial biomass carbon.

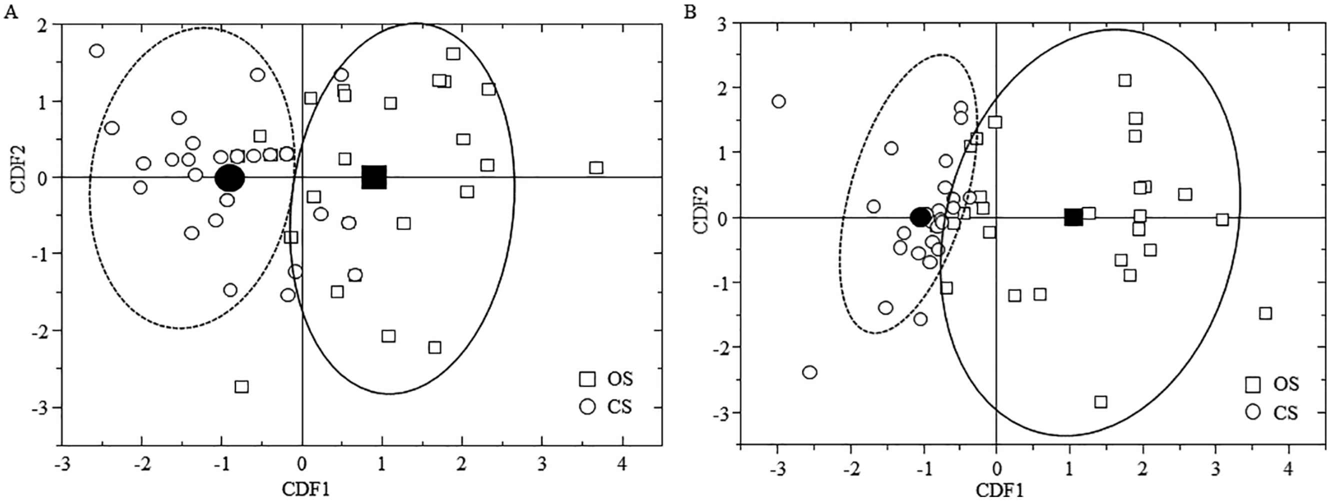

**Figure 3.** Relation between the first and second canonical discriminant function (CDF1 and CDF2) and the mean (centroid, in black) of the standardized canonical coefficients (CCP) for the studied environmental variables, discriminating organic (OS) and conventional farming system (CS), in summer (A) and winter (B), in Espírito Santo, Brazil.

Table 4 displays the potential of each soil macrofaunal property to discriminate soil quality, since they contribute the most for separation between cultivation systems. Positive PDR values indicate separation between systems, while negative values indicate similarities of the property between cultivating systems (Baretta et al. 2010). Orthoptera (0.32), Isoptera (0.24), Coleoptera (0.21) and Araneae (0.14) represent groups which contribute most to separate OS from CS in summer. In winter, among groups with the greatest potential to separate cultivation systems we find Gastropoda (0.45), Chilopoda (0.16) and Oligochaeta (0.13), respectively.

## 4. *Diversity of earthworms (Oligochaeta)*

Earthworm population density, in summer and winter, was higher in OS (59 and 26 ind. m$^{-2}$, respectively) than in CS (13 and 14 ind. m$^{-2}$, respectively) (Table 5). When comparing both sampling periods, within each system, there were differences only for OS (higher density in summer). It is worth noting that most earthworms found in the areas are juveniles, especially in winter samples. Excluding juvenile specimens, three species were present overall, being two in the OS systems and three in CS. CS had the highest species diversity in summer. *Amynthas corticis* was present only in CS and members of the family Megascolecidae

**Table 4.** Parallel discrimination rates (PDR) calculated by multiplying the standardized canonical coefficients (SCC) and the correlation coefficients (*r*) (PDR = *r*×SCC) for groups sampled by TSBF in organic (OS) and conventional farming systems (CS) in summer and winter, in Espírito Santo, Brazil.

| **Macrofauna groups** | **CDF1[1]** | | | **CDF1** | | |
|---|---|---|---|---|---|---|
| | **Summer** | | | **Winter** | | |
| | ***r*** | **SCC** | **PDR** | ***r*** | **SCC** | **PDR** |
| Araneae | -0.52 | -0.26 | **0.14** | -0.23 | -0.12 | 0.03 |
| Blattodea | 0.41 | 0.22 | 0.09 | 0.02 | 0.30 | 0.01 |
| Chilopoda | 0.32 | 0.26 | 0.08 | 0.39 | 0.42 | **0.16** |
| Coleoptera | 0.52 | 0.40 | **0.21** | 0.16 | 0.21 | 0.03 |
| Dermaptera | 0.41 | 0.21 | 0.09 | 0.00 | 0.00 | 0.00 |
| Diplopoda | 0.21 | -0.16 | -0.03 | 0.37 | 0.13 | 0.05 |
| Gastropoda | 0.15 | 0.07 | 0.01 | 0.80 | 0.56 | **0.45** |
| Hemiptera | 0.02 | 0.00 | 0.00 | 0.31 | 0.13 | 0.04 |
| Hymenoptera | -1.28 | 0.06 | -0.08 | -0.05 | -0.02 | 0.00 |
| Isopoda | 0.00 | 0.00 | 0.00 | -0.25 | 0.22 | -0.06 |
| Isoptera | 0.54 | 0.45 | **0.24** | 0.22 | 0.15 | 0.03 |
| Oligochaeta | -0.47 | 0.03 | -0.01 | 0.39 | 0.33 | **0.13** |
| Opiliones | -0.52 | 0.00 | 0.00 | -0.25 | -0.24 | 0.06 |
| Orthoptera | 1.44 | 0.23 | **0.32** | 0.00 | 0.00 | 0.00 |
| Pseudoscorpionida | 0.00 | 0.00 | 0.00 | -0.13 | -0.16 | 0.02 |
| Others[2] | -0.42 | 0.13 | -0.06 | 0.22 | 0.22 | 0.05 |

[1] CDF – Canonical Discriminant Functions. [2] Others – Sum of other less common groups. Values in bold represent the most important macrofauna groups to discriminate areas of study.

**Table 5.** Earthworm species (ind. $m^{-2}$) sampled by TSBF in organic (OS) and conventional farming systems (CS) in summer and winter, in Espírito Santo, Brazil.

| **Family/Genus/Species** | **Native/Exotic** | **Summer** | | **Winter** | |
|---|---|---|---|---|---|
| | | **OS[2]** | **CS[3]** | **OS** | **CS** |
| Glossoscolecidae | | | | | |
| *Pontoscolex corethrurus* (Müller, 1857) | Exotic | 73.6 | 14.4 | 1.6 | 0 |
| Megascolecidae | | | | | |
| Megascolecidae (Family) | Exotic | 0 | 0 | 1.6 | 0 |
| *Amynthas* sp. (Genus) | Exotic | 4.8 | 1.6 | 0 | 0 |
| *Amynthas corticis* (Kinberg 1867) | Exotic | 0 | 1.6 | 0 | 0 |
| Acanthodrilidae | | | | | |
| *Dichogaster gracilis* (Michaelsen, 1892) | Exotic | 4.8 | 1.6 | 0 | 0 |
| Juveniles[4] | | 11.2 | 1.6 | 38.4 | 22.4 |
| Total | | 94.4 | 20.8 | 41.6 | 22.4 |

[1] Number of individuals converted to individuals $m^{-2}$. [2] OS – Organic system. [3] CS – Conventional system. [4] Young earthworms not possible to identify at the taxonomic level.

only in OS. Native species were not found neither in organic nor in conventional systems. All species found are peregrine or exotic.

## 5. *Principal Components Analysis (Oligochaeta)*

The PCA on earthworms sampled with TSBF, in summer, showed that the two first principal components (PC1 and PC2) explain 89.9% of the total variability of data, with 70.4% explained by PC1 and 14.5% by PC2 (Figure 4A). In summer, properties as moisture, OM, N, as well as ACP, ALP and MBC correlated more with OS, localized at the right side of the graph (Figure 4A). Acid phosphatase, OM, MBC, N and moisture were associated with *P. corethrurus* (Pcor), while ALP was associated preferentially with the juvenile earthworms. *D. gracilis* (Dgra) and individuals of the genus *Amynthas* sp. (Asp) showed association with P and with soil pH. In opposition, the micronutrients B and Cu showed more association with CS and with the earthworm *A. corticis*.

In winter, the PCA explained 93.3% of the total variability of the data, with 74.5% for PC1 and 18.8% for PC2 (Figure 4B). In winter, OS and CS can be seen localized in the middle of the graph, quite different from what happened in summer; this demonstrates that changes in chemical and microbiological attributes occurred related to the seasons of the year (Figure 4B). Nevertheless, OS always correlated more with these soil attributes. The juvenile earthworms (Juv) and *P. corethrurus*

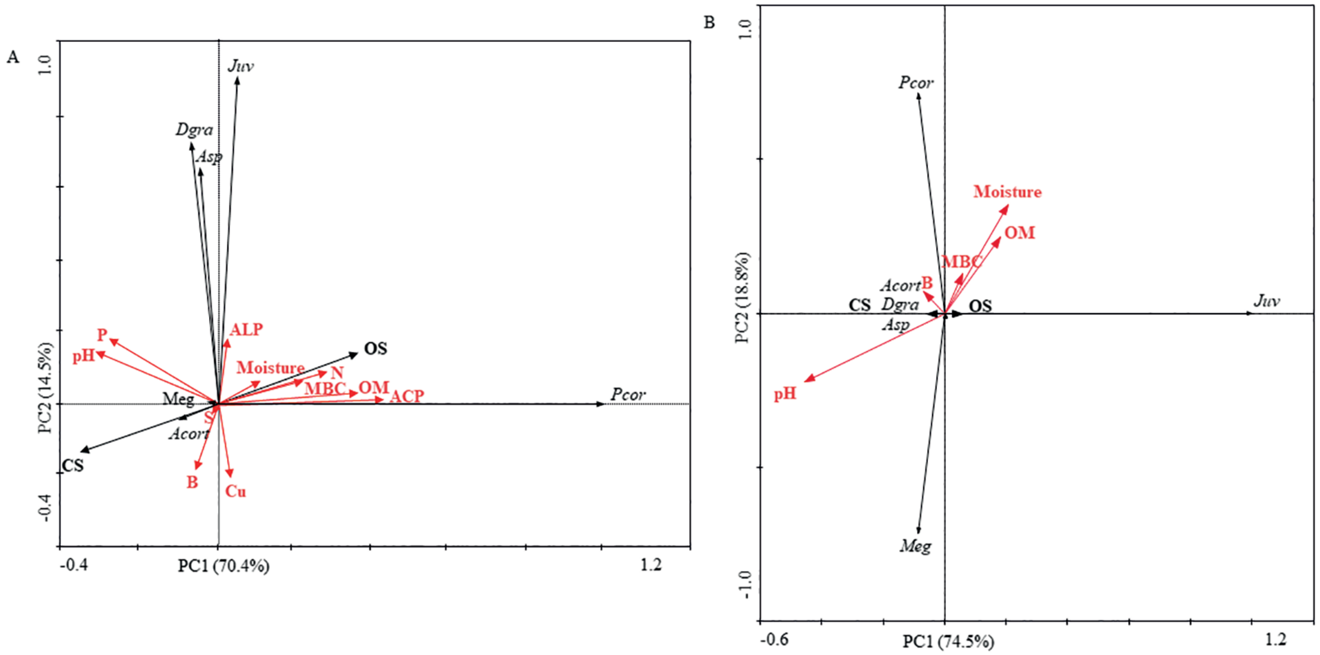

**Figure 4.** Relationship between the principal component 1 (PC1) and the principal component 2 (PC2), taking into account the organic (OS) and conventional farming system (CS), the earthworms (→) and the selected explicative environmental attributes (→) in summer (A) and winter (B), in Espírito Santo, Brazil. *Acort*: *Amynthas corticis* (Megascolecidae), *Asp*: *Amynthas* (Genus), *Dgra*: *Dichogaster gracilis* (Acanthodrilidae), Meg: Megascolecidae (Family), *Pcor*: *Pontoscolex corethrurus*. Cu: cupper, N: nitrogen, B: boron, S: sulfur, pH: hydrogen potential, P: phosphorus, ALP: alkaline phosphatase, ACP: acid phosphatase, OM: organic matter, MBC: microbial biomass carbon.

associated more with OM, moisture, and MBC in OS. Meanwhile the earthworms *A. corticis* (Acort), *D. gracilis* (Dgra) and other species of the genus *Amynthas* (Asp) assumed a more central position on the graph, without any close association with either one of the cultivation systems. pH correlated with earthworms of the family Megascolecidae.

## Discussion

### 1. *Macrofauna*

In OS, we found a greater density of soil macrofauna in winter, a result that differs from most references in the literature, where the normal is to find a greater density in summer. Pimentel et al. (2011) report a greater density in coffee plantations in summer, while Fernandes et al. (2013) highlight a greater mobility of soil fauna in coffee plantations in the rainy season. Silva et al. (2012) mention that summer is more adequate for reproduction, resulting in a greater numbers of soil fauna community, so that most authors disagree from our results.

We assume that the organic management contributes to greater soil health and therefore presents greater ecological diversity and a greater functionality, since it avoids agricultural practices that have a negative impact on the environment (Rahmann 2011). Organic agricultural management produces a more heterogeneous, although stable environment, with greater nutritional equilibrium and with a greater offer of different foodstuffs for the soil macrofaunal community, as well as a greater number of habitats and ecological niches (Siegrist et al. 1998). For these reasons, somehow, it is natural to find a greater macrofaunal diversity in OS, although they do not completely explain the greater macrofaunal density in winter. In winter, obviously, the temperatures and rainfall were lower than in summer (Figure 1A), and these values lied below the optimum for the macrofaunal metabolism in winter. However, if considering the extreme dryness (see Material and Methods section 1 for climatic data - there was a steep decrease in precipitation, much more than in temperature during winter), it becomes understandable that OS, with much higher moisture in soil, can be more favorable for macrofaunal survival and even for reproduction during this period than CS. Thus, perhaps, we should not consider that soil conditions were optimal for macrofauna in OS during winter, but that they were worse in CS during this time. Teixeira et al. (2014) corroborate our study, since they report similar differences in macrofauna in an intercropped coffee plantation in another region of the state of Espírito Santo. Shannon's indices follow the same reasoning and confirm that the organic system provides greater diversity of macrofauna groups, showing higher means in both seasons (Figure 1). We attribute the increase of this index in winter for CS to a smaller temperature oscillation.

Oligochaeta sometimes is one of the most abundant taxonomic groups of soil macrofauna in agriculture (Lebbink et al. 1994, Zwart et al. 1994, Bartz et al. 2013, Rosa et al. 2015), however, in our research, the number of earthworms found was rather small, although the low number is partially compensated by their relatively greater weight. Reasons for these differences may be due to the natural and anthropogenic history of the areas, and the presence/absence of exotic or invasive species (Decaëns et al. 2004).

A fact that possibly contributed to the greater abundance of macrofauna in OS is that, shortly before sampling, the OS soils received organic compost incorporation. Some earthworm species are also important for the distribution and incorporation of organic materials into soil, what may have contributed to an overall increase in macrofauna, because of better access to energetic food sources and to moisture (Mäder et al. 2002, Masto et al. 2008).

In OS, we identified the presence of Orthoptera and Dermaptera only in summer, and Isopoda and Pseudoscorpionida only in winter (Figure 2). All these groups are important members of the food chain for OM degradation in soil (Bird et al. 2000, Morón-Ríos et al. 2010, Ponce et al. 2011).

Results of PCA and CDA (Figure 2 and Table 4, respectively) suggest that the micronutrients Cu and B may have been a limiting factor for macrofauna, especially for earthworms, in CS. Some pesticides used in coffee plantations in CS have Cu in their composition, and increased amounts of this element may cause negative impacts on earthworms and many other soil invertebrates. In minimum tillage and conventional coffee plantations, respectively, Zaller et al. (2014) and Bartz et al. (2009) report some evidence of detrimental effects of the herbicide glyphosate and of copper-based fungicides on earthworms.

Microbial biomass carbon is one of the most responsive properties to the organic cultivation and often there is a close similarity between MBC values in OS and in the Atlantic Forest in Brazil (Partelli et al. 2012). There are reports on increases of MBC in organic cultivation systems, and considered to be very important for OS, as highlighted by other authors (Maluche-Baretta et al. 2006). In CS, however, as shown by the PCA, there was a positive correlation with mineral nutrients, B in summer and Cu and B in winter. Silva et al. (2012, 2013) and Ferreira et al. (2013) report an increase of soil pH up to 6.5 in coffee plantations under OS, which coincides with our results (Table 1). Several other authors detected an increase of soil CEC, P, MBC and pH in organic coffee plantations (Pimentel et al. 2006, Fernandes et al. 2013).

In OS, there was also a correlation with P, and it is quite common to find greater P availability, probably related to an increase in acid and alkaline phosphatases (Nannipieri et al. 2012), while in CS, with systematic applications of mineral fertilizers and pesticides, we find an inhibition of phosphatase activities (Nannipieri et al. 2011, 2012). Generally, soil OM, clay content and moisture correlate with OS, and these correlate with soil fertility in coffee plantations (Silva & Lima 2013, Machado et al. 2014). As a rule, OS also has higher numbers of macrofauna when compared with CS. Soil under long-term OS usually presents better properties for coffee plantations, in comparison with CS (Velmourougane 2016) and has higher values for most of the biological properties, including higher populations of Oligochaeta (Lammel et al. 2015).

Regardless of the sample collection period, we observed, through PDR values, that macrofauna was effective in separating the areas studied, showing potential as indicators. Baretta et al. (2010) also found positive values of PDR coefficients for Chilopoda, Isoptera and Pereira et al. (2017) found for Chilopoda, Oligochaeta and Gastropoda, considered an indicator of changes in natural and replanted areas with Araucaria. The other groups of macrofauna were less sensitive, with lower values of PDR, and they contributed less to the function recommended for separation between the areas (Table 2). This result confirms recommendation this groups, besides Araneae, Coleoptera, Orthoptera, as important in discriminating between organic and conventional systems, because they provided separation between the areas.

### 2. *Oligochaeta*

In conventional agricultural systems with the highest use intensity, earthworm communities often are harmed directly by the aggressive tillage practices or indirectly through decreases in food supply (Falco et al. 2015). OS coffee plantations resulted in an evident increase of earthworm abundance when compared to CS; thus, Bartz et al. (2009) found higher numbers and diversity of adult and juvenile earthworms in organic coffee plantations in winter (July). In our study, we found greater adult earthworm density in summer, whereas, in winter, there was a greater contribution of juveniles in both cultivation systems (Table 5), showing the importance of the addition of young specimens to the edaphic community.

The abundance of earthworm communities greatly decreased between the two sampling seasons in OS, while in CS it remained the same (Table 5). The climatic conditions may be prone to explain these results. Considering the influence of rainfall for soil moisture and total abundance of earthworms in the systems, there was a possible effect of rainfall on temporal changes between the two periods (Figure 1A). Rainfall may have been less beneficial for earthworms in the CS than in OS, probably because the latter was able to hold a much greater water volume (Pelosi et al. 2015).

No doubt, history of the areas and chemical and physical properties (Table 1) influenced distribution of earthworms and dominance of *P. corethrurus* in OS. Since use of pesticides affects presence of earthworms, this may partially explain their rarity in CS. Two earthworm species, *P. corethrurus* (soil feeding) and *A. corticis* (litter feeding), were recorded in shaded coffee plantations without glyphosate-based herbicide treatment, whereas the latter species was absent from plots with glyphosate-based herbicides (García-Pérez et al. 2014), however, in our research, the only individual of the species *A. corticis* was detected in CS (Table 5).

In our study, fertilizer and pesticide applications and variations in organic matter input could have contributed to the differences found in earthworm densities between organic and conventional systems (Tables 1 and 2). In fact, differences found in earthworm density would be attributable to fertilization and pesticides, which varied between treatments (Sánchez-de León et al. 2006). Organic management practices are particularly favorable for increasing *P. corethrurus* and *Amynthas* sp. populations (Bartz et al. 2009). Aquino et al. (2008), when surveying earthworm populations, also found great diversity, including *P. corethrurus,* which is an exotic and cosmopolitan species. The presence of other exotic species, as *A. corticis* and *D. gracilis*, as well as some specimens of the family Megascolecidae and of the genus *Amynthas* may represent a problem at the ecological level, because these organisms are well distributed and very adaptable to different environments, posing a risk to the survival of native species (Brown et al. 2006). In intensive agricultural management, the earthworm community is mainly composed of exotic species given their adaptability (Fragoso 2001, Grosso et al. 2006). Dominance of introduced species is another characteristic of highly disturbed sites (Winsome et al. 2006, Chan & Barchia 2007). In both evaluated coffee cultivation systems exotic earthworm species predominated, and this may pose a risk to the survival of native species however this a generalized fact in Brazilian agricultural soils. Soil use intensity is also a probable mechanism to explain the presence of a few species (e.g. *P. corethrurus*, *A. corticis*, *D. gracilis*), adapted to a great environmental variability (Falco et al. 2015).

Soil attributes measured in the present study are known to affect abundance of earthworm species; the relatively pronounced variation from organic to conventional systems (Table 1), likely had an influence on the variation in earthworm species abundance, added to differences in soil physical attributes (e.g., bulk density), which could help to explain this variation. We recognize that the role of environmental variability as predictor of organism diversity and abundance varies with the scale of ecological studies (Ettema & Wardle 2002). Soil use intensity was also a probable mechanism to explain the presence of a few species (e.g. *P. corethrurus*, *A. corticis*, *D. gracilis*), adapted to a great environmental variability (Falco et al. 2015).

## Conclusions

The study provided significant data on the soil arthropod community of the organic and conventional management system adopted in coffee and its relationship with management and soil properties. Abundance of macrofauna groups suffers relatively little influence of the agricultural management system adopted in coffee cultivation, but OS provided greater diversity of taxonomic groups than CS. The soil macrofauna groups Oligochaeta, Coleoptera, Gastropoda, Hymenoptera, Isoptera and Chilopoda were most abundant in organic cultivation systems. Chemical and microbiological soil attributes interfere on the communities of soil fauna organisms in soil.

In coffee plantations, earthworms are good indicators and discriminate between the organic and conventional cultivation system, and both systems has a dominance of exotic earthworm.

Multivariate statistical analyses, as principal components analysis and canonical discriminant analysis, are adequate tools to evaluate ecological parameters in coffee agroecosystems. The application of the PDR coefficient, which is a result of the CDA, has proved to be a powerful tool for the selection of soil quality indicators, and the most promising properties for separation between the areas with coffee plantations were Araneae, Chilopoda, Coleoptera, Gastropoda, Isoptera, Oligochaeta e Orthoptera.

## Acknowledgements

J. B. dos Santos thanks the Espírito Santo Research Support and Innovation Foundation (FAPES) for a post-graduate research grant. E. J. B. N. Cardoso and D. Baretta acknowledges a research grant from the Brazilian Research Council (CNPq). We thank L. F. Baldesin and P. R. Alves, both of the University of São Paulo, Brazil, for their help with the chemical analyses and providing references on coffee plantations, respectively. Our gratefulness to M. L. C. Bartz of the University Positivo, in Paraná, for help with the taxonomy of the earthworms.

## Authors' Contributions

Janaina Biral dos Santos: responsible for sampling of macrofauna and for data collection, contributed to manuscript preparation, critical revision, and adding intellectual content.

Alessandro Coutinho Ramos and Romildo Azevedo Júnior: helped in defining areas and in sampling. The first one was co-responsible for the general outline of the research project, while the second assisted with laboratory procedures, data collection, and preparation of figures.

Luís Carlos Iuñes de Oliveira Filho: contribution to data analysis and interpretation, contribution to critical revision, adding intellectual content.

Dilmar Baretta and Elke Jurandy Bran Nogueira Cardoso: substantial contribution in the concept and design of the study, contribution to data analysis and interpretation, contribution to manuscript preparation, contribution to critical revision, adding intellectual content.

## Conflicts of interest

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

## References

ALBRECHT, M., SCHIMID, B., OBRIST, M.K., SCHÜPBACH, B., KLEIJN, D. & DUELLI, P. 2010. Effects of ecological compensation meadows on arthropod diversity in adjacent intensively managed grassland. Biol. Conserv. 143:642-649.

ALEF, K. 1995. Soil respiration. In Methods in Applied Soil Microbiology and Biochemistry (K. Alef & P. Nannipieri, eds.). Academic Press, London, p.234-245.

ANDERSON, J.M. & INGRAM, J.S.I. 1993. Tropical Soil Biology and Fertility: A Handbook on Methods, 2 ed. CAB International, Wallingford.

ANDERSON, T.H. & DOMSCH, K.H. 1993. The metabolic quotient for $CO_2$ ($qCO_2$) as a specific activity parameter to assess the effects of environmental conditions, such as pH, on the microbial biomass of forest soils. Soil Biol. Biochem. 25:393-395.

ANTUNES, S.C., CASTRO, B.B., MOREIRA, C., GONÇALVES, F. & PEREIRA, R. 2013. Community-level effects in edaphic fauna from an abandoned mining area: integration with chemical and toxicological lines of evidence. Ecotoxicol. Environ. Saf. 88:65-71.

AQUINO, A.M., MELOVIRGÍNIO FILHO, E., RICCI, M.S.F. & CASANOVES, F. 2008. Populações de minhocas em sistemas agroflorestais com café convencional e orgânico. Cienc. agrotec. 32:1184-1188.

AZEVEDO JUNIOR, R.R., SANTOS, J.B., BARETTA, D., RAMOS, A.C. & CARDOSO, E.J.B.N. 2017. Chemical and microbiological soil properties in organic and conventional management systems of *Coffea arabica* L. J. Plant Nutr. 40:2076-2086.

BARETTA, D., BROWN, G.G. & CARDOSO, E.J.B.N. 2010. Potencial de la macrofauna y de otras variables edáficas como indicadoras de la calidad del suelo en áreas con *Araucaria angustifolia*. Acta Zool. Mex. 26, 135-150.

BARETTA, D., BROWN, G.G., JAMES, S.W. & CARDOSO, E.J.B.N. 2007. Earthworm populations sampled using collection methods in Atlantic forests with *Araucaria angustifolia*. Sci. Agric. 64:384-392.

BARETTA, D., SANTOS, J.C.P., FIGUEIREDO, S.R. & KLAUBERG-FILHO, O. 2005. Efeito do monocultivo de *Pinus* e da queima do campo nativo em atributos biológicos do solo no Planalto sul Catarinense. Rev. Bras. Cienc. Solo 29:715-724.

BARETTA, D., SANTOS, J.C.P., SEGAT, J.C., GEREMIA, E.V., OLIVEIRA FILHO, L.C.I. & ALVES, M.V. 2011. Fauna edáfica e qualidade do solo. In Tópicos em Ciência do Solo (O. Klauberg-Filho, Á.L. Mafra & L.C. Gatiboni, eds.). Sociedade Brasileira de Ciência do Solo, Viçosa, p.119-170.

BARTZ, M.L.C., BROWN, G.G., PASINI, A., FERNANDES, J.D.O., CURMI, P., DORIOZ, J. & RALISCH, R. 2009. Earthworm communities in organic and conventional coffee cultivation. Pesq. agropec. bras. 44:928-933.

BARTZ, M.L.C., BROWN, G.G., ROSA, M.G., KLAUBERG FILHO, O., JAMES, S.W., DECAËNS, T. & BARETTA, D. 2014. Earthworm richness in land-use systems in Santa Catarina, Brazil. Appl. Soil Ecol. 83:59-70.

BARTZ, M.L.C., PASINI, A. & BROWN, G.G. 2013. Earthworms as soil quality indicators in Brazilian no-tillage systems. Appl. Soil Ecol. 69:39-48.

BIAGGINI, M., CONSORTI, R., DAPPORTO, L., DELLACASA, M., PAGGETTI, E. & CORTI, C. 2007. The taxonomic level order as a possible tool for rapid assessment of Arthropod diversity in agricultural landscapes. Agric. Ecosyst. Environ. 122:183-191.

BIRD, S., COULSON, R.N. & CROSSLEY JR., D.A. 2000. Impacts of silvicultural practices on soil and litter arthropod diversity in a Texas pine plantation. For. Ecol. Manage. 131:65-80.

BITYUTSKII, N., KAIDUN, P. & YAKKONEN, K. 2016. Can earthworms alleviate nutrient disorders of plants subjected to calcium carbonate excess? Appl. Soil Ecol. 98:20-29.

BROWN, G., PASHANASI, B., VILLENAVE, C., PATRÓN, J.C., SENAPATI, B., GIRI, S., BAROIS, I., LAVELLE, P., BLANCHART, E., BLAKEMORE, R.J., SPAIN, A.V. & BOYER, J. 1999. Effects of earthworms on plant production in the tropics. In Earthworm Management in Tropical Ecosystems (P. Lavelle, L. Brussaard & P.F. Hendrix, eds.). CABI, Wallingford, p.87-147.

BROWN, G.G., BAROIS, I. & LAVELLE, P. 2000. Regulation of soil organic matter dynamics and microbial activity in the drilosphere and the role of interactions with other edaphic functional domains. Eur. J. Soil Biol. 36:177-198.

BROWN, G.G., JAMES, S.W., PASINI, A., NUNES, D.H., BENITO, N.P., MARTINS, P.T. & SAUTTER, K.D. 2006. Exotic, peregrine, and invasive earthworms in Brazil: Diversity, distribution, and effects on soils and plants. Caribb. J. Sci. 42:339-358.

CARDOSO, E.J.B.N., VASCONCELLOS, R.L.F., BINI, D., MIYAUCHI, M.Y.H., SANTOS, C.A., ALVES, P.R.L., PAULA, A.M., NAKATANI, A.S., PEREIRA, J.M. & NOGUEIRA, M.A. 2013. Soil health: looking for suitable indicators. What should be considered to assess the effects of use and management on soil health? Sci. Agric. 70:274-289.

CHAN, K.Y. & BARCHIA, I., 2007. Soil compaction controls the abundance, biomass and distribution of earthworms in a single dairy farm in south-eastern Australia. Soil Tillage Res. 94:75-82.

COTES, B., CAMPOS, M., PASCUAL, F., GARCÍA, P.A. & RUANO, F. 2010. Comparing taxonomic levels of epigeal insects under different farming systems in Andalusian olive agroecosystems. Appl. Soil Ecol. 44:228-236.

DECAËNS, T., JIMÉNEZ, J.J., BARROS, E., CHAUVEL, A., BLANCHART, E., FRAGOSO, C. & LAVELLE, P. 2004. Soil macrofaunal communities in permanent pastures derived from tropical forest or savanna. Agric. Ecosyst. Environ. 103:301-312.

EFFGEN, T.A.M., PASSOS, R.R., ANDRADE, F.V., LIMA, J.S.S., REIS, E.F. & BORGES, E.N. 2012. Propriedades físicas do solo em função de manejos em lavouras de cafeeiro Conilon. Rev. Ceres 59:414-421.

EFFGEN, T.A.M., PASSOS, R.R., LIMA, J.S.S., BORGES, E.N., DARDENGO, M.C.J.D. & REIS, E.F. 2008. Atributos químicos do solo e produtividade de lavouras de cafeeiro Conilon submetidas a diferentes tratos culturais no sul do estado do Espírito Santo. Biosci. J. 24:7-18.

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária 1997. Manual de métodos de análise de solo. Embrapa Solos, Rio de Janeiro.

ETTEMA, C.H. & WARDLE, D.A. 2002. Spatial soil ecology. Trends Ecol. Evol. 17:177-183.

FALCO, L.B., SANDLER, R., MOMO, F., DI CIOCCO, C., SARAVIA, L. & COVIELLA, C. 2015. Earthworm assemblages in different intensity of agricultural uses and their relation to edaphic variables. PeerJ 3:e979.

FERNANDES, A.L.T., SANTINATO, F., FERREIRA, R.T. & SANTINATO, R. 2013. Adubação orgânica do cafeeiro, com uso do esterco de galinha, em substituição à adubação mineral. Coffee Sci. 8:486-499.

FERREIRA, J.T.P., FERREIRA, E.P., OLIVEIRA, M.L., SILVA, G.S., OLIVERIA FILHO, J.S. & SANTOS, J.W.G. 2013. Avaliação da fertilidade dos solos cultivados com café Conilon (*Coffea canephora*) no município de Santa Teresa - ES. Encicl. Biosf. 9: 356-366.

FRAGOSO, C. 2001. Las lombrices de tierra de México (Annelida, Oligochaeta): diversidad, Ecología y manejo. Acta Zool. Mex. 131-171.

FREDERICO, S. 2013. Cafeicultura Científica Globalizada e as Montanhas Capixabas: a produção de café Arábica nas regiões do Caparaó e Serrana do Espírito Santo. Rev. Soc. Nat. 25:7-20.

GARCÍA-PÉREZ, J.A., ALARCÓN-GUTIÉRREZ, E., PERRONI, Y. & BAROIS, I. 2014. Earthworm communities and soil properties in shaded coffee plantations with and without application of glyphosate. Appl. Soil Ecol. 83: 230-237.

GKISAKIS, V., VOLAKAKIS, N., KOLLAROS, D., BÀRBERI, P. & KABOURAKIS, E.M. 2016. Soil arthropod community in the olive agroecosystem: Determined by environment and farming practices in different management systems and agroecological zones. Agric. Ecosyst. Environ. 218:178-189.

GLOVER, J.D., REGANOLD, J.P. & ANDREWS, P.K. 2000. Systematic method for rating soil quality of conventional, organic, and integrated apple orchards in Washington State. Agric. Ecosyst. Environ. 80:29-45.

GROSSO, E., JORGE, G. & BROWN, G.G. 2006. Exotic and Native Earthworms in Various Land Use Systems of Central, Southern and Eastern Uruguay. Caribb. J. Sci. 42:294-300.

GÜNDOĞMUŞ, E. 2006. Energy use on organic farming: A comparative analysis on organic versus conventional apricot production on small holdings in Turkey. Energ. Convers. Manage. 47:3351-3359.

HOLE, D.G., PERKINS, A.J., WILSON, J.D., ALEXANDER, I.H., GRICE, P. V. & EVANS, A.D. 2005. Does organic farming benefit biodiversity? Biol. Conserv. 122:113-130.

IUSS WORKING GROUP WRB 2015. World Reference Base for Soil Resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome, p.203.

KASCHUK, G., ALBERTON, O. & HUNGRIA, M. 2010. Three decades of soil microbial biomass studies in Brazilian ecosystems: Lessons learned about soil quality and indications for improving sustainability. Soil Biol. Biochem. 42:1-13.

LAMINE, C. & BELLON, S. 2009. Conversion to Organic Farming: A Multidimensional Research Object at the Crossroads of Agricultural and Social Sciences - A Review. Sustain. Agric. 29:97-112.

LAMMEL, D.R., AZEVEDO, L.C.B., PAULA, A.M., ARMAS, R.D., BARETTA, D. & CARDOSO, E.J.B.N. 2015. Microbiological and faunal soil attributes of coffee cultivation under different management systems in Brazil. Brazilian J. Biol. 75:894-905.

LAVELLE, P., PASHANASI, B., CHARPENTIER, F., GILOT, C., ROSSI, J.P., DEROUARD, L., ANDRE, J., PONGE, J.F. & BERNIER, N. 1999. Large-scale effects of earthworms on soil organic matter and nutrient dynamics. In Earthworm Ecology (C.A. Edwards, ed.). St. Lucie Press, Boca Raton, p.103-122.

LAVELLE, P. & SPAIN, A.V. 2001. Soil Ecology. 1 ed. Kluwer Scientific, Amsterdam.

LEBBINK, G., VAN FAASSEN, H.G., VAN OUWERKERK, C. & BRUSSAARD, L. 1994. The Dutch Programme on Soil Ecology of Arable Farming Systems: Farm management monitoring programme and general results. Agric. Ecosyst. Environ. 51:7-20.

MACHADO, L.V., RANGEL, O.J.P., MENDONÇA, E.S., MACHADO, R.V. & FERRARI, J.L. 2014. Fertilidade e compartimentos da matéria orgânica do solo sob diferentes sistemas de manejo. Coffee Sci. 9:2897-299.

MÄDER, P., FLIESSBACH, A., DUBOIS, D., GUNST, L., FRIED, P. & NIGGLI, U. 2002. Soil fertility and biodiversity in organic farming. Science 296:1694-1697.

MALUCHE-BARETTA, C.R.D., AMARANTE, C.V.T. & KLAUBERG FILHO, O. 2006. Análise multivariada de atributos do solo em sistemas convencional e orgânico de produção de maçãs. Pesq. agropec. bras. 41:1531-1539.

MASTO, R.E., CHHONKAR, P.K., SINGH, D. & PATRA, A.K. 2008. Changes in soil quality indicators under long-term sewage irrigation in a sub-tropical environment. Environ. Geol. 56:1237-1243.

MOHAMEDOVA, M. & LECHEVA, I. 2013. Effect of heavy metals on microarthropod community structure as an indicator of soil ecosystem health. Sci. P. Series A. Agron. LVI:73-78.

MORÓN-RÍOS, A., RODRÍGUEZ, M.Á., PÉREZ-CAMACHO, L. & REBOLLO, S. 2010. Effects of seasonal grazing and precipitation regime on the soil macroinvertebrates of a Mediterranean old-field. Eur. J. Soil Biol. 46:91-96.

NANNIPIERI, P., GIAGNONI, L., LANDI, L. & RENELLA, G. 2011. Role of Phosphatase Enzymes in Soil. In Phosphorus in Action: Biological Processes in Soil Phosphorus Cycling (E.K. Bünemann, A. Oberson & E. Frossard, eds.). Springer-Verlag Berlin Heidelberg, Berlin, p.215-243.

NANNIPIERI, P., GIAGNONI, L., RENELLA, G., PUGLISI, E., CECCANTI, B., MASCIANDARO, G., FORNASIER, F., MOSCATELLI, M.C. & MARINARI, S. 2012. Soil enzymology: classical and molecular approaches. Biol. Fertil. Soils 48:743-762.

ODUM, E.P. 1983. Ecologia. 1 ed., Guanabara, Rio de Janeiro.

PARTELLI, F.L., VIEIRA, H.D., FERREIRA, E.P. DE B., VIANA, A.P., MARTINS, M.A. & URQUIAGA, S. 2012. Chemical and Microbiological Soil Characteristics under Conventional and Organic Coffee Production Systems. Commun. Soil Sci. Plant Anal. 43:847-864.

PARTELLI, F.L., VALICHESKI, R.R., VIEIRA, H.D., GONTIJO, I., & BRITO FERREIRA, E.P. 2016. Physical soil attributes of conilon coffee (*Coffea canephora*) under organic and conventional management systems. Aust. J. Crop Sci. 10(5):646-653.

PELOSI, C., BERTRAND, M., THÉNARD, J. & MOUGIN, C. 2015. Earthworms in a 15 years agricultural trial. Appl. Soil Ecol. 88:1-8.

PIMENTEL, M.S., AQUINO, A.M., ELIZABETH, M., CORREIA, F., COSTA, J.R., FREIRE, S. & DE-POLLI, H. 2006. Atributos biológicos do solo sob manejo orgânico de cafeeiro, pastagem e floresta em região do médio Paraíba Fluminense-RJ. Coffee Sci. 1:85-93.

PIMENTEL, M.S., DE-POLLI, H., AQUINO, A.M. DE, CORREIA, M.E.F. & ROUWS, J.R.C. 2011. Bioindicators of soil quality in coffee organic cultivation systems. Pesq. agropec. bras. 46:545-552.

PONCE, C., BRAVO, C., DE LEÓN, D.G., MAGAÑA, M. & ALONSO, J.C. 2011. Effects of organic farming on plant and arthropod communities: A case study in Mediterranean dryland cereal. Agric. Ecosyst. Environ. 141:193-201.

RAHMANN, G. 2011. Biodiversity and organic farming: What do we know? Agric. For. Res. 3:189-208.

ROSA, M.G., KLAUBERG FILHO, O., BARTZ, M.L.C., MAFRA, Á.L., SOUSA, J.P.F.A. & BARETTA D. 2015. Macrofauna edáfica e atributos físicos e químicos em sistemas de uso do solo no Planalto Catarinense. Rev. Bras. Cienc. Solo. 39:1544-1554.

ROUSSEAU, L., FONTE, S.J., TÉLLEZ, O., VAN DER HOEK, R. & LAVELLE, P. 2013. Soil macrofauna as indicators of soil quality and land use impacts in smallholder agroecosystems of western Nicaragua. Ecol. Indic. 27:71-82.

SÁNCHEZ-DE LEÓN, Y., DE-MELO, E., SOTO, G., JOHNSON-MAYNARD, J. & LUGO-PÉREZ, J. 2006. Earthworm Populations, Microbial Biomass and Coffee Production in Different Experimental Agroforestry Management Systems in Costa Rica. Caribb. J. Sci. 42:397-409.

SANTORUFO, L., VAN GESTEL, C.A.M., ROCCO, A. & MAISTO, G. 2012. Soil invertebrates as bioindicators of urban soil quality. Environ. Pollut. 161:57-63.

SAS INSTITUTE 1999. SAS/STAT: User's Guide Statistics. SAS Institute, Cary.

SCHERR, S.J. & MCNEELY, J.A. 2008. Biodiversity conservation and agricultural sustainability: towards a new paradigm of "ecoagriculture" landscapes. Philos. Trans. R. Soc. Lond. B. Biol. Sci. 363:477-94.

SIEGRIST, S., SCHAUB, D., PFIFFNER, L. & MÄDER, P. 1998. Does organic agriculture reduce soil erodibility? The results of a long-term field study on loess in Switzerland. Agric. Ecosyst. Environ. 69:253-264.

SILVA, J., JUCKSCH, I. & TAVARES, R.C. 2012. Invertebrados edáficos em diferentes sistemas de manejo do cafeeiro na Zona da Mata de Minas Gerais. Rev. Bras. Agroecol. 7:112-125.

SILVA, S.A. & LIMA, J.S.S. 2013. Atributos físicos do solo e sua relação espacial com a produtividade do café arábica. Coffee Sci. 8:395-403.

SILVA, V.M., TEIXEIRA, A.F.R., REIS, E.F., BENASSI, A.C. & MENDONÇA, E.S. 2013. Atributos químicos do solo em sistemas de adubação orgânica de Conilon. Coffee Sci. 8:469-477.

SWIFT, M.J., IZAC, A.-M.N. & VAN NOORDWIJK, M. 2004. Biodiversity and ecosystem services in agricultural landscapes—are we asking the right questions? Agric. Ecosyst. Environ. 104:113-134.

TABATABAI, M.A. & BREMNER, J.M. 1969. Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. Soil Biol. Biochem. 1:301-307.

TEIXEIRA, A.F.R., SILVA, V.M. & MENDONÇA, E.S. 2014. Fauna edáfica em sistemas arborizados de café conilon em solo de tabuleiros costeiros. Coffee Sci. 9:385-393.

TER BRAAK, C.J.F. & ŠMILAUER, P. 2002. CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (Version 4.5). Microcomputer Power, Wageningen.

TOMÉ JR, J.B. 1997. Manual para interpretação de análises de solo. Agropecuária, Guaíba.

VAN GROENIGEN, J.W., LUBBERS, I.M., VOS, H.M., BROWN, G.G., DE DEYN, G.B. & VAN GROENIGEN, K.J. 2014. Earthworms increase plant production: a meta-analysis. Sci. Rep. 4:6365

VAN RAIJ, B., ANDRADE, J.C., CANTARELLA, H. & QUAGGIO, J.A. 2001. Análise química para avaliação da fertilidade de solos tropicais. Instituto Agronômico de Campinas, Campinas.

VANCE, E.D., BROOKES, P.C. & JENKINSON, D.S. 1987. An extraction method for measuring soil microbial biomass C. Soil Biol. Biochem. 19:703-707.

VASCONCELLOS, R.L.F., SEGAT, J.C., BONFIM, J.A., BARETTA, D. & CARDOSO, E.J.B.N. 2013. Soil macrofauna as an indicator of soil quality in an undisturbed riparian forest and recovering sites of different ages. Eur. J. Soil Biol. 58:105-112.

VELMOUROUGANE, K. 2016. Impact of Organic and Conventional Systems of Coffee Farming on Soil Properties and Culturable Microbial Diversity. Scientifica. 2016:1-9.

WINSOME, T., EPSTEIN, L., HENDRIX, P.F. & HORWATH, W.R. 2006. Competitive interactions between native and exotic earthworm species as influenced by habitat quality in a California grassland. Appl. Soil Ecol. 32:38-53.

ZALLER, J.G., HEIGL, F., RUESS, L. & GRABMAIER, A. 2014. Glyphosate herbicide affects belowground interactions between earthworms and symbiotic mycorrhizal fungi in a model ecosystem. Sci. Rep. 4:5634.

ZWART, K.B., BURGERS, S.L.G.E., BLOEM, J., BOUWMAN, L.A., BRUSSAARD, L., LEBBINK, G., DIDDEN, W.A.M., MARINISSEN, J.C.Y., VREEKEN-BUIJS, M.J. & RUITER, P.C. 1994. Population dynamics in the belowground food webs in two different agricultural systems. Agric. Ecosyst. Environ. 51:187-198.

*Received: 11/01/2018*
*Revised: 12/03/2018*
*Accepted: 16/03/2018*

Biota Neotropica 18(2): e20170428, 2018
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
article

# Pioneer tree species as fruit flies parasitoids reservoir in the Brazilian Amazon

*Ricardo Adaime*[1,2], *Maria do Socorro Miranda de Sousa*[2,*], *Jonh Carlo Reis Santos*[3] *& Ezequiel da Glória Deus*[2]

[1]*Embrapa Amapá, Macapá, AP, Brasil*
[2]*Universidade Federal do Amapá, Macapá, AP, Brasil*
[3]*Instituto Macapaense do Melhor Ensino Superior, Macapá, AP, Brasil*
**Corresponding author: Maria do Socorro Sousa, e-mail: socorro-ap@hotmail.com*

ADAIME, R., SOUSA, M. S. M., SANTOS, J. C. R., DEUS, E. G. **Pioneer tree species as fruit flies parasitoids reservoir in the Brazilian Amazon**. Biota Neotropica. 18(2): e20170428. http://dx.doi.org/10.1590/1676-0611-BN-2017-0428.

**Abstract:**The objective of this study was to evaluate the potential of the pioneer plant species *Bellucia grossularioides* (L.) Triana (Melastomataceae) to act as a reservoir for parasitoids of fruit flies in the Brazilian Amazon. We collected 48 samples of fruits (total of 4,012 fruits, 43.98 kg) during the months of July, August and September of 2013, in 15 of the 16 municipalities of Amapá State, Brazil. All samples showed infestation by fruit flies, with rates varying from 60.6 to 239.1 puparia/kg of fruit (mean of 106.8 puparia/kg of fruit). The percentage of emergence varied 18.6 to 64.3% (mean of 39.9%). Specimens of *Anastrepha coronilli* Carrejo & González (Diptera: Tephritidae) were obtained from all samples collected. Specimens of *Neosilba* (Diptera: Lonchaeidae) were obtained from five samples, where they were represented by *Neosilba bella* Strikis & Prado and *Neosilba glaberrima* (Wiedemann). The mean percentage of parasitism was 12.8%, varying 4.7 to 26.7%. Four species of parasitoids were obtained: *Doryctobracon areolatus* (Szépligeti), *Doryctobracon* sp.2, *Opius bellus* Gahan (Braconidae) and *Aganaspis pelleranoi* (Brèthes) (Figitidae). *Doryctobracon areolatus*, present in all municipalities sampled, was the most abundant species. Considering that *B. grossularioides* is a plant species that is abundant in the area sampled, its relevance with respect to the maintenance of the population of parasitoids is discussed in the context of the integrated management of fruit flies in the Amazon.

**Keywords:** *Biological control, Natural enemies, Anastrepha coronilli, Doryctobracon areolatus.*

# Espécie de árvore pioneira como reservatório de parasitoides de moscas-das-frutas na Amazônia brasileira

**Resumo:** O objetivo deste trabalho foi avaliar o potencial da espécie vegetal pioneira *Bellucia grossularioides* (L.) Triana (Melastomataceae) para atuar como reservatório de parasitoides de moscas-das-frutas na Amazônia brasileira. Foram realizadas coletas de 48 amostras de frutos (4.012 frutos, 43,98 kg) durante os meses de julho, agosto e setembro de 2013, em 15 dos 16 municípios do estado do Amapá, Brasil. Todas as amostras apresentaram infestação por dípteros, com índices que variaram de 60,6 a 239,1 pupários/kg de fruto (média de 106,8 pupários/kg de fruto). O percentual de emergência variou de 18,6% a 64,3% (média de 39,9%). Exemplares de *Anastrepha coronilli* Carrejo & González (Diptera: Tephritidae) foram obtidos de todas as amostras coletadas. Exemplares de *Neosilba* (Diptera: Lonchaeidae) foram obtidos de cinco amostras, sendo representadas por *Neosilba bella* Strikis & Prado e *Neosilba glaberrima* (Wiedemann). O percentual médio de parasitismo foi de 12,8%, variando de 4,7% a 26,7%. Quatro espécies de parasitoides foram obtidas: *Doryctobracon areolatus* (Szépligeti), *Doryctobracon* sp.2, *Opius bellus* Gahan (Braconidae) e *Aganaspis pelleranoi* (Brèthes) (Figitidae). *Doryctobracon areolatus*, presente em todos os municípios amostrados, foi a espécie mais abundante. Considerando-se que *B. grossularioides* é uma espécie vegetal abundante na área amostrada, sua relevância quanto à manutenção da população de parasitoides é discutida no contexto do manejo integrado de moscas-das-frutas na Amazônia.

**Palavras-chave:** *Controle biológico, Inimigos naturais, Anastrepha coronilli, Doryctobracon areolatus.*

## Introduction

Fruit flies (Diptera: Tephritidae) are among the most important pests worldwide due to their economic impacts and the severe quarantine restrictions imposed by many countries to prevent their entry (Aluja 1994, Follett & Neven 2006, Aluja & Mangan 2008). The information needed to understand the biology, ecology and evolution of these insects should be determined in areas of practically unchanged native vegetation, especially when one considers that the rapid deforestation of the tropics may be causing the disappearance or even extinction of many species of fruit flies, consequently threatening the associated native parasitoid species (Hymenoptera) (Aluja 1999, Aluja et al., 2003). These insects, especially those belonging to the family Braconidae, play an important role in the natural biological control of fruit flies, considered as pests (López et al., 1999, Ovruski et al., 2000).

In a study carried out in the state of Veracruz, Mexico, López et al. (1999) demonstrated the need to protect native vegetation due to its important role as a reservoir of fruit flies parasitoids. The authors reported that native plants in the wild harbor significantly more parasitoids per fruit than do cultivated plants, corroborating the work of Sivinski (1991) and Hernández-Ortíz et al. (1994).

López et al. (1999), in summarizing studies with parasitoids in various countries, indicated that: 1) *Doryctobracon areolatus* (Szépligeti) (Hymenoptera: Braconidae) is the most abundant and widespread native parasitoid of *Anastrepha*; 2) most parasitoid species are generalists (they attack many *Anastrepha* species); and 3) many native species are found preferentially parasitizing *Anastrepha* larvae in wild native fruit trees.

Aluja (1999) suggested that in regions where producers have few resources, the following actions can be promoted as alternatives to the wide use of insecticides: 1) the preservation of habitats where parasitoids develop; 2) artificial increase of certain reservoirs of parasitoids and species of trees promoting and multiplying biodiversity. More recently, Aluja et al. (2014) proposed three categories of fruit plants of interest for the conservative biological control of fruit flies: 1) parasitoid multiplier plants: species that serve as alternative hosts for fruit flies pests when their commercial hosts are not available, in which they are exceptionally vulnerable to parasitism; 2) parasitoid reservoir plants: native or introduced trees in whose fruits non-pest fruit flies serve as hosts of generalist parasitoids that are capable of attacking tephritid pests on other commercially grown fruit species; and 3) pest-based parasitoid reservoir plants: native or introduced species that are not economically important locally but harbor fruit flies that would otherwise be pests and serve as hosts for parasites of major pests in the vicinity.

*Bellucia* is a Neotropical plant genus comprising seven species (Renner 1986, 1987). In general, activities such as timber extraction, road construction and pasture formation have provided excellent habitats for species of this genus. *Bellucia grossularioides* (L.) Triana (Figure 1) occurs from Mexico to the Brazilian Amazon. It grows in areas of altered and unchanged vegetation, being adapted to a variety of soil types. It is among the most important pioneer species in terms of number of individuals per area in the Central Amazon. It flowers and bears fruit for long periods or continuously throughout the year. Eventually, fruits are consumed by animal species (especially mammals) and, less frequently, by humans. They usually reach a maximum height of 20 to 25 m. The minimum diameter for the beginning of the reproductive phase is 7.8 cm. The main dispersants are birds and monkeys (Bentos et al., 2008, Santos et al., 2012).

*Anastrepha coronilli* Carrejo & González (Diptera: Tephritidae) is a species of the *fraterculus* group, considered to be of no economic importance, especially associated with Melastomataceae species (Norrbom et al., 2013). In the Brazilian Amazon, some surveys were carried out to determine the infestation rates of *B. grossularioides* by *A. coronilli* and associated parasitoids. Parasitism of up to 28% of puparia was recorded in samples from Ferreira Gomes, Amapá State (Deus et al., 2013). The species of parasitoids recorded were: 1) Braconidae - *Asobara anastrephae* (Muesebeck) (Deus et al., 2009), *Doryctobracon areolatus* (Bomfim et al., 2007, Deus et al., 2009, Pereira 2009, Pereira et al., 2010, Marsaro Júnior et al., 2011, Ronchi-Teles et al., 2011, Silva et al., 2011a, Deus et al., 2013, Dutra et al., 2013), *Doryctobracon crawfordi* (Viereck) (Deus et al., 2013), *Doryctobracon* sp. (Bomfim et al., 2007), *Opius bellus* Gahan (Dutra et al., 2013, Adaime et al. 2017) and *Utetes anastrephae* (Viereck) (Dutra et al., 2013); 2) Figitidae - *Aganaspis nordlanderi* Wharton (Ronchi-Teles et al., 2011) and *Aganaspis pelleranoi* (Brèthes) (Deus et al., 2013, Dutra et al., 2013). In all studies carried out in the region, *D. areolatus* was the predominant species.

This work was carried out to determine the potential of *B. grossularioides* to act as a reservoir of fruit flies parasitoids in the Amapá State in the Brazilian Amazon.

## Material and Methods

### 1. Geographic area covered

The Amapá State (area of 143,453.70 km$^2$) is situated in Eastern Amazon and is considered the most preserved of the country. It is bordered to the south and west by Pará State, to the east by the Atlantic Ocean, to the north by French Guiana and to the northwest by Suriname (Figure 2) (Porto 2007). The climate in the region, according to the Koëppen-Geiger classification, is Aw (tropical savanna) and Am (tropical monsoon) types, with mean annual precipitation between 2,300 and 2,400 mm (Pell et al., 2007). The rainy season occurs from January to June and a characteristically dry period is more frequent from September to November. The mean annual temperature is 26ºC (IBGE 2011). The region is composed of domains of cerrado, floodplain forest, upland forest and the transition forests cerrado/forest and cerrado/floodplain forest (IEPA 2002).

**Figure 1.** *Bellucia grossularioides*. A) Flowering plant, B) fruits in ventral view. Photographs: Jonh Carlo Reis dos Santos.

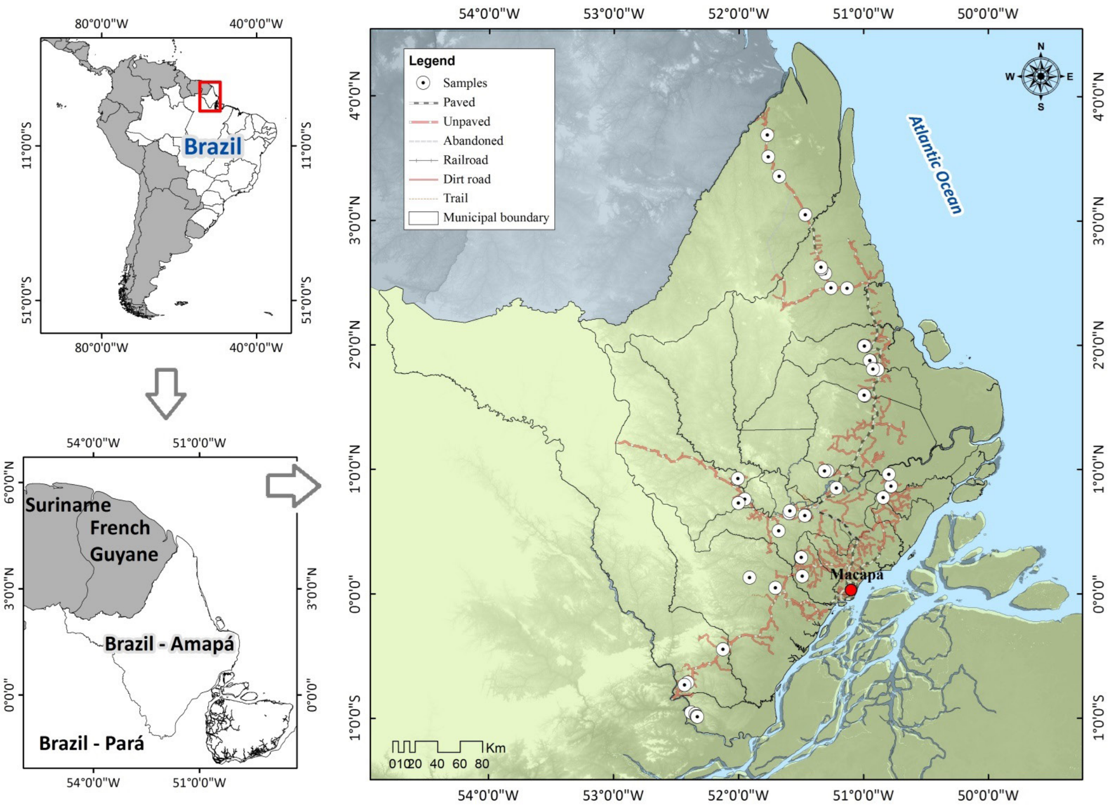

**Figure 2.** Location of sampling points for *Bellucia grossularioides* in various municipalities of Amapá State (July to September of 2013).

## 2. Collection and processing of samples

Samples of *B. grossularioides* fruits were collected during July, August and September of 2013 in 15 of the 16 municipalities of Amapá State (Table 1 and Figure 2). The collections were made especially in the side of vicinal roads, locating plants with a good amount of fruits. Each sample was composed of fruits of the same plant, whose size depended on the availability of fruits. The fruits were collected directly from the plant and ground (intact fruits, freshly fallen), weighed on a digital balance and placed in plastic jars (14 cm in diameter), under on a thin layer of moistened sand, covered with organza and an open lid. The geographical coordinates of the sampling points were determined with the aid of a GPS.

In the laboratory of Plant Protection at Embrapa Amapá, the fruits were transferred to plastic trays, under a layer of moistened sand, covered with organza and fastened in place with rubber bands. Every seven days the samples were examined. The puparia obtained from each sample were packed in plastic bottles (6.5 cm in diameter) containing a thin layer of moist vermiculite. The bottles were kept in climatized chambers under controlled conditions of temperature (26±0.5ºC), relative humidity (70 ± 10%) and photophase (12 hours) and observed daily to determine the number of fruit flies and parasitoids. The emerged adults were preserved in 70% ethanol for later identification.

## 3. Identification of insects

The insects were identified using the keys of Zucchi (2000), Canal and Zucchi (2000), Marinho et al. (2011), Strikis (2011) and Zucchi et al. (2011). Voucher specimens were deposited in the Plant Protection Laboratory of Embrapa Amapá.

**Table 1.** Period collection of *Bellucia grossularioides* in various municipalities of Amapá State (July to September of 2013).

| Municipalities* | Collection dates |
|---|---|
| Amapá | 8/14/2013 and 8/16/2013 |
| Calçoene | 7/29/2013 and 7/31/2013 |
| Cutias do Araguari | 8/23/2013 |
| Ferreira Gomes | 8/16/2013 |
| Laranjal do Jari | 7/18/2013 and 9/5/2013 |
| Macapá | 8/23/2013 |
| Mazagão | 9/5/2013 |
| Oiapoque | 7/30/2013 |
| Pedra Branca do Amapari | 9/3/2013 |
| Porto Grande | 7/20/2013 and 8/6/2013 |
| Pracuúba | 8/16/2013 |
| Santana | 9/17/2013 |
| Serra do Navio | 8/13/2013 |
| Tartarugalzinho | 8/15/2013 and 8/16/2013 |
| Vitória do Jari | 9/6/2013 |

*In alphabetical order.

## 4. Data analysis

We calculated: 1) infestation rate (number of puparia obtained in the sample ÷ weight of the sample), expressed as number of puparia/kg of fruit; 2) emergence percentage [(number of emerged adults ÷ number of puparia obtained in the fruit) x 100], expressed as a percentage; and 3) percentage of parasitism in pupae [(number of emerged parasitoids ÷ number of puparia obtained) x 100], expressed as a percentage.

## Results

Forty-eight samples of *B. grossularioides* fruits (4,012 fruits, 43.98 kg) were collected, covering an extensive area of Amapá State (Table 2, Figure 1). All samples showed infestation by fruit flies (Table 2). A total of 4,307 puparia were obtained, with infestation rates varying from 60.6 to 239.1 puparia/kg of fruit (mean of 106.8 puparia/kg of fruit).

The emergence percentage ranged 18.6 to 64.3%, with a mean of 39.9% (Table 2). Specimens of *A. coronilli* Carrejo & González, 1993 (Diptera: Tephritidae) were obtained from all collected samples, totaling 571♀ and 548♂. Specimens of *Neosilba* (Diptera: Lonchaeidae) were obtained from five samples, represented by *Neosilba bella* Strikis & Prado (14♂) and *N. glaberrima* (Wiedemann) (1♂).

The mean percentage of parasitism was 12.8%, ranging 4.7 to 26.7% (Table 2). Only three samples (6.3% of the total of 48) did not show parasitism. Four species of parasitoids were obtained: *Doryctobracon areolatus* (582 specimens), *Doryctobracon* sp.2 (1), *Opius bellus* (3) (Braconidae) and *Aganaspis pelleranoi* (3) (Figitidae). *Doryctobracon areolatus*, present in all municipalities sampled, was the most abundant species

## Discussion

### *1. Infestion rate and percentage of parasitism*

In the state of Amapá, some other surveys had been carried out to determine the infestation rates of *B. grossularioides* by fruit flies and associated parasitoids. Table 3 shows data for 11 municipalities, with 97.8% of the samples being infested (the highest infestation rate was 242.5 puparia/kg, in samples from Mazagão). Only *A. coronilli* specimens were obtained.

Additionally, Jesus-Barros et al. (2012) carried out extensive fruit sampling in five municipalities of Amapá (Cutias do Araguari, Itaubal do Piririm, Ferreira Gomes, Pracuúba and Tartarugalzinho). Thirty samples (1,892 fruits, 21.16 kg) of *B. grossularioides* were collected, and 28 of them were infested by fruit flies. A total of 636 puparia (infestation rate of 30.06 puparia/kg) were obtained, from which *A. coronilli* (225), *A. striata* Schiner (24) and *A. antunesi* Lima (3) emerged. The fact that *A. striata* and *A. antunesi* specimens were found is noteworthy in the present study. However, in relation to the total number of females obtained, the species corresponded to only 9.5 and 1.19%, respectively. In the state of Rondônia, Pereira et al. (2010) obtained only one specimen of *A. striata* in fruits of *B. grossularioides*.

In other states of the Brazilian Amazon, few samples of *B. grossularioides* were collected (Table 4). The highest infestation rate recorded was 141.2 puparia/kg, in fruits from the state of Rondônia (Pereira et al., 2010).

The most frequent host of *A. coronilli* is actually *B. grossularioides*, and it is also found in *Bellucia dichotoma* Cogn. (Table 5). Four other hosts were also recorded for the species in the Brazilian Amazon, and of them, only guava (*Psidium guajava* L.) is of commercial importance. However, it should be noted that the frequency and abundance of *A. coronilli* in guava is very low. In intensive work in Amapá, Jesus-Barros et al. (2012) collected 255 guava samples (9,657 fruits, 425.97 kg), of which 222 showed infestation by fruit flies. A total of 17,531 puparia were obtained (infestation rate of 41.16 puparia/kg), from which six species of *Anastrepha* emerged: *A. striata* (4176♀), *A. fraterculus* (Wiedemann) (95♀), *A. coronilli* (16♀), *A. parishi* Stone (15♀), *A. distincta* Greene (13♀) and *A. zenildae* Zucchi (2♀). It can be seen that only 0.37% of females obtained from guava in that study were *A. coronilli*. In a survey in Rondônia, Pereira et al. (2010) obtained only one specimen of *A. coronilli* in guava.

In Brazil, records of species of lance flies associated with fruit species are scarce, because in many studies their presence is neglected. However, the classification of some species as pests has recently attracted the attention of researchers (Veloso et al., 1994, Uchôa-Fernandes & Zucchi 1999, Uchôa-Fernandes et al., 2002, Bittencourt et al., 2006). Recent studies indicate that larvae of some species of Lonchaeidae colonize a larger number of fruit species than larvae of flies of the family Tephritidae (Ferreira et al., 2003).

Recently, Strikis et al. (2011) collected available information on Lonchaeidae in the Brazilian Amazon and published new records of lance flies obtained from wild and cultivated fruit species. So far, only *N. pendula* (Bezzi) had been reported in fruits of *B. grossularioides* in Cantá, Roraima. In the present work the species *N. bella* and *N. glaberrima* are reported for the first time in this plant species (Table 5). Therefore, it is possible that these species use fruits of *B. grossularioides* as an alternative host.

The results indicated considerable parasitism (mean of 12.8% of parasitized puparia) (Table 2). In addition, 93.7% of the samples had parasitized puparia (43 of 48 samples). Four species of parasitoids were obtained, where

**Table 2.** Infestation rates of *Bellucia grossularioides* by fruit flies and associated parasitoids in various municipalities of Amapá State (July to September of 2013).

| Municipalities | SC/IS[1] | Fruits (n) | Weight (kg) | P[2] (n) | Infestation (PP/kg) | Emergence (%) | Tephritidae[3] (n) | Lonchaeidae[4] (n) | PP[5] (%) | Parasitoids[6] (n) |
|---|---|---|---|---|---|---|---|---|---|---|
| Amapá | 5/5 | 475 | 5.73 | 437 | 76.3 | 37.1 | Ac (34♀), 42♂ | | 19.7 | Da (86) |
| Calçoene | 5/5 | 491 | 5.96 | 397 | 66.6 | 53.9 | Ac (40♀), 57♂ | Nb (8♂), Ng (1♂), 2♀ | 26.7 | Da (106) |
| Cutias do Araguari | 2/2 | 132 | 1.06 | 85 | 80.0 | 36.5 | Ac (12♀), 14♂ | | 5.9 | Da (5) |
| Ferreira Gomes | 1/1 | 162 | 1.61 | 385 | 239.1 | 33.2 | Ac (34♀), 31♂ | Nb (1♂) | 16.1 | Da (60), Ob (1), Ap (1) |
| Laranjal do Jari | 3/3 | 297 | 3.02 | 452 | 149.7 | 18.6 | Ac (28♀), 31♂ | | 5.5 | Da (25) |
| Macapá | 1/1 | 90 | 0.69 | 55 | 79.7 | 23.6 | Ac (1♀), 3♂ | | 16.4 | Da (9) |
| Mazagão | 2/2 | 175 | 1.26 | 168 | 133.3 | 64.3 | Ac (38♀), 51♂ | 1♀ | 10.7 | Da (18) |
| Oiapoque | 4/4 | 343 | 4.29 | 349 | 81.4 | 34.7 | Ac (41♀), 41♂ | Nb (5♂), 6♀ | 8.0 | Da (28) |
| Pedra Branca do Amapari | 3/3 | 219 | 3.48 | 279 | 80.2 | 54.5 | Ac (72♀), 67♂ | | 4.7 | Da (11), Ob (2) |
| Porto Grande | 5/5 | 478 | 5.59 | 627 | 112.2 | 42.3 | Ac (79♀), 70♂ | 1♀ | 18.3 | Da (114), Ap (1) |
| Pracuúba | 2/2 | 126 | 1.12 | 68 | 60.7 | 23.5 | Ac (1♀), 2♂ | | 19.1 | Da (13) |
| Santana | 4/4 | 324 | 3.44 | 344 | 100.0 | 46.2 | Ac (76♀), 51♂ | | 9.3 | Da (32) |
| Serra do Navio | 1/1 | 63 | 0.53 | 81 | 152.8 | 45.7 | Ac (16♀), 15♂ | | 7.4 | Da (6) |
| Tartarugalzinho | 5/5 | 312 | 3.60 | 313 | 86.9 | 35.5 | Ac (36♀), 32♂ | | 14.4 | Da (42), Ob (1), Dsp2 (1), Ap (1) |
| Vitória do Jari | 5/5 | 325 | 2.60 | 267 | 102.7 | 49.4 | Ac (63♀), 41♂ | | 10.5 | Da (27), Ob (1) |
| Total | 48/48 | 4012 | 43.98 | 4307 | 106.8* | 39.9* | Ac (571♀), 548♂ | Nb (14♂), Ng (1♂), 10♀ | 12.8* | Da (582), Ob (5), Ap (3), Dsp2 (1) |

[1]SC/IS: samples collected/infested samples, [2]P: puparia; [3]♀ identified (Ac: *Anastrepha coronilli*); [4]♂ identified (Nb: *Neosilba bella;* Ng: *Neosilba glaberrima*); [5]PP: percentage of parasitism; [6]Da: *Doryctobracon areolatus*; Dsp2: *Doryctobracon* sp2; Ob: *Opius bellus*; Ap: *Aganaspis pelleranoi.* *mean for municipalities.

**Table 3.** Occurrence of *Anastrepha coronilli* in fruits of *Bellucia grossularioides* and associated parasitoids in Amapá State, Brazil.

| Municipalities | SC/IC* | Fruits (n) | Weight (kg) | Puparia obtained (n) | *A. coronilli* (n) | Parasitoids (n) | Infestation (puparia/kg) | PP* (%) | References** |
|---|---|---|---|---|---|---|---|---|---|
| Pedra Branca do Amapari | 7/7 | 349 | 5.80 | 272 | 66♀, 69♂ | *Asobara anastrephae*<br>*Doryctobracon areolatus* | 46.9 | 15.80 | Deus et al. (2009) |
| Serra do Navio | 4/4 | 276 | 6.15 | 103 | 28♀, 31♂ | *Asobara anastrephae*<br>*Doryctobracon areolatus* | 16.8 | 12.62 | Deus et al. (2009) |
| Laranjal do Jari | 4/4 | 524 | 5.05 | 112 | 17♀, 21♂ | *Doryctobracon areolatus* | 22.2 | 11.6 | Silva et al. (2011a) |
| Vitória do Jari | 3/3 | 335 | 2.79 | 56 | 9♀, 19♂ | - | 20.1 | 0 | Silva et al. (2011a) |
| Amapá | 2/2 | 41 | 0.50 | 16 | 5♀, 7♂ | *Doryctobracon areolatus* | 32.0 | 12.50 | Deus et al. (2013) |
| Calçoene | 2/2 | 38 | 0.37 | 14 | 6♀, 5♂ | - | 37.8 | 0 | Deus et al. (2013) |
| Ferreira Gomes | 2/2 | 93 | 0.79 | 175 | 22♀, 27♂ | *Doryctobracon areolatus*<br>*Aganaspis pelleranoi* | 221.5 | 28.00 | Deus et al. (2013) |
| Mazagão | 2/2 | 69 | 0.47 | 114 | 24♀, 30♂ | *Doryctobracon areolatus* | 242.5 | 15.78 | Deus et al. (2013) |
| Pedra Branca do Amapari | 2/2 | 13 | 0.57 | 18 | 3♀, 5♂ | *Doryctobracon areolatus* | 31.6 | 5.55 | Deus et al. (2013) |
| Porto Grande | 7/6 | 205 | 2.00 | 398 | 73♀, 109♂ | *Doryctobracon areolatus*<br>*Aganaspis pelleranoi*<br>*Doryctobracon crawfordi* | 199.0 | 12.56 | Deus et al. (2013) |
| Santana | 1/1 | 7 | 0.05 | 2 | 1♀, 1♂ | - | 40.0 | 0 | Deus et al. (2013) |
| Serra do Navio | 2/2 | 110 | 1.20 | 202 | 43♀, 44♂ | *Doryctobracon areolatus*<br>*Aganaspis pelleranoi* | 168.3 | 11.38 | Deus et al. (2013) |
| Oiapoque | 3/3 | 142 | 1.70 | 88 | 19♀, 17♂ | *Doryctobracon areolatus* | 51.8 | 11.4 | Adaime et al. (2017) |
| Calçoene | 4/4 | 140 | 1.89 | 80 | 15♀, 24♂ | *Doryctobracon areolatus*<br>*Opius bellus* | 42.3 | 16.3 | Adaime et al. (2017) |
| Total | 45/44 | 2342 | 29.33 | 1650 | - | - | - | - | - |

*SC/IS: samples collected/infested samples, PP: percentage of parasitism.

** In chronological order.

**Table 4.** Occurrence of parasitoids in fruits of *Bellucia grossularioides* infested by *Anastrepha coronilli* in the Brazilian Amazon.

| States<br>Municipalities | SC/IS* | Fruits (n) | Weight (kg) | Puparia obtained (n) | Infestation (P/kg)* | Parasitoids (n) | PP* (%) | References |
|---|---|---|---|---|---|---|---|---|
| Acre<br>Capixaba | 1/1 | 50 | 0.60 | 49 | 81.7 | *Doryctobracon areolatus* | 10.20 | Pereira et al. (2010) |
| Amazonas<br>Manaus | 1/1 | 219 | 2.20 | 151 | 68.6 | *Doryctobracon areolatus* | 8.61 | Dutra et al. (2013) |
| Amazonas<br>Manaus | 1/1 | 758 | 5.03 | 68 | 13.5 | *Doryctobracon areolatus*<br>*Aganaspis nordlanderi* | 11.76 | Ronchi-Teles et al. (2011) |
| Amazonas<br>Presidente Figueiredo | 1/1 | 226 | 1.50 | 133 | 88.7 | *Doryctobracon areolatus*<br>*Opius bellus*<br>*Utetes anastrephae*<br>*Aganaspis pelleranoi* | 11.28 | Dutra et al. (2013) |
| Pará<br>Santarém<br>Belterra | 6/6 | 203 | 1.90 | 149 | 78.4 | *Doryctobracon areolatus* | 2.7 | Pereira (2009) |
| Rondônia<br>Ouro Preto do Oeste | 4/4 | 131 | 0.85 | 120 | 141.2 | *Doryctobracon areolatus* | 2.50 | Pereira et al. (2010) |
| Roraima<br>Cantá | 1/1 | 32 | 0.50 | 16 | 32.0 | *Doryctobracon areolatus* | 12.5 | Marsaro Júnior et al. (2011) |
| Tocantins<br>Palmas | nd | nd | nd | nd | nd | *Doryctobracon areolatus*<br>*Doryctobracon* sp. | nd | Bomfim et al. (2007) |

*SC/IS: samples collected/infested samples, P/kg: puparia/kg, PP: percentage of parasitism, nd: not determined.

*Doryctobracon* sp.2 was recorded for the first time in larvae of *A. coronilli* in fruits of *B. grossularioides*. It is a species that has been recently collected in Brazil but not yet formally described (Marinho et al., 2011). In other studies carried out in Amapá, the highest rate of parasitism of *A. coronilli* puparia was 28.0%, obtained in Ferreira Gomes. In most samples, the rate obtained has been greater than 10% (Table 3). Jesus-Barros et al. (2012) found parasitism of 5.97%, with *D. areolatus* (37 specimens) and *A. anastrephae* (1) being collected in five municipalities of Amapá. In other places in the Brazilian Amazon, the highest parasitism rate observed was 12.5% in Roraima (Table 4) (Marsaro Júnior et al., 2011).

It should be considered that the rates of parasitism found in studies in which fruits were collected in the field and placed under laboratory

**Table 5.** Distribution and hosts of *Anastrepha coronilli* in the Brazilian Amazon.

| Hosts* | States | References |
|---|---|---|
| *Bellucia dichotoma* (Melastomataceae) (= *Bellucia imperialis*) | Amazonas | Costa (2005) |
| | Amapá | Silva et al. (2009) |
| *Bellucia grossularioides* (Melastomataceae) | Amapá | Ronchi-Teles et al. (1996) |
| | Amazonas | Ronchi-Teles et al. (1998) |
| | Pará | Pereira (2009) |
| | Tocantins | Bomfim et al. (2007) |
| *Dolicarpus sp.* (Dileniaceae) | Amazonas | Costa (2005) |
| *Guatteria discolor* (Annonaceae) | Amazonas | Costa (2005) |
| *Loreya mespiloides* Miq. (Melastomataceae) | Roraima | Marsaro Júnior et al. (2010) |
| *Mouriri dimorphandra* (Memecylaceae) | Amazonas | Costa (2005) |
| *Psidium guajava* (Myrtaceae) | Amapá | Jesus-Barros et al. (2012) |
| | Rondônia | Pereira et al. (2010) |

*****In alphabetical order.

**Table 6.** Parasitoids in fruits of *Bellucia grossularioides* infested by *Anastrepha coronilli* in the Brazilian Amazon.

| Species* | States | References |
|---|---|---|
| *Aganaspis nordlanderi* | Amazonas | Ronchi-Teles et al. (2011) |
| *Aganaspis pelleranoi* | Amapá | Deus et al. (2013) and present work |
| | Amazonas | Dutra et al. (2013) |
| *Asobara anastrephae* | Amapá | Deus et al. (2009) |
| *Doryctobracon areolatus* | Amapá | Deus et al. (2009), Deus et al. (2013), Silva et al. (2011a) and present work |
| | Amazonas | Dutra et al. (2013) and Ronchi-Teles et al. (2011) |
| | Pará | Pereira (2009) |
| | Rondônia | Pereira et al. (2010) |
| | Roraima | Marsaro Júnior et al. (2011) |
| | Tocantins | Bomfim et al. (2007) |
| *Doryctobracon crawfordi* | Amapá | Deus et al. (2013) |
| *Doryctobracon* sp. | Tocantins | Bomfim et al. (2007) |
| *Doryctobracon* sp2. | Amapá | Present work |
| *Opius bellus* | Amapá | Adaime et al. (2017) |
| | Amazonas | Dutra et al. (2013) |
| *Utetes anastrephae* | Amazonas | Dutra et al. (2013) |

*****In alphabetical order.

conditions are not real because the fruits were removed from the natural environment, possibly with eggs and larvae of first and second instars of fruit flies. Thus, when immatures are removed from the field, they are no longer likely to be parasitized (Uchôa-Fernandes et al., 2003). Therefore, it is estimated that the actual parasitism rate in *A. coronilli* larvae infesting *B. grossularioides* fruits is even higher.

In the present work, nine species of fruit fly parasitoids (two from Figitidae and seven from Braconidae) have been found on *B. grossularioides* in the Brazilian Amazon (Table 6).

## *2. Implications for the integrated management of fruit flies*

The results demonstrate the capacity of *B. grossularioides* to act as a fruit fly parasitoid reservoir (as proposed by Aluja et al., 2014) in the state of Amapá and, therefore, in the Brazilian Amazon. The collections have been more extensive than in any other state in the region. The plant species clearly plays a fundamental role in the maintenance of the fruit fly parasitoid population. It is a pioneer species that is widely distributed and adapted to various soil conditions. Because it is not a species of economic interest, the biological control of fruit flies is favored, since the possibility of removal of the plants due to some commercial interest therefore does not seem to be a threat. Although fruits are consumed by animals, especially mammals, there does not seem to be considerable reduction in the amount of fruits on the ground, which potentially contains parasitoids. In general, when the infested fruits fall, the larvae abandon it and enter the soil, to proceed to the pupa phase. Thus, even if a certain amount of fruit is consumed, the parasitoids that infested fly larvae would be preserved, since they would already be in the pupa stage, in the soil.

In summary, the results suggest that *B. grossularioides* is a species that can be conserved in its environments of occurrence for maintenance of the parasitoid population. Another possibility that presents itself is to cultivate this plants species around orchards. The plants would act as reservoirs of parasitoids, which, being generalists, can help to reduce populations of pest species.

Another important point is that *B. grossularioides* hosts almost exclusively *A. coronilli*, a species of no economic importance. Thus, when considering the amount of fruits sampled and the total number of *A. coronilli* specimens obtained, the number of adults of other species becomes very small. Still, it is suggested that further, intensive surveys be conducted for a whole year to substantiate this notion.

It is therefore possible to attempt to develop systems through which parasitoid reservoirs can be managed to naturally increase the number of parasitoids in areas of native vegetation (López et al., 1999). Thus, cultivation or maintenance of the natural populations of *B. grossularioides* could contribute to increasing the community of fruit flies parasitoids without the risk of increasing the population of pest species.

### *3. Research demands*

The results obtained open new perspectives of research for the better understanding of the tritrophic interaction between *B. grossularioides*, *A. coronilli* and associated parasitoids. Studies based on individualized fruits could help considerably in this regard, as detailed by Silva et al. (2011b). Undoubtedly, it is essential to study the phenology of *B. grossularioides* in local conditions of natural occurrence, detailing the fruiting period, the consequent infestation by fruit flies and the corresponding parasitism rate throughout the year. To quantify the fruits produced per plant per year is a determinant for estimating the contribution of each individual as parasitoid reservoir.

Moreover, it is also important to study the biology of *A. coronilli* and its behavioral aspects. In general, studies on species of no economic importance have been neglected. The main aspects to be studied are feeding and reproduction behaviors, as well as biological aspects, especially reproductive potential, immature development time and adult longevity.

## Acknowledgments

We thank Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the Research Productivity grant awarded to Ricardo Adaime, Carlos Alberto Morais for his help with fieldwork, and the student Orimax Monteiro Cruz for help with laboratory work. Dr. A. Leyva (USA) provided English translation and editing of the manuscript.

## Authors' Contributions

RA and EGD contributed to the concept and design of the study, to data analysis and interpretation, and to the manuscript preparation. MSMS and JCRS contributed to the data collection, to the critical revision, adding intelectual content.

## Conflicts of interest

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

## References

ADAIME, R., SOUSA, MSM., JESUS BARROS, CR., DEUS, EG., PEREIRA, JF., STRIKIS, PC. & SOUZA-FILHO, MF. 2017. Frugivorous Flies (Diptera: Tephritidae, Lonchaeidae), their host plants, and associated parasitoids in the extreme north of Amapá State, Brazil. Fla. Entomol. 100 (2): 316-324.

ALUJA, M., SIVINSKI, J., VAN DRIESCHE, R., ANZURES-DADDA, A. & GUILLÉN, L. 2014. Pest management through tropical tree conservation. Biodivers. Conserv. 23 (4): 831-853.

ALUJA, M. 1994. Bionomics and management of *Anastrepha*. Annu. Rev. Entomol. 39 (1): 155-178.

ALUJA, M. 1999. Fruit fly (Diptera: Tephritidae) research in Latin America: myths, realities and dreams. An. Soc. Entomol. Brasil. 28 (4): 565-594.

ALUJA, M. & MANGAN, RL. 2008. Fruit fly (Diptera: Tephritidae) host status determination: critical conceptual, methodological, and regulatory considerations. Annu. Rev. Entomol. 53: 473-502.

ALUJA, M., RULL, J., SIVINSKI, J., NORRBOM, AL., WHARTON, RA., MACÍAS-ORDÓÑEZ, R., DÍAZ-FLEISCHER, F. & LÓPEZ, M. 2003. Fruit flies of the genus *Anastrepha* (Diptera: Tephritidae) and associated native parasitoids (Hymenoptera) in the Tropical Rainforest Biosphere Reserve of Montes Azules, Chiapas, Mexico. Environ. Entomol. 32 (6): 1377-1385.

BENTOS, TV., MESQUITA, RCG. & WILLIAMSON, GB 2008. Reproductive phenology of Central Amazon pioneer trees. Trop. Conserv. Sci. 1 (3): 186-203.

BITTENCOURT, MAL., SILVA, ACM., BOMFIM, ZV., SILVA, VES., ARAÚJO, EL. & STRIKIS, PC 2006. Novos Registros de Espécies de *Neosilba* (Diptera: Lonchaeidae) na Bahia. Neotrop. Entomol. 2 (35): 282-283.

BOMFIM, DA., UCHÔA-FERNANDES, MA. & BRAGANÇA, MAL 2007. Hosts and Parasitoids of Fruit Flies (Diptera: Tephritoidea) in the State of Tocantins, Brazil. Neotrop. Entomol. 36 (6): 984-986.

CANAL, NA & ZUCCHI, RA. 2000. Parasitóides – Braconidae. In Moscas-das-frutas de importância econômica no Brasil: conhecimento básico e aplicado (A. MALAVASI & R.A. ZUCCHI, eds.). Holos, Ribeirão Preto, p.119-126.

COSTA, SGM. 2005. Himenópteros parasitóides de larvas frugívoras (Diptera: Tephritoidea) na Reserva Florestal Adolpho Ducke, Manaus, Amazonas, Brasil. Dissertação de Mestrado, Instituto Nacional de Pesquisas da Amazônia, Amazonas.

DEUS, EG., PINHEIRO, LS., LIMA, CR., SOUSA, MSM., GUIMARÃES, JA., STRIKIS, PC. & ADAIME, R 2013. Wild hosts of frugivorous dipteran (Tephritidae and Lonchaeidae) and associated parasitoids in the Brazilian Amazon. Fla. Entomol. 96 (4): 1621-1625.

DEUS, EG., SILVA, RA., NASCIMENTO, DB., MARINHO, CF. & ZUCCHI, RA 2009. Hospedeiros e parasitóides de espécies de Anastrepha (Diptera, Tephritidae) em dois municípios do Estado do Amapá. Rev. Agric. 84 (3): 194-203.

DUTRA, VS., RONCHI-TELES, B., GARCIA, MVB, ADAIME, R. & SILVA, JG 2013. Native hosts and parasitoids associated with *Anastrepha fractura* and other *Anastrepha* species (Diptera: Tephritidae) in the Brazilian Amazon. Fla. Entomol. 96 (1): 270-273.

FERREIRA, HJ., VELOSO, VRS., NAVES, RV. & BRAGA-FILHO, JR. 2003. Infestação de moscas-das-frutas em variedades de manga (*Mangifera indica* L.) no estado de Goiás. Pesqui. Agropecu. Trop. 33 (1): 43-48.

FOLLETT, PA. & NEVEN, LG 2006. Current trends in quarantine entomology. Annu. Rev. Entomol. 51: 359-385.

HERNÁNDEZ-ORTÍZ, V., PÉREZ-ALONSO, R. & WHARTON, RA 1994. Native parasitoids associated with the genus *Anastrepha* (Dipt.: Tephritidae) in Los Tuxtlas, Veracruz, Mexico. Entomophaga. 39 (2): 171-178.

IBGE - INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. http://www.ibge.gov.br/cidadesat/topwindow.htm?1 (last access in 07/08/2011.)

IEPA - INSTITUTO DE PESQUISAS CIENTÍFICAS E TECNOLÓGICAS DO ESTADO DO AMAPÁ. 2002. Macrodiagnóstico do Estado do Amapá: primeira aproximação do ZEE. Macapá: IEPA. 140 p.

JESUS-BARROS, CR., ADAIME, R., OLIVEIRA, MN., SILVA, WR., COSTA-NETO, SV. & SOUZA-FILHO, MF 2012. *Anastrepha* (Diptera: Tephritidae) species, their hosts and parasitoids (Hymenoptera: Braconidae) in five municipalities of the state of Amapá, Brazil. Fla. Entomol. 95 (3): 694-705.

LÓPEZ, M., ALUJA, M. & SIVINSKI, J. 1999. Hymenopterous larval-pupal and pupal parasitoids of *Anastrepha* flies (Diptera: Tephritidae) in Mexico. Biolog. Control. 15: 119-129.

MARINHO, CF, SILVA, RA & ZUCCHI, RA. 2011. Chave de identificação de Braconidae (Alysiinae e Opiinae) parasitoides de larvas frugívoras na região Amazônica. In Moscas-das-frutas na Amazônia brasileira: diversidade, hospedeiros e inimigos naturais (R.A. SILVA, W.P. LEMOS & R.A. ZUCCHI, eds.). Embrapa Amapá, Macapá, p. 91-102.

MARSARO JUNIOR, AL., SILVA, RA., SILVA, WR., LIMA, CR., FLORES, AS. & RONCHI-TELES, B 2010. New records of *Anastrepha* (Diptera: Tephritidae), its hosts and parasitoids in the Serra do Tepequém, Roraima state, Brazil. Rev. Agric. 85 (1): 15-20.

MARSARO JUNIOR, AL., SOUZA-FILHO, MF., ADAIME, R. & STRIKIS, PC 2011. First report of natural infestation of *Pereskia aculeata* Mill. (Cactaceae) by *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae) in Brazil. Rev. Agric. 86 (2): 151-154.

NORRBOM, A.L., KORYTKOWSKI, C.A., ZUCCHI, R.A., URAMOTO, K., VENABLE, G.L., MCCORMICK, J. & DALLWITZ, M.J. 2012. *Anastrepha* and *Toxotrypana*: descriptions, illustrations, and interactive keys. Version: 28th September 2013. http://delta-intkey.com.

OVRUSKI, SM., ALUJA, M., SIVINSKI, J., WHARTON, RA 2000. Hymenopteran parasitoids on fruit-infesting Tephritidae (Diptera) in Latin America and the Southern United States: diversity, distribution, taxonomic status and their use in fruit fly biological control. Integrated Pest Manag Rev.5 (2): 81-107.

PEEL, MC., FINLAYSON, BL. & MCMAHON, TA. 2007. Updated world map of the Köoppen-Geiger climate classification. Hydrol. Earth Syst. Sci. 11: 1633-1644.

PEREIRA, JDB. 2009. Contribuição ao conhecimento de moscas-das-frutas (Tephritidae e Lonchaeidae) no Pará: diversidade, hospedeiros e parasitóides associados. Dissertação de Mestrado. Universidade Federal do Amapá, Macapá.

PEREIRA, JDB, BURITI, DP, LEMOS, WP, SILVA, WR, SILVA, RA Espécies de *Anastrepha* Schiner (Diptera, Tephritidae), seus hospedeiros e parasitoides nos estados do Acre e Rondônia, Brasil. Biota Neotropica. 10 (3): http://www.biotaneotropica.org.br/v10n3/pt/abstract?short-communication+bn00410032010. (last access on 31/07/2017)

PORTO, J. 2007. Amapá: principais transformações econômicas e institucionais – 1943 a 2000. Edição do autor, Macapá, Amapá.

RENNER, SS. 1986. Reproductive biology of *Bellucia* (Melastomataceae). Acta Amaz. 16: 197-208.

RONCHI-TELES, B, DUTRA, VS, TREGUE-COSTA, AP, AGUIAR-MENEZES, EL, MESQUITA, ACA & SILVA, JG 2011. Natural host plants and native parasitoids associated with *Anastrepha pulchra* and other *Anastrepha* species (Diptera: Tephritidae) in Central Amazon, Brazil. Fla. Entomol. 94 (2): 347-349

RONCHI-TELES, B., SILVA, N.M. & ZUCCHI, R.A. 1998. Constatação de *Anastrepha coronilli* (Diptera: Tephritidae) na Amazônia brasileira. In 17º Congresso Brasileiro de Entomologia, 8º Encontro Nacional de Fitossanitaristas. Sociedade Entomológica do Brasil, Rio de Janeiro, p. 862.

RONCHI-TELES, B., SILVA, N.M. & NORRBOM, A. 1996. New records of *Anastrepha* spp. (Diptera: Tephritidae) and their host in Rondônia and Amapá States - Brazilian Amazonia. In 2º Meeting of the Working Group of fruiti flies of the Western Hemisphere. Viña Del Mar, p. 32-33.

SANTOS, GGA, SANTOS, BA & NASCIMENTO, HEM 2012. Contrasting demographic structure of short- and long-lived pioneer tree species on Amazonian forest edges. Biotropica. 44 (6): 771-778.

SILVA, R.A., DEUS, E.G., RAGA, A., PEREIRA, J.D.B., SOUZA FILHO, M.F. & COSTA NETO, S.V. 2011b. Monitoramento de moscas-das-frutas na Amazônia: amostragem de frutos e uso de armadilhas. In Moscas-das-frutas na Amazônia brasileira: diversidade, hospedeiros e inimigos naturais (R.A. SILVA, W.P. LEMOS & R.A. ZUCCHI, eds.). Embrapa Amapá, Macapá, p. 33-50.

SILVA, RA, LIMA, AL, XAVIER, SLO, SILVA, WR, MARINHO, CF, ZUCCHI, RA *Anastrepha* species (Diptera: Tephritidae), their hosts and parasitoids in southern Amapá State, Brazil. Biota Neotropica. 11 (3): http://www.biotaneotropica.org.br/v11n3/pt/abstract?short-communication+bn03511032011 (last access on 31/07/2017)

SILVA, RA, SOUZA, MSM, SILVA, WR & SOUZA-FILHO, MF 2009. Novo registro de hospedeiro de *Anastrepha coronilli* Carrejo & González (Diptera: Tephritidae) no Brasil. O Biológico. 7 (2): 135.

SIVINSKI, J 1991.The influence of host fruit morphology on parasitization rates in the Caribbean fruit fly, *Anastrepha suspensa.* Entomophaga. 36 (3): 447-454.

STRIKIS, PC 2011. Description of 11 new species of genus *Neosilba* (Diptera: Lonchaeidae) from Brazil, its hosts and geographical distribution. Trends in Entomol. 7: 67-79.

STRIKIS, P.C., DEUS, E.G., SILVA, R.A., PEREIRA, J.D.B., JESUS, C.R. & MARSARO JÚNIOR, A.L. 2011. Conhecimento sobre Lonchaeidae na Amazônia brasileira. In Moscas-das-frutas na Amazônia brasileira: diversidade, hospedeiros e inimigos naturais (R.A. SILVA, W.P. LEMOS & R.A. ZUCCHI, eds.). Embrapa Amapá, Macapá, p. 205-216.

UCHÔA-FERNANDES, MA, MOLINA, RMS, OLIVEIRA, I, ZUCCHI, RA, CANAL, NA & DÍAZ, NB 2003. Larval endoparasitoids (Hymenoptera) of frugivorous flies (Diptera, Tephritoidea) reared from fruits of the cerrado of the State of Mato Grosso do Sul, Brazil. Rev. Bras. entomol. 47 (2): 181-186.

UCHÔA-FERNANDES, M.A., OLIVEIRA, I., MOLINA, R.M.S. & ZUCCHI, R.A. 2002. Species diversity of frugivorous flies (Diptera: Tephritoidea) from hosts in the Cerrado of the State of Mato Grosso do Sul, Brazil. Neotrop. Entomol. 31 (4): 515-524.

UCHÔA-FERNANDES, MA & ZUCCHI, RA 1999. Metodología de colecta de Tephritidae y Lonchaeidae frugívoros (Diptera: Tephritoidea) y sus parasitoides (Hymenoptera). An. Soc. Entomol. Brasil. 28 (4): 601-610.

VELOSO, VRS, FERNANDES, PM, ROCHA, MR, QUEIROZ, MV & SILVA, RMR 1994. Armadilhas para o monitoramento e controle das moscas-das-frutas *Anastrepha* spp. e *Ceratitis capitata* (Wied.). An. Soc. Entomol. Brasil. 23 (3): 487–493.

ZUCCHI, R.A., URAMOTO, K. & SOUZA-FILHO, M.F. 2011. Chave ilustrada para as espécies de *Anastrepha* da Região Amazônica. In Moscas-das-frutas na Amazônia brasileira: diversidade, hospedeiros e inimigos naturais (R.A. SILVA, W.P. LEMOS & R.A. ZUCCHI, eds.). Embrapa Amapá, Macapá, p. 71-90.

ZUCCHI, R.A. 2000. Taxonomia. In Moscas-das-frutas de importância econômica no Brasil: conhecimento básico e aplicado (A. MALAVASI & R.A. ZUCCHI, eds.). Holos, Ribeirão Preto, p. 13-24.

*Received: 18/08/2017*
*Revised: 29/01/2018*
*Accepted: 15/02/2018*
*Published online: 05/03/2018*

Biota Neotropica 18(2): e20170410, 2018
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)

**Inventory**

# Hexapod decomposers of Serra de Santa Catarina, Paraíba, Brazil: an area with high potential for conservation of Caatinga biodiversity

*Matilde Vasconcelos Ernesto[1], Carolina Nunes Liberal[1], Aila Soares Ferreira[1], Ana Claudia Firmino Alves[1], Douglas Zeppelini[2], Celso Feitosa Martins[1], Alessandre Pereira-Colavite[1], Antônio José Creão-Duarte[1], Alexandre Vasconcellos[1]**

[1]*Universidade Federal da Paraíba Campus I, Departamento de Sistemática e Ecologia, João Pessoa, PB, Brasil*
[2]*Universidade Estadual da Paraíba Campus V, Departamento de Biologia, Centro de Ciências Biológicas e Sociais Aplicadas, João Pessoa-PB, Brasil*
**Corresponding author: Alexandre Vasconcellos, e-mail: alextermites@gmail.com*

ERNESTO, M. V., LIBERAL, C. N., FERREIRA, A. S., ALVES, A. C. F., ZEPPELINI, D., MARTINS, C. F., PEREIRA-COLAVITE, A., CREÃO-DUARTE, A. J., VASCONCELLOS, A. **Hexapod decomposers of Serra de Santa Catarina, Paraíba, Brazil: an area with high potential for conservation of Caatinga biodiversity**. Biota Neotropica. 18(2): e20170410. http://dx.doi.org/10.1590/1676-0611-BN-2017-0410

***Abstract:*** In detritus-based trophic systems, springtails, dung beetles, saprophagous calyptrate flies and termites consume and fragment organic matter and control populations of decomposer microorganisms, exerting a strong influence on energy and nutrient fluxes. A faunal inventory of these four groups of hexapods was performed in Serra de Santa Catarina (SSC), an area of arboreal-shrub caatinga located in the state of Paraíba, with the purpose of characterizing the assemblages of these taxa, and highlighting their unique links to the local ecosystem. Samplings were performed in May, 2014, and April, 2015, both during the rainy season. Standard sampling protocols for biodiversity inventory of the various taxa were used, including both active and passive sampling methods. In general, 114 species of hexapods were captured, with 26 species of springtails, 20 dung beetles, 30 saprophagous calyptrate flies and 38 termites, with sampling sufficiency varying from 69.5 to 96.8% of total estimated richness. Species richness of the groups are among the highest recorded for a single area of Caatinga, with some taxa being recorded for the first time for the domain. Several morphospecies had indeterminate taxonomic *status*, especially springtails and termites, and are quite likely new species to science. The structure of the assemblages of springtails, dung beetles, saprophagous calyptrate flies and termites recorded in SSC, suggest that this conserved area is unique within the highly impacted landscape of Caatinga, and has great potential for the conservation of biodiversity of this domain in the Northeast Region of Brazil.

***Keywords:*** *Coleoptera, Collembola, Diptera, Isoptera, Seasonally Dry Tropical Forests, Semiarid.*

# Hexápodes decompositores da Serra de Santa Catarina, Paraíba, Brasil: uma área com elevado potencial para a conservação da biodiversidade da caatinga

***Resumo:*** No sistema trófico baseado em detritos, os colêmbolos, besouros escarabeíneos, moscas saprófagas e térmitas atuam no consumo e fragmentação da matéria orgânica e no controle das populações de microrganismos decompositores, exercendo forte influência nos fluxos de energia e nutrientes. Um inventário faunístico desses quatro grupos de hexápodes foi realizado na Serra de Santa Catarina (SSC), uma área de Caatinga arbóreo-arbustiva localizada no Estado da Paraiba, com intuito de caracterizar as taxocenoses desses táxons, salientando as suas peculiaridades ligadas ao ecossistema local. As coletas foram realizadas em maio/2014 e abril/2015, durante o período chuvoso na região. De acordo com o táxon, foram utilizados protocolos amostrais padronizados para inventários de biodiversidade, com métodos passivos e ativos de coleta. No geral, 114 espécies de hexápodes foram capturadas, sendo 26 de colêmbolos, 20 de besouros escarabeíneos, 30 de dípteros e 38 de térmitas, com suficiência amostral variando de 69,5 a 96.8% da total estimada. A riqueza de espécies por grupo está entre as maiores para uma única área de Caatinga, com alguns táxons sendo registrados pela primeira vez para o domínio. Especialmente para os colêmbolos e térmitas, várias morfoespécies tiveram seus *status* taxonômicos indeterminados, havendo elevada possibilidade de serem nova para a ciência. As estruturas e funcionalidades das taxocenoses de colêmbolos, besouros escarabeíneos, moscas saprófagas e térmitas registradas na SSC, sugerem que esse ecossistema é singular, dentro de um cenário generalizado de impacto antrópico presente na Caatinga, e possui um elevado potencial para a conservação da biodiversidade desse domínio no nordeste brasileiro.

***Palavras-chave:*** *Coleoptera, Collembola, Diptera, Florestas Tropicais Sazonalmente Secas, Isoptera, Semiárido.*

## Introduction

Hexapods comprise a large group of Arthropoda and represent significant evolutionary success as indicated by their great diversity among ecosystems of the world. The subphylum Hexapoda is divided into two taxa: Entognatha (Collembola, Protura and Diplura) and Insecta (Brusca & Brusca 2013). These groups perform several fundamental processes for terrestrial ecosystems, especially in the tropics, such as nutrient cycling, soil aeration, energy flux, pollination and seed dispersal (Gullan & Cranston 2008).

Detritus-based trophic systems contain several invertebrate groups that consume and fragment organic matter and control populations of decomposing microorganisms, among which springtails, dung beetles, saprophagous calyptrate flies and termites stand out (Coleman et al. 2004, Lavelle & Spain 2005). Springtails are among the most abundant representatives of soil fauna (Cassagne et al. 2003), with more than 8,000 described species (Bellinger et al. 1996-2017). Dung beetles (Scarabaeidae *sensu stricto*) represent an important component of tropical ecosystems with more than 6,200 described species (Tarasov & Génier 2015). The saprophagous calyptrate flies, families Calliphoridae, Sarcophagidae, Muscidae and Fanniidae, are notable for their role in the decomposition of organic matter of animal origin (Cornaby 1974); these families together account for about 9,000 described species distributed throughout the world (Carvalho et al. 2012). Lastly, termites account for high amounts of biomass in tropical regions, especially between the tropics of Cancer and Capricorn, with approximately 3,000 described species throughout the world (Vasconcellos 2010, Krishna et al. 2013).

The Caatinga domain is a mosaic of thorny shrub land and dry forests located in the semiarid region of northeastern Brazil (Leal et al. 2005), and composes the largest continuous complex of Seasonally Dry Tropical Forests (Särkinen et al. 2015). The biodiversity of the Caatinga has always been stigmatized as being poor and with low levels of endemism, but over the last decade this thinking has progressively changed (Santos et al. 2011, Bravo & Calor 2014). Even with many areas not yet well known to science, the Caatinga has been subjected to heavy anthropic pressure, especially related to the removal of plant biomass and unbridled hunting of vertebrates (Leal et al. 2005, Portillo-Quintero & Sánchez-Azofeifa 2010, Santos et al. 2011).

Studies on hexapod biodiversity can generate a rich database that can support conservation actions, both locally and regionally. According to Leivas & Carneiro (2012), hexapods can serve as informative indicators of habitat quality because they exhibit relative sedentarism, are easily sampled, perform wide range of ecological functions, influence primary and secondary productivity of terrestrial ecosystems, exhibit microhabitat fidelity and possess short life cycles. The present study undertook a faunal inventory of four selected groups of hexapod decomposers (springtails, dung beetles, saprophagous calyptrate flies and termites) in Serra de Santa Catarina (SSC), an unique area of arboreal-shrub Caatinga with high potential value for conservation of the biodiversity of this domain in the state of Paraíba, in order to characterize their assemblages, and highlighting their peculiarities associated with the local ecosystem.

## Material and Methods

### 1. *Study area*

Serra de Santa Catarina (SSC) is located in the caatinga region of the state of Paraíba (centered approximately at 7°00’46’’S, 38°11’12’’W) (Figure 1), and extends for approximately 25 km encompassing an area of approximately 112.1 km², from the Olho d’água do Frade (municipality of Nazarezinho) to the stream Saco dos Bois (São José da Lagoa Tapada) (Brandão et al. 2009), reaching elevations of over 830 m at some points (Sousa 2011). The area contains one of the few patches with arboreal formation in the Caatinga dominion in the state of Paraíba, but has undergone intense degradation with the withdrawal of vegetal biomass and illegal hunting. The predominant soil type is Litholic Neosol and there is a vegetative gradient of caatinga from shrubby, to arboreal-shrubby, to arboreal to forest patches, along the elevational gradient. Its phytogeographic system is classified as seasonal deciduous caatinga forest, forested savanna steppe and forest (IBGE 2012).

The climate is As (dry tropical) according to the Köppen classification (Alvares et al. 2013), with seven to eight dry months and irregular annual precipitation. The mean annual temperature of the area is 24.3ºC with an average annual rainfall of 892 mm, according to data obtained from WorldClim with a resolution of 30 arc-seconds (http://www.worldclim.org).

### 2. *Faunistic Inventory*

Samplings were made in May, 2014, and April, 2015, during the rainy period of the region. Standardized biodiversity sampling protocols for each specific taxa were used. Specimens of springtails, dung beetles, saprophagous calyptrate flies were collected passively with traps. Active collections were employed for termite and also springtails. Ten points separated by at least 100 m were randomly selected for passive sampling. Sets of traps were installed at each point for collecting springtails, dung beetles, saprophagous calyptrate flies, which were exposed for 48 h. Termites were sampled through active searches along six 65x2 m transects each with five 5x2 m plots spaced at 10 m. Transects were distributed with a minimum distance of 50 m from the border of the area and between transects.

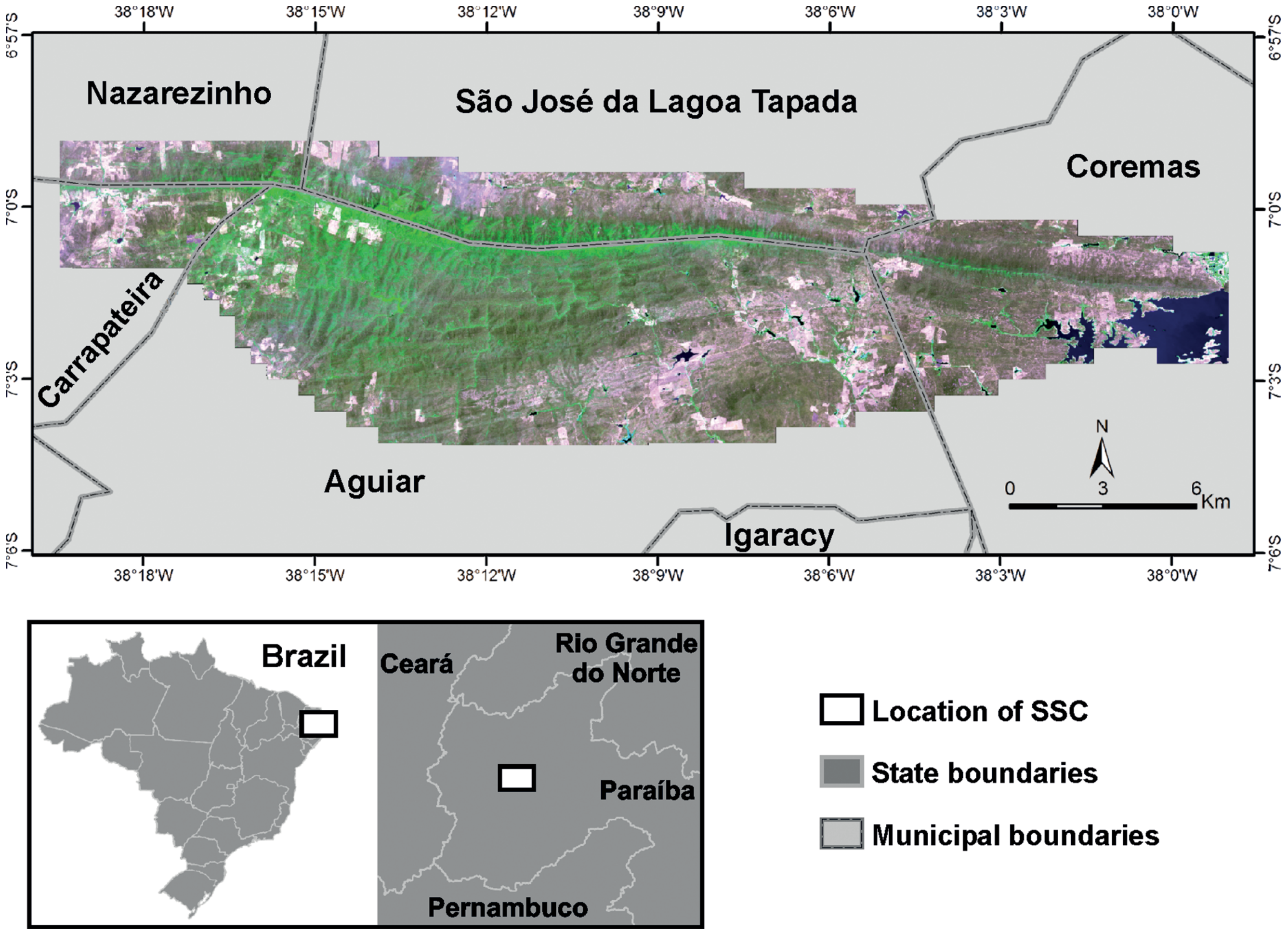

**Figure 1.** Location of Serra de Santa Catarina, Paraiba State, NE, Brazil.

### 2.1. Springtails

For sampling springtails, five pitfalls (diameter 11 cm, height 7 cm) were installed at each sampling point arranged in a cross and separated from each other by 1 m (Figure 2A). No bait was used and 70% alcohol was added to fix specimens. A Styrofoam disc was placed about 15 cm above the soil surface over each trap to protect against direct sunlight, litter fall and rain. A 30 min/person active search was performed at each point using an entomological aspirator. A Winkler extractor was also used to collect springtails in 1 $m^2$ of litter per point, remaining active for six days (Querner & Bruckner 2010). Sampling material was deposited in the Universidade Estadual da Paraíba (UEPB)

### 2.2. Dung beetles

Dung beetles were collected at each point with an array of four pitfalls (diameter 9.5 cm, height 20 cm) arranged in a square. Each array was composed of two traps baited with human feces (Figure 2C) and two with meat (rotten bovine spleen) (Figure 2D), distributed alternately in each of the vertices of the square array and separated by 3 m from each other. These are common baiting for dung beetles (Favila & Halffter 1997, Milhomen et al. 2003). Originally with coprophagous habits, South American dung beetles diversified their diet after the extinction of mammal megafauna in the Pleistocene epoch, resulting in reduction of dung supply and increasing availability of carcasses as substrate, leading to new feeding habits, like necrophagy (Halffter & Edmonds 1982; Halffer 1991).

Styrofoam discs were placed over the traps. After 48 h of exposure, trapped specimens were transferred to properly labeled containers containing 70% alcohol. The collected material was deposited in the Universidade Federal da Paraíba (UFPB).

### 2.3. Saprophagous calyptrate flies

Saprophagous calyptrate flies were collected at each point using a set of four traps (Figure 2E), separated by at least 10 m from each other. Although most of these flies have necrophagous habits (Souza & Linhares 1997), some synatropic species are attracted by human feces and decaying organic vegetable matter (Carvalho et al. 2002), assuming coprophagous and saprophagous habits. To sampling all calyptratae Diptera in the study areas (Souza & Linhares 1997; Carvalho et al. 2002), the traps were baited with about 100 g of four types of lure (Figure 2B): decaying sardine, meat (bovine spleen) and banana, and human feces. At the end of exposure, the collected dipterans were placed in a killing jar containing cotton soaked in ethyl acetate, and then transferred to properly labeled containers with 70% alcohol. The collected material was deposited in the Universidade Federal da Paraíba (UFPB).

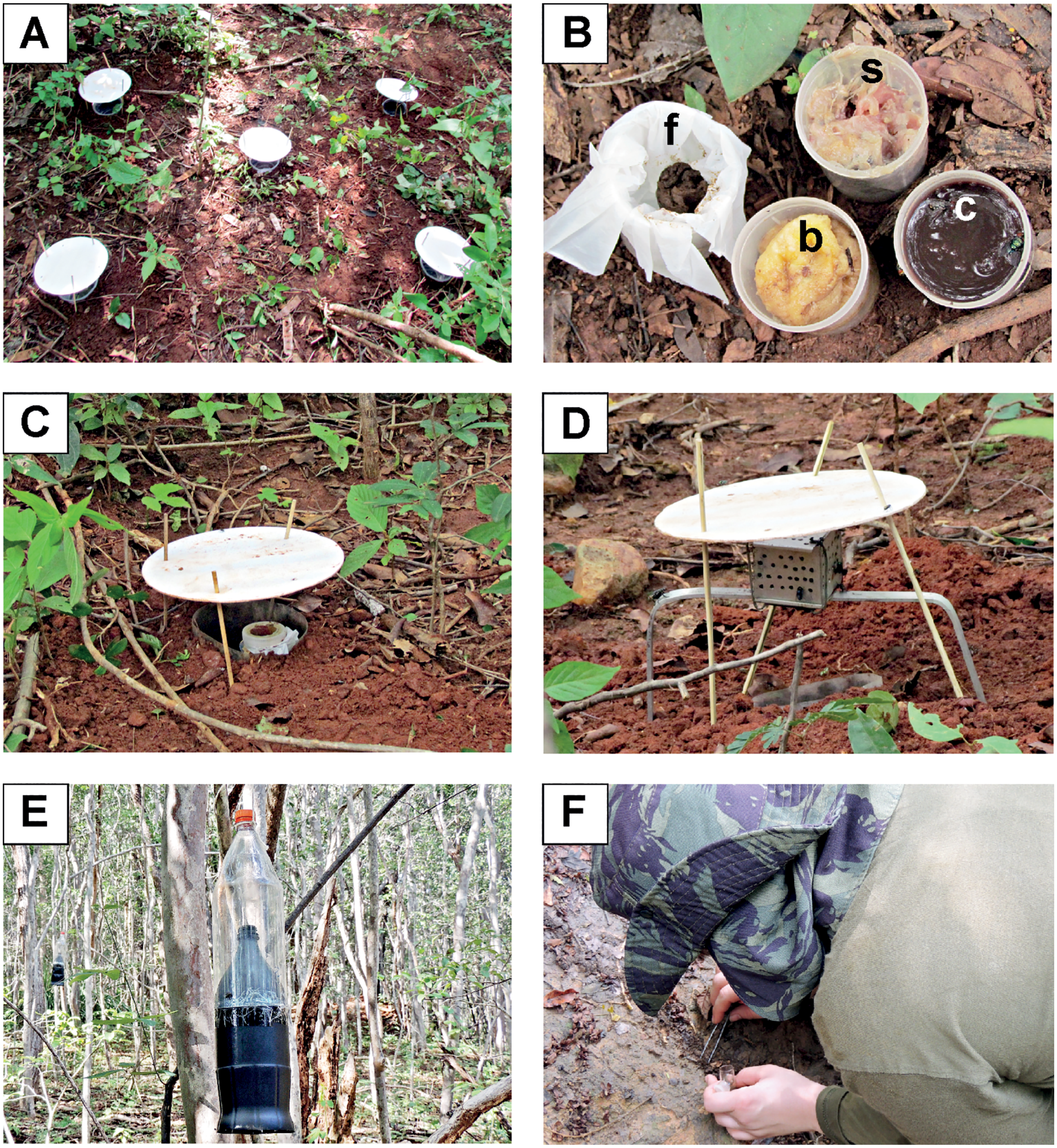

**Figure 2.** Sampling methods for sampling the diversity of springtails, dung beetles, saprophagous calyptrate flies and termites, in May, 2014, and April, 2015, in Serra de Santa Catarina, state of Paraíba, Brazil. A. Arrangement of pitfalls for collecting species of springtails; B. Baits: feces (f), sardines (s), banana (b) and bovine spleen (c); C. pitfalls baited with feces installed for collecting dung beetles; D. pitfalls baited with bovine spleen installed for collecting dung beetles; E. Traps for capturing saprophagous calyptrate flies installed in the field; F. Active search for termites in a 10-m² plot.

### 2.4. Termites

Termites were sampled from thirty 5x2 m plots for a total of 300 m² each year (Cancello et al. 2002). Plots were sampled for 1 h x person, during which termites were sought in active and abandoned nests, tunnels, live and dead tree trunks, foliage, inside and under fallen branches, in the ground, under rocks and in dead roots (Figure 2F). Sub-samples, mainly soldiers, were collected from colonies found in the plots. Samples were preserved in 80% alcohol. The species were categorized into food groups according to Vasconcellos et al. (2010), Vasconcellos & Moura (2014) and from *in situ* observations of feeding habits. The collected material was deposited in the Universidade Federal da Paraíba (UFPB).

### 3. *Analyses*

Species accumulation curves and estimates of species richness were obtained using EstimateS 9.1.0 software (Colwell 2016), with 1,000 randomizations without replacement. In the case of termites, the frequency of occurrence of encounters in the plots was treated as an indirect measure of relative abundance. One-way analysis of variance was performed to compare the species richness and abundance according to the bait type. The data were analyzed using Statistica 8.0 (Statsoft 2007). The assumptions of ANOVA were tested.

## Results

A total of 114 species of hexapods were captured, with 26 species of springtails, 20 dung beetles, 30 saprophagous calyptrate flies and 38 termites (Tables 1, 2, 3 and 4). The numbers of individuals were 2,326 of springtails, 1,303 of dung beetles and 7,669 saprophagous calyptrate flies. There were 287 encounters with termites in the plots.

### 1. *Springtails*

A total of 26 species of springtails were collected representing 11 families and 17 genera (Table 1). The family Entomobryidae had the greatest richness with eight species, four of which were new to science. *Seira* and *Lepidocyrtus* were the richest genera with five and three species, respectively. The species gen.n.1 of the family Bourletiellidae was the most abundant, with 493 individuals, followed by *Sphaeridia* sp., with 466 individuals. According to the mean estimated species richness, 96.83% of the species of Collembola at SSC were sampled (Sobs=26; Sest mean=26.85) (Figure 3).

### 2. *Dung beetles*

A total 1,303 dung beetles were recorded of 20 species distributed among eight genera (Table 2). The genera with the greatest species richness were *Canthon* (eight species) and *Deltochilum* (four species). The most abundant species was *Canthon chalybaeus* (N=674). Two other species of this genus, *C. mutabilis* and *C. simulans*, as well as the genus *Eutrichillum*, represented by *E. hirsutum*, were recorded for the first time in the Caatinga. It was estimated that 89.89% of the species of beetles at SSC were sampled (Sobs=20; Sest mean=22.25) (Figure 3). No significant difference was found in dung beetles abundance (F=0.12327; d.f.=1;38; p=0.73) and species richness (F=3.2208;

**Table 1.** Springtails collected during the rainy period (May, 2014, and April, 2015) in Serra de Santa Catarina, state of Paraíba, Brazil.

| Taxon | Abundance |
|---|---|
| PODUROMORPHA | |
| **Brachystomellidae** | |
| *Brachystomella agrosa* Wray, 1953 | 139 |
| *Brachystomella* sp.n.1 | 1 |
| **Hypogastruridae** | |
| *Xenylla* sp.1 | 11 |
| **Neanuridae** | |
| *Neotropiella* sp.1 | 28 |
| *Neotropiella* sp.2 | 54 |
| ENTOMOBRYOMORPHA | |
| **Entomobryidae** | |
| *Lepidocyrtus nigrosetosus* Folsom, 1927 | 25 |
| *Lepidocyrtus* sp. n.1 | 44 |
| *Lepidocyrtus* sp. n.2 | 18 |
| *Seira paraibensis* Bellini & Zeppelini, 2009 | 47 |
| *Seira mirianae* Arlé & Guimaraes, 1981 | 56 |
| *Seira* ritae Bellini & Zeppelini, 2011 | 111 |
| *Seira* sp. n.1 | 41 |
| *Seira* sp. n.2 | 55 |
| **Isotomidae** | |
| *Isotomiella* sp. | 11 |
| *Isotomurus* sp. | 28 |
| *Paracerura* sp. | 13 |
| *Proisotoma* sp. | 17 |
| **Paronellidae** | |
| *Trogolaphysa* sp. | 26 |
| SYMPHYPLEONA | |
| **Bourletiellidae** | |
| gen.n.1 | 493 |
| *Stenognathriopes janssensi* Zeppelini & Silva, 2012 | 108 |
| **Dicyrtomidae** | |
| *Calvatomina* sp. | 22 |
| **Sminthuridae** | |
| *Temeritas* sp. | 233 |
| *Varelasminthurus potiguarus* Silva & Bellini, 2015 | 49 |
| **Sminthurididae** | |
| *Sphaeridia heloisea* | 52 |
| *Sphaeridia* sp. | 466 |
| **Katiannidae** | |
| *Sminthurinus* sp. | 178 |
| **Total number of individuals** | **2,326** |
| **Total number of species** | **26** |

**Table 2.** Dung beetles collected during the rainy period (May, 2014, and April, 2015) in Serra de Santa Catarina, state of Paraíba, Brazil.

| **Taxon** | **Abundance** | | **Total** |
|---|---|---|---|
| | **Meat** | **Feces** | |
| **Ateuchini** | | | |
| *Eutrichillum hirsutum* (Boucomont, 1928) | 27 | | 27 |
| *Trichillum externepunctatum* Preudhomme de Borre, 1886 | 6 | 1 | 7 |
| *Uroxys* sp. | 6 | 40 | 46 |
| **Canthonini** | | | |
| *Canthon mutabilis* Lucas, 1857 | 1 | | 1 |
| *Canthon simulans* (Martínez, 1950) | | 5 | 5 |
| *Canthon chalybaeus* Blanchard, 1843 | 409 | 265 | 674 |
| *Canthon* sp.1 | 1 | | 1 |
| *Canthon* sp.2 | 12 | 3 | 15 |
| *Canthon* sp.3 | 39 | 84 | 123 |
| *Canthon* sp.4 | 1 | 5 | 6 |
| *Canthon* sp.5 | 7 | 8 | 15 |
| *Deltochilum pseudoicarus* Balthasar, 1939 | 8 | | 8 |
| *Deltochilum verruciferum* Felsche, 1911 | 4 | 1 | 5 |
| *Deltochilum* aff. *irroratum* (Laporte, 1840) | 31 | 10 | 41 |
| *Deltochilum* sp. | 40 | 12 | 52 |
| **Coprini** | | | |
| *Dichotomius geminatus* (Arrow, 1913) | 16 | 1 | 17 |
| *Dichotomius nisus* (Olivier, 1789) | | 3 | 3 |
| *Dichotomius puncticollis* (Luederwaldt, 1935) | 1 | | 1 |
| **Onthophagini** | | | |
| *Onthophagus* aff. *ranunculus* Arrow, 1913 | 19 | 173 | 192 |
| **Phanaeini** | | | |
| *Coprophanaeus cyanescens* (Olsufieff, 1924) | 64 | | 64 |
| **Total number of individuals** | **692** | **611** | **1,303** |
| **Total number of species** | **18** | **14** | **20** |

d.f.=1;38; p=0.08) among the baits; 692 specimens belonging to 18 species were found on meat and 611 specimens of 14 species were found on feces bait. However, evaluating the species composition, it was found that *Coprophanaeus cyanescens* and *Eutrichillum* sp. occurred exclusively in meat baits.

## 3. *Saprophagous calyptrate flies*

A total of 7,669 saprophagous flies were collected of 30 species distributed among four families (Table 3). Sarcophagidae was the richest family (S=15), followed by Calliphoridae (S=7), Muscidae (S=6) and Faniidae (S=2). With regard to abundance, Calliphoridae surpassed all other families with 78% of the specimens collected. According to the mean estimated species richness, 92.26% of the species of the area were sampled (Sobs=31; Sest mean=33.6) (Figure 3). Significant difference was found in abundance (F=15.864; d.f=3;76; p<0.0001) and species richness (F=140.72; d.f.=3;76; p<0.0001) of saprophagous flies among the baits. There was no difference in abundance (p=0.84) and species richness (p=0.83) between the most attractive baits, meat (N=4.150) and sardine (N=3.506). The traps baited with banana (N=7) and feces (N=6) showed little attractiveness to the studied families, showing no significant difference between abundance (p=1.00) and species richness (p=0.99).

## 4. *Termites*

Thirty-eight species of termites, representing 23 genera and three families, were recorded for the area (Table 4), with a total of 287 encounters. In general, the family Termitidae was the most represented both with regard to species richness (89%), and frequency of encounters (90%). In relation to feeding habits, consumers of wood and consumers of humus were dominant. Eight termite species construct conspicuous nests, seven of which are arboreal-type and one epigeous-type. Nests of *Syntermes cearensis* were abundant in the landscape of the area, and these nests represented more than 11% of all. According to the mean estimated species richness, 69.52% of the species of the area were sampled (Sobs=38; Sest mean=54.66) (Figure 3).

**Table 3.** Saprophagous calyptrate flies collected during the rainy period (May, 2014, and April, 2015) in Serra de Santa Catarina, state of Paraíba, Brazil.

| **Taxon** | **Abundance** | | | | **Total** |
|---|---|---|---|---|---|
| | **Meat** | **Sardine** | **Feces** | **Banana** | |
| **Calliphoridae** | | | | | |
| *Chloroprocta idioidea* (Robineau-Desvoidy, 1830) | 103 | 74 | - | - | 177 |
| *Chrysomya albiceps* (Wiedemann, 1819) | 1,838 | 2,416 | - | - | 4,254 |
| *Chrysomya megacephala* (Fabricius, 1794) | 1,107 | 212 | - | - | 1,319 |
| *Chrysomya putoria* (Wiedemann, 1818) | 18 | 17 | - | - | 35 |
| *Cochliomyia hominivorax* (Coquerel, 1858) | - | 1 | - | - | 1 |
| *Cochliomyia macellaria* (Fabricius, 1775) | 106 | 67 | - | - | 173 |
| *Lucilia eximia* (Wiedemann, 1819) | 44 | 11 | - | - | 55 |
| **Sarcophagidae** | | | | | |
| *Microcerella halli* (Engel, 1931) | 1 | 4 | - | - | 5 |
| *Oxysarcodexia amorosa* (Schiner, 1868) | 4 | 3 | - | - | 7 |
| *Oxysarcodexia thornax* (Walker, 1849) | 13 | 30 | - | - | 43 |
| *Peckia (E.) collusor* (Curran & Walley, 1934) | 9 | 7 | - | - | 16 |
| *Peckia (P.) pexata* (Wulp, 1895) | 17 | 31 | - | - | 48 |
| *Peckia (S.) lambens* (Wiedemann, 1830) | 13 | 11 | - | - | 24 |
| *Peckia (S.) ingens* (Walker, 1849) | 2 | 2 | - | - | 4 |
| *Peckia (P.) chrysostoma* (Wiedemann, 1830) | 1 | - | - | - | 1 |
| *Ravinia belforti* (Prado & Fonseca, 1932) | 4 | 4 | - | - | 8 |
| *Ravinia effrenata* (Walker, 1861) | 1 | - | - | - | 1 |
| *Retrocitomyia mizuguchiana* Tibana & Xerez, 1985 | 6 | - | - | - | 6 |
| *Sarcofahrtiopsis cuneata* (Townsend, 1935) | 1 | - | - | - | 1 |
| *Sarcophaga (L.) crispina* Lopes, 1938 | - | 1 | - | - | 1 |
| Sarcophagidae sp. | 1 | 3 | - | - | 4 |
| Sarcophagidae spp. (fêmeas) | 266 | 234 | 6 | 1 | 507 |
| **Muscidae** | | | | | |
| *Atherigona orientalis* Schiner, 1868 | 45 | 37 | - | - | 82 |
| *Neomuscina goianensis* Lopes & Khouri, 1995 | 5 | 3 | - | 1 | 9 |
| *Neomuscina snyderi* Pereira-Colavite & Carvalho, 2012 | 11 | 15 | - | 1 | 27 |
| *Neomuscina stabilis* (Stein, 1911) | 5 | 4 | - | - | 9 |
| *Ophyra aenescens* (Wiedemann, 1830) | 20 | 2 | - | - | 22 |
| *Synthesiomyia nudiseta* (Wulp, 1883) | 14 | 8 | 1 | - | 23 |
| **Fanniidae** | | | | | |
| *Fannia pusio* (Wiedemann, 1830) | 442 | 263 | - | - | 705 |
| *Fannia* sp. | 53 | 46 | - | 3 | 102 |
| **Total number of individuals** | **4,150** | **3,506** | **7** | **6** | **7,669** |
| **Total number of species** | **29** | **26** | **2** | **1** | **30** |

**Tabela 4.** Termites sampling during the rainy period (May, 2014, and April, 2015) in Serra de Santa Catarina, state of Paraíba, Brazil.

| **Taxon** | **Relative abundance** | **Nesting*** | **Feeding group**** |
|---|---|---|---|
| **Kalotermitidae** | | | |
| *Rugitermes* sp. | 2 | Wo | W |
| **Rhinotermitidae** | | | |
| *Coptotermes testaceus* (Linnaeus, 1758) | 1 | So/Wo | W |
| *Heterotermes longiceps* (Snyder, 1924) | 23 | So/Wo | W |
| *Heterotermes sulcatus* Mathews, 1977 | 1 | So/ Wo | W |
| **Termitidae** | | | |
| Apicotermitinae | | | |
| *Anoplotermes* sp.1 | 16 | So | S |
| *Anoplotermes* sp.2 | 3 | So | S |
| *Anoplotermes* sp.3 | 3 | So | S |
| *Aparatermes* sp.1 | 1 | So | S |
| *Grigiotermes* sp.1 | 1 | So | S |
| *Grigiotermes* sp.2 | 3 | So | S |
| *Ruptitermes reconditus* (Silvestri, 1901) | 21 | Li | L |
| *Ruptitermes* sp.1 | 7 | Li | L |
| *Ruptitermes* sp.2 | 1 | Li | L |
| Nasutitermitinae | | | |
| *Atlantitermes* sp.1 | 1 | Wo? | W/S |
| *Constrictotermes cyphergaster* (Silvestri, 1901) | 6 | Ar | W |
| *Diversitermes diversimiles* (Silvestri, 1901) | 19 | Li | W/L |
| *Nasutitermes callimorphus* Mathews, 1977 | 4 | Wo | W |
| *Nasutitermes corniger* (Motschulsky, 1855) | 23 | Ar | W |
| *Nasutitermes ephratae* (Holmgren, 1910b) | 20 | Ar | W |
| *Nasutitermes macrocephalus* (Silvestri, 1903) | 1 | Ar | W |
| *Nasutitermes* sp.1 | 1 | ? | W |
| *Nasutitermes* sp.2 | 1 | ? | W |
| *Nasutitermes* sp.3 | 1 | X | W |
| *Subulitermes* sp. | 1 | So | S |
| *Velocitermes aporeticus* (Mathews, 1977) | 4 | Li | W/L |
| Syntermitinae | | | |
| *Labiotermes emersoni* (Araujo, 1954) | 8 | So | S |
| *Silvestritermes euamignathus* (Silvestri, 1901) | 1 | Ar | S |
| *Syntermes cearensis* Constantino, 1995 | 33 | Ep | L |
| *Syntermes molestus* (Burmeister, 1839) | 10 | So | L |
| Termitinae | | | |
| *Amitermes amifer* Silvestri, 1901 | 8 | Wo | W/S |
| *Cylindrotermes sapiranga* Rocha & Cancello, 2007 | 14 | Wo | W/S |
| *Inquilinitermes fur* (Silvestri, 1901) | 1 | In | S |
| *Inquilinitermes microcerus* (Silvestri, 1901) | 2 | In | S |
| *Microcerotermes indistinctus* Mathews, 1977 | 28 | Ar | W |
| *Microcerotermes strunckii* (Soerensen, 1884) | 3 | Ar | W |
| *Neocapritermes opacus* (Hagen, 1858) | 5 | So | S |
| *Spinitermes trispinosus* (Hagen, 1858) | 2 | So | S |
| *Termes fatalis* Linnaeus, 1758 | 7 | In | W/S |
| **Total number of individuals** | **287** | | |
| **Total number of species** | **38** | | |

***Nesting:** So, soil; Wo, wood; Li, litter; Ep, epigeous nest; Ar, arboreal nest; In, inquiline, termites which inhabit nests built by other termite species.

****Feeding groups:** W, wood-feeding; S, soil-feeding; W/S, interface wood/soil-feeding; L, leaf-feeding; X/L, interface wood/leaf-feeding.

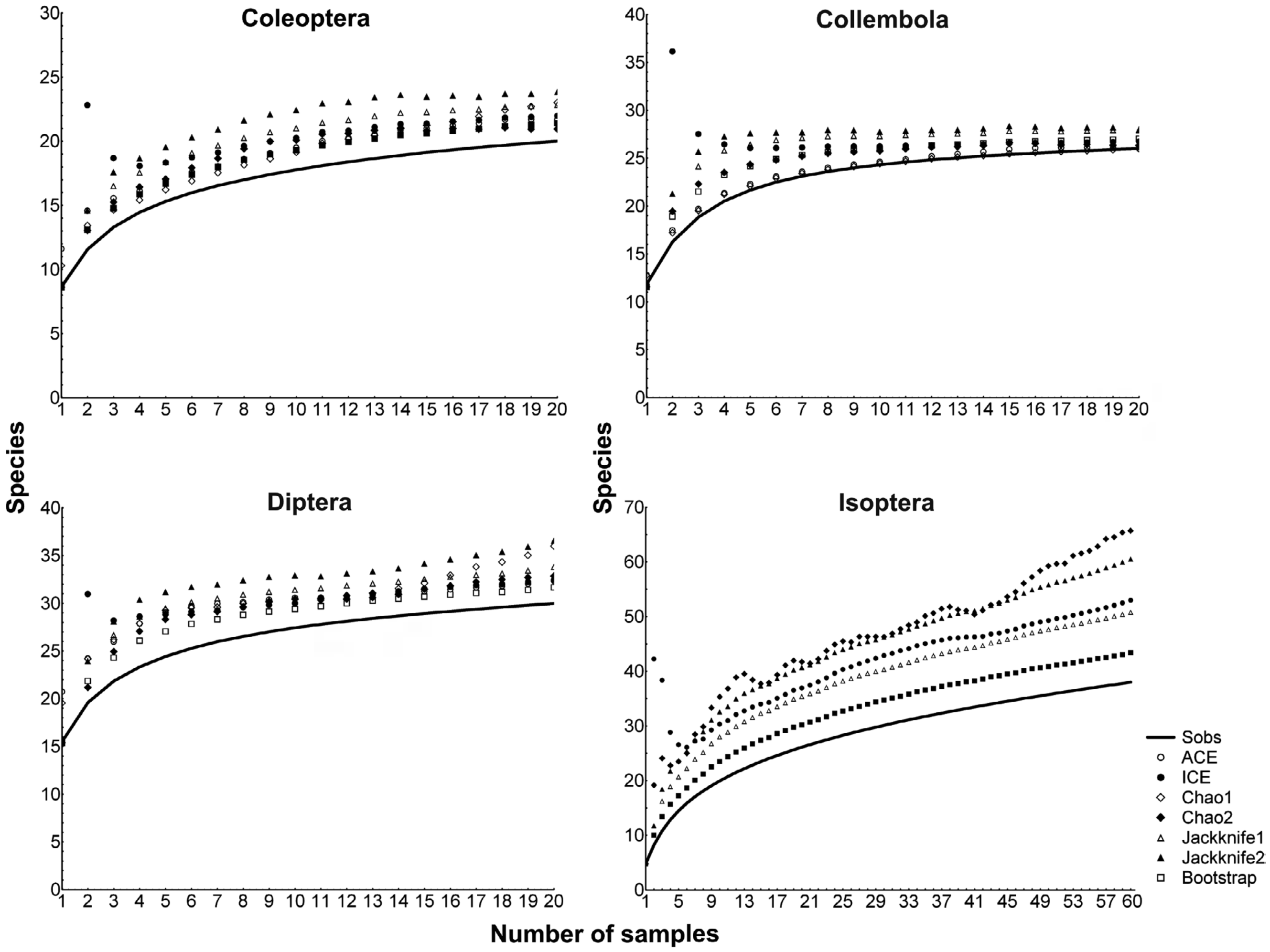

**Figure 3.** Species accumulation curve and the performance of estimators for each taxon. * For termites only estimators based on incidence data were analyzed (ICE, Chao2, Jackknife 1 and 2, and Bootstrap).

## Discussion

According to the groups of hexapod decomposers studied, Serra de Santa Catarina stands out in terms of species richness for the Caatinga, possessing assemblages of springtails, dung beetles, saprophagous calyptrate flies and termites characteristic of a conserved area. In addition to new records for science, the species richness of springtails (S=26), saprophagous flies (S=30) and termites (S=38) of SSC are among the highest recorded for an area of Caatinga in Northeast Brazil (Vasconcellos et al. 2010, Santos-Rocha et al. 2011, Ferreira et al. 2013, Alves et al. 2014, Vasconcellos & Moura 2014, Vasconcelos & Salgado 2014). For the dung beetles, the total richness observed (S=20) was greater or close to that found in other areas of Caatinga in Northeast Brazil (S=4-23) and identical to two other areas of Caatinga in the state of Paraíba (Hernández 2005, 2007, Lopes et al. 2006, Liberal et al. 2011, Salomão 2012, Salomão & Iannuzzi 2017).

Species richness recorded for Collembola in the Caatinga ranges from 2 to 15 (Bellini & Zeppelini 2009, Santos-Rocha et al. 2011, Ferreira et al. 2013), with the genus *Seira* being dominant with 17 species. Bellini & Zeppelini (2009) state that the Northeast Region of Brazil is, possibly, one of the areas of greatest species richness for the genus *Seira* in the world. The richness of Colembolla encountered in SSC is similar to that of the Atlantic Forest, which ranges from 17 to 25 species (Bellini & Zeppelini 2009). Approximately 23% of the species recorded in SSC are new to science and, if conservation measures are not adopted in the area, part of this fauna could be lost without ever being known.

Among the dung beetles, the most abundant species, *Canthon chalybaeus*, is found in open areas of wet forests, such as the Amazon Forest (Scheffler 2005, Silva et al. 2014) and the Atlantic Forest (Costa et al. 2009, Silva et al. 2010, Filgueiras et al. 2015), but has also been recorded in areas of Brejo de Altitude (Silva et al. 2007), Restinga (Costa et al. 2014) and Cerrado – in a area of transition with the Atlantic Forest (Durães et al. 2005). Because it is characteristic of open areas and is generally associated with humid environments (Scheffler 2005, Costa et al. 2009, 2013, 2014), this species seems to be well adapted to the peculiar conditions found in the Caatinga, such as high temperatures and low humidity, when the environment possesses well conserved forest structure. The genus *Eutrichillum* was recorded in this study for the first time from the Caatinga, represented by *E. hirsutum*. This species occurred only in the meat bait, as expected, once it usually presents a necrophagous behavior (Vaz-de-Mello 2008). This genus has a disjunct distribution, occurring in the Chaco, Paraná, Amazon sub-regions, Cerrado, Central America and the Caribbean (Vaz-de-Mello 2008, Andrade et al. 2011). In general, the other species recorded at SSC are widely distributed in open areas (ex.: *Trichillum externepunctatum*) or characteristic of the Caatinga (ex.: *Deltochilum verruciferum*, *Dichotomius geminatus* and *Dichotomius puncticollis*) (Lopes et al. 2006, Almeida & Louzada 2009, Costa et al. 2009). The occurrence of *Coprophanaeus cyanescens* is particularly notable. This species possesses a wide distribution, being found in areas of Atlantic Forest, Brejo de Altitude, Caatinga and Cerrado, but with less abundance in the latter two environments (Lopes et al. 2006, Silva et al. 2007, Costa et al. 2009, Gillett et al. 2010, Filgueiras et al. 2015). Large-sized species, such as those of the genus *Coprophanaeus*, are more affected by the structure of the environment and, in general, are restricted to well-conserved forest habitats (Klein 1989, Filgueiras et al. 2011). Species of this genus are mostly necrophagous (Halffter & Edmonds 1982) and occurred in the SSC only in the meat baits. Most of dung beetles of the SSC were not selective for the baits used in the present study. In relation to the resource exploitation, the feeding behavior of the dung beetle is, in general, opportunistic (Hanski and Cambefort, 1991). This trophic generality tends to decrease the competition for ephemeral and/or scarce food resources (Silva 2011) and to enhance the ability to explore the environment and to resist to the food shortage periods.

Among the calyptrate flies, the species *Peckia (E.) collusor*, *Peckia (S.) ingens*, *Sarcofahrtiopsis cuneata* (Sarcophagidae), *Neomuscina goianensis*, *Neomuscina snyderi* and *Neomuscina stabilis* (Muscidae) are recorded for the first time from the Caatinga. The absence of *Musca domestica* among the representatives collected of the family Muscidae, may be indicative of a good state of conservation of the area, since this species is predominantly associated with human and/or degraded environments (Carvalho et al. 2002).

The abundance of calliphorids in SSC was due to the presence of *Chrysomya albiceps* and *Chrysomya megacephala*, introduced species that are currently distributed throughout Brazil due to their considerable abilities for dispersion and acclimatization (Guimarães et al. 1979). Their establishment in the Caatinga is due to their aggressive behavior, high fecundity, dispersal capacity and short life cycle (Alves et al. 2014). These species may represent threats to populations of native species (Faria et al. 1999, Vasconcelos & Salgado 2014), although there are no reports of competitive exclusion due to their presence in Caatinga ecosystems.

The high species richness of sarcophagids in SSC was similarly observed in other inventories carried out in a variety of different Brazilian ecosystems (Carvalho & Linhares 2001, Barros et al. 2008, Barbosa et al. 2009, Vairo et al. 2011, Rosa et al. 2011, Vasconcelos et al. 2015). However, the species composition differs among these environments. These flies, unlike the calliphorids, seem to be more sensitive to the selective pressures of the environment, and are associated only with certain environments or climates. Studies on Sarcophagidae of the Caatinga are scarce, and the data for this family are restricted to distribution notes and species lists (Alves et al. 2014). The other studies in the Northeast are restricted to humid forests, such as the Atlantic Forest (Lopes 1974, Vasconcelos & Araújo 2012, Vasconcelos et al. 2013, Barbosa et al. 2017).

Rotten meat and sardine showed potential for collection of these flies, evidencing the necrophilic habit of the families. D'Almeida (1992) studied the attractiveness of Muscidae and Anthomyidae using the same baits, and found that fish is the most attractive lure. Similar results were found for Calliphoridae and Sarcophagidae (d'Almeida & Lopes 1983; d'Almeida 1984). D'Almeida e Fraga (2007) using five different baits found similar results, rotten sardine was the most attractive bait, followed by bovine liver; traps baited with fermented banana were unsuccessful in collecting flies of these families.

The species richness of termites at SSC, when compared to other areas of the Caatinga, is the greatest yet recorded for a single area (Mélo & Bandeira 2004, Vasconcellos et al. 2010, Alves et al. 2011, Vasconcellos & Moura 2014). Fourteen species (36%) are of indeterminate taxonomic *status*, with great likelihood that they a species new to science. The average number of species estimated for the area (S=54) represents 50% of the species estimated for the entire Caatinga by Vasconcellos & Moura (2014), highlighting the potential of SSC as a priority area for the conservation of Caatinga biodiversity. Unlike other areas of Caatinga in the state of Paraíba, SSC possesses a high density (>20 nests/ha) of mounds of *S. cearenses*, which has a strong influence on the formation of soils in the area. In addition, *S. cearenses* is among the largest termites in the Neotropical Region and certainly represents a conspicuous source of resources for its predators throughout the year, with peaks of supply during the rainy season when there are winged individuals.

The assemblages of springtails, dung beetles, saprophagous calyptrate flies and termites at SSC exhibited high levels of species richness when compared to other areas of the Caatinga, records of new occurrences for the domain and high potential of the occurrence of new species, demonstrating the relevance of the area for the conservation of the biodiversity of this sector of the Caatinga. These hexapod taxa are also recognized as indicators of habitat quality (Brown 1997, Ekschmitt et al. 2003, Taylor & Doran 2004, Uehara-Prado et al. 2009), including studies conducted in the Caatinga for termites (Vasconcellos et al. 2010, Alves et al. 2011), that found the structure of their assemblages, linked to species richness, individual abundance and functional diversity, to be positively related to levels of habitat conservation. In addition, flies, dung beetles, saprophagous calyptrate flies and termites act primarily on the detritus-based trophic system, which receives inputs of dead organic matter of plant and animal origin, and the structures of its assemblages demonstrate the dynamic functioning of this system. Hexapoda are dominant on a series of ecosystem processes (Gullan & Cranston 2008), and the high diversity found at the SSC shows the relevance of the area for biodiversity conservation. Serra de Santa Catarina is a peculiar area and represents one of the few ecosystems that still have conserved vegetation cover in the state of Paraíba. Given the continuous anthropic pressure, the SSC should be seen as a priority by initiatives to conserve the biodiversity of the Caatinga.

## Acknowledgments

We thank the *Tropical Forest Conservation Act* (TFCA), CNPq (Processo nº 461875/2014-4), and the team of the Laboratório de Ornitologia da UFPB – *campus* II. We also thank Josimar Guedes Bezerra, our field guide, and Luciana Iannuzzi and Fernando Z. Vaz-de-Mello, for help in identifying dung beetles.

## Author Contributions

Matilde Vasconcelos Ernesto: Substantial contribution in the concept and design of the study; Contribution to data collection; Contribution to data analysis and interpretation; Contribution to manuscript preparation and critical revision, adding intellectual content.

Carolina Nunes Liberal: Substantial contribution in the concept and design of the study; Contribution to data collection; Contribution to data analysis and interpretation; Contribution to manuscript preparation and critical revision, adding intellectual content.

Aila Soares Ferreira: Substantial contribution in the concept and design of the study; Contribution to data collection; Contribution to data analysis and interpretation; Contribution to manuscript preparation and critical revision, adding intellectual content.

Ana Claudia Firmino Alves: Contribution to data collection; Contribution to data analysis and interpretation; Contribution to manuscript preparation.

Douglas Zeppelini: Contribution to critical revision, adding intellectual content.

Antonio José Creão-Duarte: Contribution to critical revision, adding intellectual content.

Celso Feitosa Martins: Contribution to critical revision, adding intellectual content.

Alessandre Pereira-Colavite: Contribution to critical revision, adding intellectual content.

Alexandre Vasconcellos: Substantial contribution in the concept and design of the study; Contribution to data analysis and interpretation; Contribution to manuscript preparation and critical revision, adding intellectual content.

## Conflicts of interest

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

## References

ALMEIDA, S.S.P. & LOUZADA, J.N.C. 2009. Estrutura da comunidade de Scarabaeinae (Scarabaeidae: Coleoptera) em fitofisionomias do cerrado e sua importância para a conservação. Neotrop. Entomol. 38(1): 32-43.

ALVES A.C.F, SANTOS W.E & CREÃO–DUARTE, A.J. 2014. Diptera (Insecta) de importância forense da região Neotropical. Entomotropica 29: 77–94.

ALVARES, C.A., STAPE, J.L., SENTELHAS, P.C., GONÇALVES, J.L.M. & SPAROVEK, G. 2013. Köppen's climate classification map for Brazil. Meteorol Z 22(6): 711-728.

ALVES, W.F., MOTA, A.S., LIMA, R.A.A., BELLEZONI, R. & VASCONCELLOS, A. 2011. Termites as Bioindicators of Habitat Quality in the Caatinga, Brazil: Is There Agreement Between Structural Habitat Variables and the Sampled Assemblages? Neotrop. Entomol. 40: 39-46.

ANDRADE, R.B., BARLOW, J., LOUZADA, J., VAZ-DE-MELLO, F.Z., SOUZA, M., SILVEIRA, J.M. & COCHRANE, M.A. 2011. Quantifying Responses of Dung Beetles to Fire Disturbance in Tropical Forests: The Importance of Trapping Method and Seasonality. PLoS ONE 6(10): e26208

BARBOSA, T.M., CARMO, R.F.R., SILVA, L.P., SALES, R.G. & VASCONCELOS, S. D. 2017. Diversity of Sarcosaprophagous Calyptratae (Diptera) on Sandy Beaches Exposed to Increasing Levels of Urbanization in Brazil. Environ. Entomol. 1–10.

BARBOSA R.R., MELLO-PATIU, C.A., MELLO R.P. & QUEIROZ, M.M.C. 2009. New records of calyptrate dipterans (Fanniidae, Muscidae and Sarcophagidae) associated with the decomposition of domestic pigs in Brazil. Mem. Inst. Oswaldo Cruz 104: 923–926.

BARROS R.M., MELLO–PATIU, C.A. & PUJOL–LUZ, J.R. 2008. Sarcophagidae (Insecta, Diptera) associados à decomposição de carcaças de *Sus scrofa* Linnaeus (Suidae) em área de Cerrado do Distrito Federal, Brasil. Rev. Bras. Entomol. 52: 606–609.

BELLINGER P.F., CHRISTIANSEN K.A. & JANSSENS F. 1996-2013**.** Checklist of the Collembola of the world. Available from: http:// www.collembola.org. [Accessed on: 06/17/2013]

BELLINI, B.C. & ZEPPELINI, D. 2009. First records of Collembola (Ellipura) from the State of Paraíba, Northeastern Brazil. Rev. Bras. entomol. 48: 433-596.

BRANDÃO, M.H.M., PEREIRA, M.S. & SOUSA, P.V.P. 2009. Indicadores Paleoclimáticos no alto sertão da Paraíba. In XIII Simpósio Brasileiro de Geografia Física Aplicada, 2009, Viçosa. A Geografia Física Aplicada e as Dinâmicas de Apropriação da Natureza. Editora da UFV, Viçosa.

BROWN JR., K.S. 1997. Diversity, disturbance, and sustainable use of Neotropical forests: insects as indicators for conservation monitoring. J. Insect Conserv. 1: 25-42.

BRUSCA, R.C & BRUSCA, G.J. 2013. Invertebrados. 2 ed. Rio de Janeiro: Guanabara Koogan.

CANCELLO, E.M.; OLIVEIRA, L.C.M.; REIS, Y.T. & VASCONCELLOS, A. 2002. Termites diversity along the Brazilian Atlantic Forest. p. 164, Proceedings of the XIV Congress International of the IUSSI (International Union for the Study of Social (Insects), Hokkaido University, Sapporo.

CARVALHO, L.M.L. & LINHARES, A.X. 2001. Seasonality of insect succession and pig carcass decomposition in a natural forest area in southeastern Brazil. J. Forensic Sci 46: 604–608.

CARVALHO C.J.B., MOURA, M.O. & RIBEIRO, P.B. 2002. Chave para adultos de dípteros (Muscidae, Fanniidae, Anthomyiidae) associados ao ambiente humano no Brasil. Rev. Bras. Entomol. 46: 107–144.

CARVALHO, C.J.B., RAFAEL, J.A., COURI, M.S. & SILVA, V.C. 2012. Diptera Linnaeus, 1758. In: Insetos do Brasil: Diversidade e Taxonomia (J.A. Rafael, G.A.R. Melo, C.J.B. Carvalho, A.S. Casari & R. Constantino, eds.). Holos, Ribeirão Preto, p.701-744.

CASSAGNE, N., GERS, C. & GAUQUELIN, T. 2003. Relationships between Collembola, soil chemistry and humus types in forest stands (France). Biol. Fertil. Soils. 3: 355–361.

COLEMAN, D.C., CROSSLEY Jr., D.A. & HENDRIX, P.F. 2004. Fundaments of soil ecology. 2 ed. Elsevier Academic Press, Boston.

CORNABY, B.W. 1974. Carrion reduction by animals in constrasting tropical habitats. Biotropica 6: 51-63.

COSTA, C.M.Q., SILVA, F.A.B., FARIAS, A.M.I. & MOURA, R.C. 2009. Diversidade de Scarabaeinae (Coleoptera, Scarabaeidae) coletados com armadilha de interceptação de vôo no Refúgio Ecológico Charles Darwin, Igarassu-PE, Brasil. Rev. Bras. Entomol. 53: 88-94.

COSTA, F.C., PESSOA, K.K.T., SALOMÃO, R.P., LIBERAL, C.N., FILGUEIRAS, B.K.C. & IANNUZZI, L. 2013. What is the importance of open habitat in a predominantly closed forest to the dung beetle community? Rev. Bras. Entomol. 57: 329-334.

COSTA, C.M.Q., BARRETTO, J.W. & MOURA, R.C. 2014. Changes in the dung beetle community in response to restinga forest degradation. J. Insect Conserv. 18: 895-902.

COLWELL, R. K. 2016. EstimateS: Statistical estimation of species richness and shared species from samples. Version 9.1.0 Persistent URL <viceroy.colorado.edu/estimates/>

D'ALMEIDA, J.M. 1984. Sinantropia de Sarcophagidae (Diptera) na região metropolitana do Estado do Rio de Janeiro. Arq. Univ. Fed. Rural Rio de Janeiro 7: 101–110.

D' ALMEIDA J.M. 1992. Calyptrate Diptera (Muscidae) and Anthomyiidae of the State of Rio de Janeiro – I. Synanthropy. Mem. Inst. Oswaldo Cruz 87: 381–386.

D'ALMEIDA, J.M. & LOPES, H.S. 1983. Sinantropia de dípteros caliptrados (Calliphoridae) no Estado do Rio de Janeiro. Arq. Univ. Fed. Rural 6: 39–48.

D'ALMEIDA, M. J. & FRAGA, M.B. 2007. Efeito de diferentes iscas na atração de califorídeos (Diptera) no Campus do Valonguinho, Universidade Federal Fluminense, Niterói, RJ, Brasil. Rev. Bras. Parasitol. Vet. 16: 199–204.

DURÃES, R., MARTINS, W.P. & VAZ-DE-MELLO, F.Z. 2005. Ecology, behavior and bionomics dung beetle (Coleoptera: Scarabaeidae) assemblages across a natural forest-cerrado ecotone in Minas Gerais, Brazil. Neotrop. Entomol. 34: 1-11.

EKSCHMITT, K., STIERHOFF, T.H., DAUBER, J., KREIMES, K. & WOLTERS, V. 2003. On the quality of soil biodiversity indicators: abiotic and biotic parameters as predictors of soil faunal richness at different spatial scales. Agric. Ecosyst. Environ. 98: 273-283.

FARIA, L.D.B, ORSI, L., TRINCA, L.A. & GODOY, W.A.C. 1999. Larval predation by *Chrysomya albiceps* on *Cochliomyia macellaria*, *Chrysomya megacephala* and *Chrysomya putoria*. Entomol. Exp. Appl. 90: 149–155.

FAVILA, M.E. & HALFFTER, G. 1997 The use of indicator groups for measuring biodiversity as related to community structure and function. Acta Zool. Mex. (n.s.) 72: 1-25.

FERREIRA, A.S., BELLINI, B.C. & VASCONCELLOS, A. 2013. Temporal variations of Collembola (Arthropoda: Hexapoda) in the semiarid Caatinga in northeastern Brazil. Zoologia (Curitiba) 30(6): 639-644.

FILGUEIRAS, B.K.C., IANNUZZI, L. & LEAL, I.R. 2011. Habitat fragmentation alters the structure of dung beetle communities in the Atlantic Forest. Biol. Conserv. 144: 362-369.

FILGUEIRAS, B.K.C., TABARELLI, M., LEAL, I.R., VAZ-DE-MELLO, F. Z. & IANNUZZI, L. 2015. Dung beetle persistence in human-modified landscapes: combining indicator species with anthropogenic land use and fragmentation-related effects. Ecol. Indic. 55: 65-73.

GILLETT, C.P.D.T., GILLETT, M.P.T., GILLETT, J.E.D.T. & VAZ-DE-MELLO, F.Z. 2010. Diversity and distribution of the scarab beetle tribe Phanaeini in the northern states of the Brazilian Northeast (Coleoptera: Scarabaeidae: Scarabaeinae). Insecta Mundi 0118: 1-19.

GUIMARÃES, J.H., PRADO, A.P. & BURALLI, G.M. 1979. Dispersal and distribution of the three newly introduced species of Chrysomya Robineau–Desvoidy in Brazil (Diptera: Calliphoridae). Rev. Bras. Entomol. 23: 245–255.

GULLAN, P.J. & CRANSTON, P.S. 2008. Os insetos: um resumo de entomologia. 7 ed. Roca, São Paulo.

HALFFTER, G. 1991. Historical and ecological factors determining the geographical distribution of beetles (Coleoptera: Scarabaeidae: Scarabaeinae). Folia Entomol. Mex. 82: 195-238

HALFFTER, G. & EDMONDS, W.D. 1982. The nesting behaviour of dung beetles (Scarabaeinae): an ecological and evolutive approach. Instituto de Ecologia, México D.F. p. 182.

HANSKI, I.; CAMBEFORT, Y. 1991. Dung beetle ecology. Princeton University Press, Princeton, New Jersey. 481p.

HERNÁNDEZ, M.I.M. 2005. Artrópodes: Besouros Scarabaeidae (Coleoptera) da área do Curimataú, Paraíba. In: Análise das Variações da Biodiversidade do Bioma Caatinga para suporte a Estratégias Regionais de Conservação (F.S. ARAÚJO, M.J.N. RODAL, M.R.V. BARBOSA, Orgs.). Ministério do Meio Ambiente, Brasília, v. 1, p.369-380.

HERNÁNDEZ, M.I.M. 2007. Besouros escarabeíneos (Coleoptera: Scarabaeidae) da Caatinga paraibana, Brasil. Oecol. Bras. 11: 356-364.

IBGE - Instituto Brasileiro de Geografia e Estatística. 2012. Manuais técnicos em geociências: Manual Técnico da Vegetação Brasileira. 2 ed. Rio de Janeiro.

KLEIN, B.C. 1989. Effects of forest fragmentation on dung and carrion beetle communities in Central Amazonia. Ecology 70: 1715-1725.

KRISHNA, K., GRIMALDI, D.A., KRISHNA, V. & ENGEL, M.S. 2013. Treatise on the Isoptera of the world. Bull. Am. Mus. Nat. Hist. 377: 1-2704.

LAVELLE, P. & SPAIN, A.V. 2005. Soil Ecology. Springer, Dordrecht.

LEAL, I.R., SILVA, J.M.C., TABARELLI, M. & LACHER, J.R.T.E. 2005. Changing the course of biodiversity conservation in the caatinga of northeastern Brazil. Conserv. Biol. 19(3): 701-706.

LEIVAS, F.W.T & CARNEIRO, E. 2012. Utilizando os hexápodes (Arthropoda, Hexapoda) como bioindicadores na Biologia da Conservação: Avanços e perspectivas. Estud. Biol., Ambiente Divers. 34(83): 203-213.

LIBERAL, C. N., FARIAS, A. M. I., MEIADO, M. V., FILGUEIRAS, B. K. C. & IANNUZZI, L. 2011. How habitat change and rainfall affect dung beetle diversity in Caatinga, a Brazilian semi-arid ecosystem? J. Insect Sci. 11: 1-11.

LOPES, H.S. 1974. Sarcophagid flies Diptera from Pacatuba, State of Ceará, Brazil. Rev. Bras. Biol. 34(2): 271-294.

LOPES, P.P., LOUZADA, J. & VAZ-DE-MELLO, F.Z. 2006. Organization of dung beetle communities (Coleoptera, Scarabaeidae) in areas of vegetation re-establishment in Feira de Santana, Bahia, Brazil. Sitientibus Ser. Ci. Biol. 6: 261-266.

MÉLO, A.C.S. & BANDEIRA, A.G. 2004. A Qualitative and Quantitative Survey of Termites (Isoptera) in an Open Shrubby Caatinga in Northeast Brazil. Sociobiol. 44: 707-716.

MILHOMEM, M.S.; VAZ-DE-MELLO, F.Z. & DINIZ, I.R. 2003. Técnicas de coleta de besouros copronecrófagos no Cerrado. Pesq. Agropec. Bras. 38(11): 1249-1256.

PORTILLO-QUINTERO, C.A. & SÁNCHEZ-AZOFEIFA, G.A. 2010. Extent and conservation of tropical dry forests in the Americas. Biol. Conserv. 143:144-155.

QUERNER, P. & BRUCKNER, A. 2010. Combining pitfall traps and soil samples to collect Collembola for site scale biodiversity assessments. Appl. Soil Ecol. 45: 293–297.

ROSA T.A., BABATA, M.L.Y., SOUZA, C.M., SOUSA, D., MELLO-PATIU, C.A., VAZ-DE-MELLO, F.Z. & MENDES, J. 2011. Arthropods associated with pig carrion in two vegetation profiles of Cerrado in the State of Minas Gerais, Brazil. Rev. Bras. Entomol. 55: 424–434.

SALOMÃO, R. P. 2012. Período de atividade de besouros (Coleoptera) copronecrófagos em um ambiente semiárido do Nordeste brasileiro. In Ecologia da Caatinga curso de campo 2012 (J.D. RIBEIRO NETO, F.M.P. OLIVEIRA, E.A.E.S. SILVA, I. LEAL, F. MELO, M. TABARELLI, & D.G. SOUZA orgs.). Editora Universitária UFPE, Recife, p.490-499.

SALOMÃO, R.P. AND IANNUZZI, L. 2017. How Do Regeneration Stages of Caatinga Forests Influence the Structure of Dung Beetle (Coleoptera: Scarabaeidae) Assemblage? Coleopt. Bull. 71(3): 578–588.

SANTOS, J.C., LEAL, I.R., ALMEIDA-CORTEZ, J.S., FERNANDES, G.W. & TABARELLI, M. 2011. Caatinga: the scientific negligence experienced by a dry tropical forest. Trop. Conserv. Sci. 4(3): 276-286.

SANTOS-ROCHA I.M., ANDREAZZE R. & BELLINI B.C. 2011. Registros de Collembola (Arthropoda, Hexapoda) no estado do Rio Grande do Norte, Brasil. Biota Neotrop. 11(3): 167-170. http://www.biotaneotropica.org.br/v11n3/en/abstract?article+bn02611032011 (último acesso em 15/03/2017).

SÄRKINEN, T., IGANCI, J.R.V., LINARES-PALOMINO, R., SIMON, M.F.& PRADO, D.E. 2011. Forgotten forests - issues and prospects in biome mapping using Seasonally Dry Tropical Forests as a case study. BMC Ecology 11: 27

SCHEFFLER, P. 2005. Dung beetle (Coleoptera: Scarabaeidae) diversity and community structure across three disturbance regimes in eastern Amazonia. J. Trop. Ecol. 21: 9-19.

SILVA, P. G. 2011. Dung beetles (Coleoptera: Scarabaeidae: Scarabaeinae) of two non-native habitats in Bagé, Rio Grande do Sul, Brazil. Zool. Stud. 50: 546-559.

SILVA, F.A.B., HERNÁNDEZ, M.I.M., IDE, S. & MOURA, R.C. 2007. Comunidade de escarabeíneos (Coleoptera, Scarabaeidae) copro-necrófagos da região de Brejo Novo, Caruaru, Pernambuco, Brasil. Rev. Bras. Entomol. 51: 228-233.

SILVA, F.A.B.; COSTA, C.M. Q.; MOURA, R.C. & FARIAS, A.M.I. 2010. Study of the Dung Beetle (Coleoptera: Scarabaeidae) Community at Two Sites: Atlantic Forest and Clear-Cut, Pernambuco, Brazil. Environ. Entomol. 39: 359-367.

SILVA, R.J., COLETTI, F., COSTA, D.A. & VAZ-DE-MELLO, F.Z. 2014. Rola-bostas (Coleoptera: Scarabaeidae: Scarabaeinae) de florestas e pastagens no sudoeste da Amazônia brasileira: Levantamento de espécies e guildas alimentares. Acta Amaz. 44(3): 345 – 352.

SOUSA, P.V.P. 2011.A Serra de Santa Catarina: um enclave subúmido no sertão paraibano e a proposta de criação de uma unidade de conservação. Dissertação de Mestrado em Geografia. Universidade Federal do Ceará, Fortaleza.

SOUZA, A.M. & LINHARES, A.X. 1997. Diptera and Coleoptera of potential forensic importance in southeastern Brazil: relative abundance and seasonality. Med. Vet. Entomol. 11: 8–12.

STATSOFT, I. 2007. STATISTICA (data analysis software system), version 8.0. www.statsoft.com.

TARASOV, S. & GÉNIER, F. 2015. Innovative Bayesian and Parsimony Phylogeny of Dung Beetles (Coleoptera, Scarabaeidae, Scarabaeinae) Enhanced by Ontology-Based Partitioning of Morphological Characters. PLoS ONE 10(3): e0116671.

TAYLOR, N. & DORAN, N. 2004. Identification of species and functional groups that give early warning of major environmental change (Indicator 1.2c). Part D: Use of terrestrial invertebrates as indicators of the ecological sustainability of forest management under the Montreal Process. Australian Government. Forest and Wood Products Research and Development Corporation.

UEHARA-PRADO, M., FERNANDES, J.O., BELLO, A.M., MACHADO, G., SANTOS, A.J., VAZ-DE-MELLO, F.Z. & FREITAS, A.V.L. 2009. Selecting terrestrial arthropods as indicators of small-scale disturbance: A first approach in the Brazilian Atlantic Forest. Biol. Conserv. 142: 1220- 1228.

VAIRO K.P., MELLO-PATIU, C.A. & CARVALHO, C.J.B. 2011. Pictorial identification key for species of Sarcophagidae (Diptera) of potential forensic importance in southern Brazil. Rev. Bras. Entomol. 55: 333–347.

VASCONCELLOS, A. 2010. Biomass and abundance of termites in three remanant areas of Atlantic Forest in northeastern Brazi. Rev. Bras. Entomol. 54(3), 455-461.

VASCONCELLOS, A. & MOURA, F.M.S. 2014. Térmitas de Oito Ecossistemas Inseridos no Domínio do Semiárido Brasileiro. In: Artrópodes do Semiárido: Biodiversidade e Conservação (F. BRAVO & A. CALOR, orgs.). Printmídia, Feira de Santana, p. 99-109.

VASCONCELLOS, A., BANDEIRA, A.G., MOURA, F.M.S., ARAÚJO, V.F.P., GUSMÃO, M.A.B. & CONSTANTINO, R. 2010. Termite Assemblages in Three Habitats under Different Disturbance Regimes in the Semi-Arid Caatinga of Ne Brazil. J. Arid Environ. 74: 298-302.

VASCONCELOS, S.D. & ARAUJO M.S.C. 2012. Necrophagous Diptera and Coleoptera in Northeastern Brazil: State of the art and challenges for the forensic entomologist. Rev. Bras. Entomol. 56(1): 7-14.

VASCONCELOS, S.D., BARBOSA, T.M. & OLIVEIRA, T.P.B. 2015. Diversity of forensically-important dipteran species in different environments in Northeastern Brazil, with notes on the attractiveness of animal baits. Fla. Entomol. 98: 770–775.

VASCONCELOS S.D, CRUZ T.M., SALGADO R.L. & THYSSEN P.J. 2013. Dipterans associated with a decomposing animal carcass in a rainforest fragment in Brazil: Notes on the early arrival and colonization by necrophagous species. J. Insect Sci. 13(145): 1-11.

VASCONCELOS S.D. & SALGADO, R.L. 2014. First record of six Calliphoridae (Diptera) species in a seasonally dry tropical forest in Brazil: evidence for the establishment of invasive species. Fla. Entomol. 97: 814–816.

VAZ-DE-MELLO, F. Z. 2008. Synopsis of the new subtribe Scatimina (Coleoptera: Scarabaeidae: Scarabaeinae: Ateuchini), with descriptions of twelve new genera and review of *Genieridium*, new genus. Zootaxa 1955: 1-75.

*Received: 26/07/2017*
*Revised: 02/03/2018*
*Accepted: 05/03/2018*

Biota Neotropica 18(2): e20170476, 2018
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
inventory

# A checklist of Rutelinae MacLeay, 1819 (Coleoptera, Melolonthidae) of Bahia, Brazil

*André da Silva Ferreira[1]*, Lúcia M. Almeida[2], Freddy Bravo[3]& Paschoal Coelho Grossi[4]*

*[1]Universidade Federal da Bahia, Instituto de Biologia, Programa de Pós-Graduação em Diversidade Animal, 40170-115, Salvador, BA, Brasil*
*[2]Universidade Federal do Paraná, Departamento de Zoologia, Laboratório de Sistemática e Bioecologia de Coleoptera, 81531-980, Curitiba, PR, Brasil*
*[3]Universidade Estadual de Feira de Santana, Departamento de Ciências Biológicas, Laboratório de Sistemática de Insetos, 44036-900, Feira de Santana, BA Brasil*
*[4]Universidade Federal Rural de Pernambuco, Rua Dom Manoel de Medeiros, 52171-900, Recife, PE, Brasil*
**Corresponding author: André da Silva Ferreira, e-mail: sferreira.and@gmail.com*

FERREIRA, A. S., ALMEIDA, L. M., BRAVO, F., GROSSI, P. C. **A checklist of Rutelinae MacLeay, 1819 (Coleoptera, Melolonthidae) of Bahia, Brazil**. Biota Neotropica. 18(2): e20170476. http://dx.doi.org/10.1590/1676-0611-BN-2017-0476

**Abstract:** A list of species of Rutelinae from Bahia state, Northeastern Brazil, is presented. The list is based on specimens deposited in Brazilian collections. The list includes 4 tribes, 23 genera, 101 species and 17 subspecies. The genera *Byrsopolis* Burmeister, 1844, *Pseudodorysthetus* Soula, 2008 and *Trizogeniates* Ohaus, 1917 are recorded for the first time in Bahia and Northeastern Brazil. Thirty species are newly recorded in Bahia: *Areoda espiritosantensis* Ohaus, 1905, *B. laticollis Burmeister, 1855*, *Bolax flavolineata* (Mannerheim, 1829), *Chlorota abdominalis* Ohaus, 1926, *C. espiritosantensis* Ohaus, 1912, *Dorysthetus espiritosantensis* Ohaus, 1905, *D. fulgidus* (Waterhouse, 1881), *Leucothyreus acanthurus* Ohaus, 1917, *L. albopilosus* Ohaus, 1917, *L. campestris* Burmeister, 1855, *L. cayapo* Ohaus, 1931, *L. duplopunctatus* Frey, 1976, *L. eligius* Ohaus, 1918, *L. fluminensis* Ohaus, 1918, *L. iridipennis* Ohaus, 1917, *L. lucipetens* Ohaus, 1931, *L. occipitalis* Ohaus, 1931, *L. pallefactus* Ohaus, 1924, *L. paulista* Ohaus, 1917, *L. punctulatus* Blanchard, 1851, *L. suturalis* Laporte, 1840, *L. trochantericus* Ohaus, 1917, *L. verticalis* Ohaus, 1924, *Macraspis cincta* (Drury, 1872), *Paranomala tricostulata* (Ohaus, 1897), *P. violacea* (Burmeister, 1844), *Pseudodorysthetus calcaratus* (Spinola, 1835), and *Trizogeniates planipennis* Ohaus, 1917. *Pelidnota unicolor unicolor* (Drury, 1778) is recorded for the first time in Bahia. Fourteen species are identified and will be described in subsequent papers: 10 of *Leucothyreus* MacLeay, 1819, 2 of *Lobogeniates* Ohaus, 1917 and 1 species of *Byrsopolis* Burmeister, 1844 and *Pelidnota* MacLeay, 1819. Rutelini is the richest tribe with 16 genera and 49 species. The information presented in the list generates an important set of knowledge regarding the diversity of Rutelinae of Bahia and Brazil and provides the basis for conducting future research within the group.

***Keywords:*** *new records, Northeastern Brazil, species list.*

## Um checklist dos Rutelinae MacLeay, 1819 (Coleoptera, Melolonthidae) da Bahia, Brasil

**Resumo**: É apresentada uma lista de espécies de Rutelinae do estado da Bahia, Nordeste do Brasil. A lista é baseada em espécimes depositados em coleções brasileiras. A lista inclui quatro tribos, 23 gêneros, 101 espécies e 17 subespécies. É feito o primeiro registro para a Bahia e região Nordeste dos gêneros *Byrsopolis* Burmeister, 1844, *Pseudodorysthetus* Soula, 2008 e *Trizogeniates* Ohaus, 1917. Trinta espécies de Rutelinae foram registradas pela primeira vez para a Bahia e região Nordeste: *Areoda espiritosantensis* Ohaus, 1905, *B. laticollis Burmeister, 1855*, *Bolax flavolineata* (Mannerheim, 1829), *Chlorota abdominalis* Ohaus, 1926, *C. espiritosantensis* Ohaus, 1912, *Dorysthetus espiritosantensis* Ohaus, 1905, *D. fulgidus* (Waterhouse, 1881), *Leucothyreus acanthurus* Ohaus, 1917, *L. albopilosus* Ohaus, 1917, *L. campestris* Burmeister, 1855, *L. cayapo* Ohaus, 1931, *L. duplopunctatus* Frey, 1976, *L. eligius* Ohaus, 1918, *L. fluminensis* Ohaus, 1918, *L. iridipennis* Ohaus, 1917, *L. lucipetens* Ohaus, 1931, *L. occipitalis* Ohaus, 1931, *L. pallefactus* Ohaus, 1924, *L. paulista* Ohaus, 1917, *L. punctulatus* Blanchard, 1851, *L. suturalis* Laporte, 1840, *L. trochantericus* Ohaus, 1917, *L. verticalis* Ohaus, 1924, *Macraspis cincta* (Drury, 1872), *Paranomala tricostulata* (Ohaus, 1897), *P. violacea* (Burmeister, 1844), *Pseudodorysthetus calcaratus* (Spinola, 1835) e *Trizogeniates planipennis* Ohaus, 1917. Foi feito o primeiro registro de *Pelidnota unicolor unicolor* (Drury, 1778) para a Bahia. Foram identificadas 14 espécies, que serão descritas em trabalhos posteriores: dez de *Leucothyreus* MacLeay, 1819, duas de *Lobogeniates* Ohaus, 1917 e uma de *Byrsopolis* Burmeister, 1844 e *Pelidnota* MacLeay, 1819. A tribo Rutelini apresenta a maior riqueza com 16 gêneros e 49 espécies. Os resultados aqui apresentados têm importantes informações para o conhecimento de Rutelinae, no estado da Bahia e no Brasil, e servirão de base para a realização de futuras pesquisas com o grupo.

***Palavras-chave:*** *lista de espécies, novos registros, Região Nordeste do Brasil.*

## Introduction

According to Kohlmann & Morón (2003) Scarabaeoidea is represented by three families: Lucanidae, Passalidae and Scarabaeidae, with this last family divided into two informal categories, "Laparosticti" (with spiracles positioned on the pleural membrane) and "Pleurosticti" (with spiracles positioned on the superior part of the abdominal ventrite). The scarabaeids include two feeding groups: coprophagous consisting of subfamilies Aphodiinae and Scarabaeinae ("Laparosticti") and the phytophagous consisting of subfamilies Cetoniinae, Dynastinae, Melolonthinae and Rutelinae ("Pleurosticti") (Lawrence & Newton 1995). Cherman & Morón (2014) recently considered the six phytophagous subfamilies in Melolonthidae (Euchirinae, Dynastinae, Hopliinae, Melolonthinae, Rutelinae and Sericinae). This paper follows the classification of Cherman & Morón (2014).

Rutelinae is the second largest subfamily of Melolonthidae according to the number of species, with approximately 4,197 species described in the world but with the greatest richness in the tropics (Hardy 1991, Jameson 2002, Ratcliffe & Jameson 2005, Krajcik 2008, Jameson & Ratcliffe 2011, Morón & Ramírez-Ponce 2012). Melolonthinae is the richest subfamily of Melolonthidae, with about 11,000 known species (Evans 2002). Seven tribes are currently recognized in Rutelinae: Adoretini, Alvarengiini, Anatistini, Anomalini, Anoplognathini, Geniatini and Rutelini (Bouchard et al. 2011).

Adult ruteline are phytophagous, playing an important ecological role in pollination of some plant species. Larvae are saprophytophagus and contribute directly to the decomposition of dead organic matter deposited in forests and in the nutrient cycle (Hardy 1991, Morón et al., 1997, Paucar-Cabrera 2003), while some species feed on roots and sometimes become pests (Ritcher 1958, Jameson et al. 2003, Jameson & Howkins 2005). In Brazil, *Paranomala testaceipennis* (Blanchard, 1851) was recorded in agricultural crops and pasture areas in Mato Grosso do Sul (Rodriguez-del-Bosque 1996, 1998, Rodrigues et al. 2008); *Leucothyreus albopilosus* Ohaus, 1917 was recorded on *Eucalyptus citriodora* (Hook, 1848); *L. dorsalis* Blanchard, 1850 was associated to the roots of *Acrocomia aculeata* (Jacq) Lodd. ex Mart. (Arecaceae) from Mato Grosso do Sul (Puker et al. 2009, Pereira et al. 2013).

In the Neotropical Region, approximately 1,337 species of Rutelinae were recorded (Morón 1990, 2004, Jameson 2008, Soula 2011, Filippini et al. 2016, Ferreira et al. 2017, Howkins 2017, Moore et al., 2017, Seidel et al. 2017, Sierra 2017), while 436 are from Brazil (Grossi & Vaz-de-Mello 2016, Ferreira et al. 2017). Grossi & Vaz-de-Mello (2016) also included 104 subspecies and 58 genera in their list from Brazil. Only one inventory of Rutelinae is known from Bahia State (Viana et al. 2001), which was performed with light traps in Cruz das Almas municipality (approximately 12°40'S–39°06'W). The authors recorded species of four genera: *Paranomala* Casey, 1915 (Anomalini), *Geniates* Kirby, 1819 *Leucothyreus* MacLeay, 1819 (Geniatini) and *Pelidnota* MacLeay (Rutelini), however, only one species was named and identified, *Pelidnota fulva* Blanchard, which is very probably a misidentified species, as this taxon occurs in another geographical region, according to the last revision (Soula 2009).

The most recent information on the diversity of the species from Bahia is scattered among 17 papers (Jameson 1996, Jameson & Hawkins 2005, Jameson & Ratcliffe 2011, Krajcik 2008, Machatschke 1972, Soula 2002a, b, 2003, 2005, 2006, 2008, 2009, 2010, 2011, Ratcliffe & Jameson 1989, Viana et al. 2001, Ferreira et al. 2017) and includes 61 species and nine subspecies in 20 genera of the tribes Anatistini, Anomalini, Geniatini and Rutelini.

In this paper, we present an updated species list of Rutelinae from Bahia that are deposited in seven collections in South, Southeast and Northeast of Brazil. Information about the geographic distribution of the species listed is also provided. The data presented here gather important information that adds new knowledge about the diversity of Rutelinae in Brazil and the Neotropical region and serves as a basis for conducting future research with the group.

## Material and Methods

Bahia is one of the biggest states of Brazil (Figure 1) with an area of 564.733,177 km$^2$ (Instituto Brasileiro de Geografia e Estatística–IBGE 2013), which represents 37.7% of all the Northeastern territory (Bahia 2013). The vegetation, climate, and altitudinal range are heterogeneous, with the presence of three Brazilian Biomes (Caatinga, Atlantic Forest and Cerrado), ecosystems of restingas, mangroves, campos rupestres, and ecotones between the biomes, rainforests, semi-deciduous forest and high montane vegetation, among others (Bahia 2013).

The collections visited for this study were (acronyms according to Evenhuis (2009) have been used when available): CEIOC – Entomological Collection of Instituto Oswaldo Cruz, Rio de Janeiro, Brazil; CERPE – Entomological Collection of Universidade Federal Rural de Pernambuco, Recife, Pernambuco, Brazil; DZUP – Entomological Collection Pe. J. S. Moure, Department of Zoology, Universidade Federal do Paraná, Curitiba, Paraná, Brazil; EPGC – Everardo and Paschoal Grossi Collection, Nova Friburgo, Rio de Janeiro, Brazil; MNRJ – National Museum, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil; MZFS – Collection Prof. Johann Becker, Museum of Zoology of Universidade Estadual de Feira de Santana, Bahia, Brazil; and MHNBA/MZUFBA – Entomological Collection of Museum of Natural History/ Zoology of Bahia State/Universidade Federal da Bahia, Salvador, Bahia, Brazil.

The species identification was based on Frey (1976), Ohaus (1905, 1912, 1913, 1917, 1918a, 1918b, 1924, 1926, 1928, 1930, 1931), Soula (1998, 2006, 2009, 2010, 2011), and by comparison with the studied collections.

For the study of male genitalia, each specimen was immersed in boiling water for approximately two to four minutes and the genitalia removed, then studied under a stereomicroscope, glued in a triangle, and pinned just below the specimen.

The geographical coordinates, when not available on the label of the specimen, were obtained by the geoLoc tool on the speciesLink online data platform (http://splink.cria.org.br/geoloc), using the IBGE as a source for the data recovery. The geographical records were plotted on the map of Bahia using QGIS version 2.10.1. The final artwork for the map of geographical records and richness of genera and species by tribe was executed using Abobe Photoshop CS6®.

The information transcribed from the labels of the examined material usually adhered to the following pattern: COUNTRY, *State*: ("Locality"; "additional information"); (Geographic Coordinates), Data, Collector. (ACRONYM OF THE MUSEUM# register number).

## Results and Discussion

A total of 1,495 specimens, of 20 genera, 79 species and 12 subspecies of the tribes Anomalini, Anatistini, Geniatini and Rutelini were examined. Before the current study, 23 genera, 101 species and 17 subspecies of Rutelinae from Bahia (Table 1) had been reported. With this study, 32 species, 11 subspecies and the genera *Anticheiroides* Soula, 1998, *Oplognathus* MacLeay, 1819 and *Parhoplognathus* Ohaus, 1930, cited from Bahia in the literature by Machatschke (1972), Soula (1998, 2008), and Moore et al. (2017) respectively were not found in the collections studied (Table 1).

The genera *Byrsopolis* Burmeister, 1844, *Pseudodorysthetus* Soula, 2008 and *Trizogeniates* Ohaus, 1917 were first recorded for Bahia and the Northeast region. Thirty species of Rutelinae were recorded for the first time in Bahia and Northeastern Brazil: *Areoda espiritosantensis* Ohaus, 1905, *Byrsopolis* aff. *castanea* Burmeister, 1844, *Bolax flavolineata* (Mannerheim, 1829), *Chlorota abdominalis* Ohaus, 1926, *C. espiritosantensis* Ohaus,

**Table 1.** List of species and subspecies of Rutelinae from Bahia state, Northeast – Brazil adding the literature data with the results presented in this study and, geographic distribution.

| SPECIES/SUBSPECIES | DISTRIBUTION |
|---|---|
| **ANOMALINI** Streubel, 1839 | |
| **Anomalina** Streubel, 1839 | |
| ***Paranomala*** Casey, 1915 | |
| *Paranomala chromicolor* (Burmeister, 1855) | Brazil (Bahia and Pará) (Machatschke 1972, Grossi & Vaz-de-Mello 2016) |
| *Paranomala foveiceps* (Ohaus, 1897) | Brazil (Bahia) (Machatschke 1972, Krajcik 2008, Grossi & Vaz-de-Mello 2016) |
| *Paranomala inconstans* (Burmeister, 1844) | Mexico, Central and South America, in Brazil (Bahia and Rio de Janeiro) (Machatschke 1972, Krajcik 2008, Grossi & Vaz-de-Mello 2016 and present study) |
| *Paranomala tricostulata* (Ohaus, 1897) | Brazil (Amazonas, Bahia (new occurrence register)) and Colombia (Mozo) (Ohaus 1897) |
| *Paranomala undulata undulata* (Melsheimer, 1844) | North, Central and South America (Machatschke 1972, Krajcik 2008, Grossi & Vaz-de-Mello 2016 and present study) |
| *Paranomala undulata varians* (Burmeister, 1844) | North America (Mexico), Brazil (Machatschke 1972, Krajcik 2008 and present study) |
| *Paranomala violacea* (Burmeister, 1844) | Brazil (Bahia (new occurrence register), Espírito Santo, Santa Catarina) (Machatschke 1972, Krajcik 2008, Grossi & Vaz-de-Mello 2016) |
| **RUTELINI** MacLeay, 1819 | |
| **Anticheirina Lacordaire, 1856** | |
| ***Anticheiroides*** Soula, 1998 | |
| *Anticheiroides inauratus bahianus* Soula, 1998 | Brazil (Bahia) (Soula 1998) |
| ***Chlorota*** Burmeister, 1844 | |
| *Chlorota abdominalis* Ohaus, 1926 | Brazil (Amazonas, Bahia (new occurrence register)) (Soula 2002a, b) |
| *Chlorota aulica* Burmeister, 1844 | Argentina, Bolivia, Brazil (Alagoas to Pernambuco, Bahia, Espírito Santo, São Paulo), Colombia, Costa Rica, Equador, Guatemala, French Guiana, Honduras, Mexico, Nicaragua, Panama, Peru, Suryname, Venezuela (Soula, (Soula 2002a, b and present study) |
| *Chlorota espiritosantensis* Ohaus, 1912 | Brazil (Bahia (new occurrence register), Espírito Santo) (Soula 2002a, b) |
| *Chlorota paulistana* Ohaus, 1912 | Brazil (Bahia, São Paulo, Rio de Janeiro, Espírito Santo, Minas Gerais) (Soula 2002a and present study) |
| ***Dorysthetus*** Blanchard, 1845 | |
| *Dorysthetus espiritosantensis* Ohaus, 1905 | Brazil (Bahia (new occurrence register), Espírito Santo) (Soula 2003) |
| *Dorysthetus fulgidus* (Waterhouse, 1881) | Brazil (Amazonas, Bahia (new occurrence register)), Colombia, Equador, Peru (Machatschke 1972, Soula 1998, 2003) |
| *Dorysthetus taeniatus taeniatus* (Perty, 1830) | Brazil (Bahia, Minas Gerais, Goiás) (Machatschke 1972, Soula 1998, 2003) |
| ***Lagochile*** Hoffmannsegg, 1817 | |
| *Lagochile amazona unipunctata* (Ohaus, 1914) | Brazil (Bahia to Ceará) (Machatschke 1972, Soula 2005 and present study) |
| *Lagochile badia* (Perty, 1830) | Brazil (Bahia, Goiás, Minas Gerais, São Paulo) (Machatschke 1972, Soula 2005) |
| *Lagochile bipunctata* (MacLeay, 1819) | Argentina, Brazil (Bahia (Atlantic Forest), Espírito Santo, Rio de Janeiro) (Machatschke 1972, Soula 2005) |
| *Lagochile emarginata* (Gyllenhal, 1817) | Brazil (Bahia, Rio de Janeiro), occurs in mountains areas in the North at the Bahia state to Paraguay Southwest, frequent in Brazilian Atlantic Forest to Argentina (Soula 2005 and present study) |
| *Lagochile emarginata nitida* (Burmeister, 1844) | Brazil (Bahia) (Machatschke 1972, Soula 2005) |
| *Lagochile glandicolor* (Burmeister, 1855) | Brazil (Amazonas, Bahia) (Soula 2005) |
| *Lagochile obscurata* (Ohaus, 1905) | Brazil (Bahia), Colombia, French Guiana, Venezuela (Soula 2006) |
| *Lagochile obscurata debahia* Soula, 2006 | Brazil (Bahia) (Soula 2006) |
| *Lagochile sparsa litoralis* Ohaus, 1903 | Brazil (Bahia, Ceará, São Paulo) (Soula 2005 and present study) |
| ***Macraspis*** MacLeay, 1819 | |
| *Macraspis chrysis* (Linnaeus, 1764) | Brazil (Bahia to Santa Catarina), Colombia, Costa Rica, North of the Argentina to Mexico and, to Paraguay, Peru to Bolivia, Nicaragua (Soula 1998) |
| *Macraspis cincta* (Drury, 1782) | Brazil (Bahia (new occurrence register), Espírito Santo, Rio de Janeiro, São Paulo) (Soula 1998, 2003) |
| *Macraspis festiva* Burmeister, 1844 | Bolivia, Brazil, Peruvian Amazon to Equador, and Paraguay, Venezuela (Soula 1998, Soula 2003) |
| *Macraspis morio* Burmeister, 1844 | Argentina, Brazil, Colombia, Venezuela (Soula 2003 and present study) |
| *Macraspis nitidissima* Burmeister, 1844 | Brazil (Bahia) (Soula 1998) |
| *Macraspis pseudochrysis pseudochrysis* Landin, 1956 | Brazil (Bahia), French Guiana, Guyana, Peruvian Amazon and Venezuela (Soula 1998) |
| *Macraspis viridis* (Thunberg, 1822) | Brazil (Bahia), Colombia (Machatschke 1972 and present study) |
| ***Paramacraspis*** Ohaus, 1915 | |
| *Paramacraspis hemichlora* (Laporte, 1840) | Brazil (Bahia, Espírito Santo) (Soula 2002a, 2003 and present study) |
| ***Pseudodorysthetus*** Soula, 1998 (new occurrence register) | |
| *Pseudodorysthetus calcaratus* (Spínola, 1835) | Brazil (Bahia (new occurrence register), Rio de Janeiro) (Soula 1998, 2003) |
| **Areodina** Burmeister, 1844 | |
| ***Areoda*** MacLeay, 1819 | |
| *Areoda espiritosantensis* Ohaus, 1905 | Brazil (Bahia (new occurrence register), Minas Gerais, Rio de Janeiro, São Paulo) (Ratcliffe & Jameson 1989) |
| *Areoda leachii* MacLeay, 1819 | Brazil (Bahia, Espírito Santo, Rio de Janeiro, São Paulo) (Ratcliffe & Jameson 1989 and present study) |

**Table 1.** Continued...

| SPECIES/SUBSPECIES | DISTRIBUTION |
|---|---|
| ***Byrsopolis*** Burmeister, 1844 (new occurrence register) | |
| *B. laticollis Burmeister,* 1855 | Brazil (Bahia (new occurrence register), Rio de Janeiro) (Machatschke 1972) |
| *Byrsopolis* sp. nov. | Brazil (Bahia) |
| ***Oplognathus*** MacLeay, 1819 | |
| *Oplognathus bahianus* Ohaus, 1912 | Brazil (Bahia) (Machatschke 1972) |
| **Pelidnotina Burmeister, 1844**<br>***Chalcoplethis*** Burmeister, 1844 | |
| *Chalcoplethis kirbii kirbii* (Gray, 1832) | Brazil (Bahia, Espírito Santo, Paraná, Rio Grande do Sul) (Gray 1832, Burmeister 1844, Blanchard 1851, Harold 1869, Ohaus 1918, 1934, Blackwelder 1944, Machatschke 1972, Hardy 1975, Soula 2006, Krajcik 2008, Moore et al. 2017 and present study), Costa Rica (Hardy 1975, Moore et al. 2017), Paraguay (Cororó) (Moore et al. 2017) |
| ***Homonyx*** Guérin-Méneville, 1839 | |
| *Homonyx bahianus* Ohaus, 1913 | Brazil (Bahia) (Ohaus 1913, 1918, 1934, Machatschke 1972, Krajcik 2008, Soula 2010, Moore et al. 2017 and present study) |
| ***Parhoplognathus*** Ohaus, 1915 | |
| *Parhoplognathus rubripennis* Ohaus, 1930 | Brazil (Bahia) (Soula 2008, Moore et al. 2017) |
| ***Pelidnota*** MacLeay, 1819 | |
| *Pelidnota alliacea* (Germar, 1824) | Brazil (Bahia, Espírito Santo, Santa Catarina) (Olivier 1789, 1802, Laporte 1840, Burmeister 1844, Blanchard 1851, Ohaus 1908, 1918, 1934, Blackwelder 1944, Machatschke 1972, Krajcik 2008, Soula 2009, Ferreira et al. 2017, Moore et al. 2017 and present study) |
| *Pelidnota bahiana bahiana* Ohaus, 1905 | Brazil (Bahia) (Soula 2006, Moore et al. 2017) |
| *Pelidnota beckeri* Ferreira, Almeida & Bravo, 2017 | Brazil (Bahia) (Ferreira et al. 2017 and present study) |
| *Pelidnota burmeisteri burmeisteri* Burmeister, 1844 | Brazil (Bahia, Minas Gerais) (Machatschke 1972, Soula 2009, Moore et al. 2017 and present study) |
| *Pelidnota chalcothorax* Perty, 1830 | Brazil (Bahia, Espírito Santo, Minas Gerais, Rio de Janeiro, São Paulo) (Perty 1830, Laporte 1840, Burmeister 1844, 1855, Blanchard 1851, Ohaus 1918a, 1918b, 1934, Blackwelder 1944, Machatschke 1972, Krajcik 2008, Soula 2009, Moore et al. 2017 and present study) |
| *Pelidnota courtini* Soula, 2009 | Brazil (Bahia, Minas Gerais) (Soula 2009, Moore et al. 2017 and present study) |
| *Pelidnota crassipes* Ohaus, 1905 | Argentina (Misiones) (Ohaus 1905, 1918, 1934, Blackwelder 1944, Machatschke 1972, Soula 2006, Krajcik 2008, Moore et al. 2017, Ferreira et al. 2017), Bolivia (Ohaus 1918, 1934, Blackwelder 1944, Moore et al. 2017, Ferreira et al. 2017), Brazil (Bahia, Minas Gerais, Goiás, Mato Grosso (Soula 2006, Moore et al. 2017, Ferreira et al. 2017 and present study), Paraguay (Asunción) (Ohaus 1905, 1918, 1934, Blackwelder 1944, Machatschke 1972, Soula 2006, Moore et al. 2017, Ferreira et al. 2017). |
| *Pelidnota cyanipes* (Kirby, 1819) | Argentina (Misiones) (Gutiérrez 1951, Soula 2009, Moore et al. 2017), Brazil (Pará, Bahia, Rio de Janeiro, Rio Grande do Sul) (Laporte 1840, Burmeister 1844, 1855, Blanchard 1851, Ohaus, 1908a, 1918b, 1934, Blackwelder 1944, Machatschke 1972, Krajcik 2008, Soula 2009, Moore et al. 2017 and present study) |
| *Pelidnota cyanitarsis* (Gory, 1833) | Brazil (Bahia, Minas Gerais, Pará)) (Guérin-Méneville 1834, Burmeister 1844, Blanchard 1851, Ohaus 1918, 1934, Blackwelder 1944, Machatschke 1972, Krajcik 2008, Soula 2009, Moore et al. 2017 and present study) |
| *Pelidnota cuprea* (Germar, 1824) | Argentina (Soula 2006, Moore et al. 2017), Bolivia (Soula 2006, Moore et al. 2017), Brazil (Bahia, Goiás, Rio de Janeiro, Rio Grande do Sul, Santa Catarina) (Germar 1824, Perty 1830, Burmeister 1844, Blanchard 1851, Ohaus 1913, 1918, 1934, Blackwelder 1944, Machatschke 1972, Soula 2006, Krajcik 2008, Moore et al. 2017 and present study), Paraguay (Ohaus 1913, 1918, 1934, Machatschke 1972, Soula 2006, Moore et al. 2017) |
| *Pelidnota ebenina* (Blanchard, 1842) | Argentina (Soula 2006, Moore et al. 2017), Brazil (Pará, Bahia) (Ohaus 1908, 1918, 1934, Blackwelder 1944, Machatschke 1972, Soula 2006, Krajcik 2008, Moore et al. 2017 and present study), Bolivia (Santa Cruz) (Blanchard 1851, Ohaus 1918, 1934, Blackwelder 1944, Machatschke 1972, Soula 2006, Krajcik 2008, Moore et al. 2017) |
| *Pelidnota fulva* Blanchard, 1851 | Bolivia (Chuquisaca) (Blanchard 1851, Burmeister 1855, Ohaus 1918, 1934, Blackwelder 1944, Machatschke 1972, Krajcik 2008, Soula 2009, Moore et al. 2017), Brazil (Bahia, Minas Gerais, Mato Grosso do Sul) (Burmeister 1855, Ohaus 1908, Rodrigues & da Silva Falco 2011, Rodrigues et al. 2012, Garcia et al. 2013, Moore et al. 2017) |
| *Pelidnota glaberrima septentrionalis* (Soula, 2006) | Brazil (Bahia) (Soula 2006, Moore et al. 2017 and present study) |
| *Pelidnota gracilis debahia* (Soula, 2006) | Brazil (Bahia) (Soula 2006, Moore et al. 2017 and present study) |
| *Pelidnota instabilis* Ohaus, 1912 | Brazil (Bahia, Espírito Santo, Rio de Janeiro, São Paulo (Ohaus 1912, 1918, 1934, Blackwelder 1944, Machatschke 1972, Soula 2006, Krajcik 2008, Moore et al. 2017, Ferreira et al. 2017 and present study) |
| *Pelidnota lagoi* Soula, 2011 | Brazil (Bahia, Goiás) (Soula 2011, Moore et al. 2017, Ferreira et al. 2017 and present study) |
| *Pelidnota liturella liturella* (Kirby, 1818) | Argentina (Misiones) (Soula 2006, Moore et al. 2017), Brazil (Bahia, Goiás, Espírito Santo, Minas Gerais, Rio de Janeiro, Paraná, Santa Catarina, Rio Grande do Sul) (Burmeister 1844, 1855, Blanchard 1851, Ohaus 1908, 1918, 1929, 1934, Machatschke 1972, Soula 2006, Krajcik 2008, Moore et al. 2017 and present study) |
| *Pelidnota ludovici* Ohaus, 1905 | Brazil (Bahia, Espírito Santo) (Machatschke 1972, Soula 2009, Moore et al. 2017 and present study). |

**Table 1.** Continued...

| SPECIES/SUBSPECIES | DISTRIBUTION |
|---|---|
| *Pelidnota pallidipennis* F. Bates, 1904 | Brazil (Pernambuco, Bahia, Goiás, Minas Gerais, São Paulo, Mato Grosso) (Bates 1904, Ohaus 1918, 1934, Guimarães 1944, Blackwelder 1944, Machatschke 1972, Krajcik 2008, Soula 2009, Moore et al. 2017) |
| *Pelidnota rugulosa rugulosa* Burmeister, 1844 | Brazil (Bahia, Rio de Janeiro, São Paulo) (Burmeister 1844, 1855, Blanchard 1851, Ohaus 1918, 1934, Blackwelder 1944, Machatschke 1972, Soula 2006, Krajcik 2008, Moore et al. 2017, Ferreira et al. 2017 and present study) |
| *Pelidnota semiaurata semiaurata* Burmeister, 1844 | Brazil (Bahia, Rio de Janeiro (INPA), Rio Grande do Sol, Santa Catarina (Ohaus 1918, 1934, Machatschke 1972, Krajcik 2008, Soula 2009, Moore et al. 2017, Ferreira et al. 2017 and present study) |
| *Pelidnota sericeicollis* (Frey, 1976) | Brazil (Bahia (Encruzilhada)) (Frey 1976, Soula 2006, Krajcik 2008, Moore et al. 2017 and present study) |
| *Pelidnota sikorskii* (Soula, 2006) | Brazil (Bahia (Povoado de Cachimbo)) (Soula 2006, Moore et al. 2017 and present study) |
| *Pelidnota sordida* (Germar, 1824) | Argentina (Ohaus 1918, 1934, Blackwelder 1944, Machatschke 1972, Moore et al. 2017), Brazil (Bahia, Goiás, Minas Gerais, Rio de Janeiro, São Paulo, Paraná) (Burmeister 1844, 1855, Ohaus 1908, 1918a, 1934b, Guimarães 1944, Blackwelder 1944, Machatschke 1972, Krajcik 2008, Soula 2009, Moore et al. 2017 and present study), Paraguay (Ohaus 1918, 1934, Blackwelder 1944, Machatschke 1972, Moore et al. 2017) |
| *Pelidnota sumptuosa* (Vigors, 1825) | Brazil (Pará, Bahia, Goiás, Minas Gerais, São Paulo, Mato Grosso) (Vigors 1825, Burmeister 1844, 1855, Blanchard 1851, Ohaus 1918, 1934, Blackwelder 1944, Machatschke 1972, Krajcik 2008, Soula 2009), Colombia (Caquetá, Meta) (Restrepo-Giraldo et al. 2003, Soula 2009, Pardo-Locarno et al. 2011), Paraguay (Soula 2009, Moore et al. 2017) |
| *Pelidnota unicolor unicolor* (Drury, 1778) | Brazil (Pernambuco, Bahia (new occurrence register), Espírito Santo, Minas Gerais, Rio de Janeiro, São Paulo, Santa Catarina) (Herbst 1790, Laporte 1840, Burmeister 1844, Blanchard 1851, Harold 1869, Ohaus 1908, 1913, 1918, 1934, Guimarães 1944, Machatschke 1972, Krajcik 2008, Soula 2009, Moore et al. 2017), Peru (Ratcliffe et al. 2015, Moore et al. 2017) |
| *Pelidnota xanthospila* (Germar, 1824) | Brazil (Bahia, Espírito Santo, Minas Gerais, Rio de Janeiro, São Paulo, Santa Catarina) (Laporte 1840, Burmeister 1844, Blanchard 1851, Ohaus, 1918, 1934, Machatschke 1972, Soula 2006, Krajcik 2008, Moore et al. 2017 and present study) |
| *Pelidnota* sp. nov. | Brazil (Bahia) |
| **Rutelina** MacLeay, 1819 | |
| ***Cnemida*** Kirby, 1827 | |
| *Cnemida lacerata* (Germar, 1824) | Brazil (Bahia, Distrito Federal (Brasília), Espirito Santo (Santa Leopoldina, Parati - Rolândia), Rio de Janeiro (Corcovado), Santa Catarina (Nova Teutônia - 271 l', 52023', Corupá, Joinville, Blumenau)) (Machatschke 1972, Jameson 1996) |
| *Cnemida retusa* (Fabricius, 1801) | Brazil (Bahia (Lençóis, Mucuri), Amapá (Porto Santana, Serro do Navio), Acre (Rio Humaits), Amazonas (Tefé, Manaus, Manacapurú, BR 319 km 275, Rio Javari, São Paulo do Olivença, Rio Tonantins, Rio Juruá, Fonte Boa), Espírito Santo (Linhares, Linhares, (P.N. Sooretama), Santa Leopoldina), Goiás (Jataí, Rio Verde, Trindade), Mato Grosso (Chapada dos Guimarães, Gleba Arinos, Reserva Humboldt (10°11'S–59°48'W)); Mato Grosso do Sul (Corumbá, Urucum), Minas Gerais, Pará, (Obidos, Obidos (Canta Galo), Colônia Rio Branco, Mocajuba, Est. Cruz Alta (Rio Trombetas), Santarém, Itaituba, Ilha de Marajó, Cameta, Mosquiero (Rio de Pará)), Amazonas (Faro); Rio de Janeiro (Jurujuba, Corcovado), Rondônia (Porto Velho (Rio Madeira), Ouro Preto do Oeste)), Bolivia (Beni, Villa Bella, Chuquisaca, El Palmar, Cochabamba, Rio Chapare), Colombia, Equador (Imbabura Pastaza, Rio Cururay), French Guiana (Cayenne, Cayenne, Roches de Kourou, Gourdonville, Charvein, Passoura (stream)), Guyana (West Berbice, Blairmont, Mazaruni-Potaro, Kartabu), Peru (Cuzco, Rio Vilcanota, Junin, 3–7 km SSW San Martin de Pangoa, Loreto, Ucayali R. Yarina Cocha, Rio Napo, Iquitos, Pucallpa (5 mi radius), Chambireyaci nr. Yurimaguas, Yurimaguas, San Martin, Mayobambo, Tarapoto), Suryname (Para, Dist. 13 Zanderij Area), Venezuela (Bolivar, Rio Caura, Distrito Federal, Caracas) (Jameson 1996 and present study) |
| ***Rutela*** Latreille, 1802 | |
| *Rutela histrio* Sahlberg, 1823 | Bolivia (Beni, Santa Cruz), Brazil (Amazonas, Bahia (Povoado de Cachimbo), Espírito Santo, Pará, Minas Gerais, Rio de Janeiro)), Colombia (Caqueta, Huila, Putumay), Equador (Loja, Morona-Santiago, Napo, Pastaza, Zamora, Chinchipe), French Guiana (Cayenne, Saint Laurent Du Moroni), Guyana (Mazaruni-Potaro), Paraguay, Peru (Amazonas, Junin, Hunaco, Lima, Loreto, Madre de Dios, Martin), Suryname, Venezuela (Bolivar, Monagas) (Jameson 1997 and present study) |
| **ANATISTINI** Lacordaire, 1856 | |
| ***Spodochlamys*** Burmeister, 1855 | |
| *Spodochlamys caesarea* Burmeister, 1855 | Brazil (Bahia, Pará and São Paulo), French Guiana (Cayenne) and Trinidad (Machatschke 1972, Jameson & Ratcliffe 2011, Ohaus 1918a and present study) |
| **GENIATINI** MacLeay, 1819 | |
| ***Bolax*** Fisher von Waldheim, 1829 | |
| *Bolax audiberti* Soula, 2011 | Brazil (Bahia) (Soula 2011) |
| *Bolax flavolineata* (Mannerheim, 1829) | Brazil (Bahia (new occurrence register), Minas Gerais, Rio de Janeiro, São Paulo) (Jameson & Hawkins 2005) |
| *Bolax sulcicollis* (Germar, 1824) | Brazil (Bahia, Espírito Santo) (Machatschke 1972, Jameson & Hawkins 2005, Soula 2011) |
| *Bolax sulcipennis* Ohaus, 1928 | Brazil (Bahia) (Machatschke 1972, Jameson & Hawkins 2005, Soula 2011) |

**Table 1.** Continued...

| SPECIES/SUBSPECIES | DISTRIBUTION |
|---|---|
| ***Geniates*** Kirby, 1819 | |
| *Geniates immaculatus* Camerano, 1878 | Brazil (Jameson & Hawkins 2005 and present study) |
| *Geniates verticalis* Burmeister, 1844 | Brazil (Jameson & Hawkins 2005 and present study) |
| ***Leucothyreus*** MacLeay, 1819 | |
| *Leucothyreus acanthurus* Ohaus, 1917 | Brazil (Bahia (new occurrence register) and Espírito Santo) (Jameson & Hawkins 2005) |
| *Leucothyreus albopilosus* Ohaus, 1917 | Brazil (Acre, Bahia (new occurrence register), Espírito Santo, Mato Grosso, Rio de Janeiro, São Paulo) (Jameson & Hawkins 2005) |
| *Leucothyreus campestris* Burmeister, 1855 | Brazil (Bahia (new occurrence register), Minas Gerais) (Jameson & Hawkins 2005) |
| *Leucothyreus cayapo* Ohaus, 1931 | Brazil (Bahia (new occurrence register), Goiás) (Jameson & Hawkins 2005) |
| *Leucothyreus duplopunctatus* Frey, 1976 | Brazil (Bahia (new occurrence register), Mato Grosso) (Jameson & Hawkins 2005) |
| *Leucothyreus eligius* Ohaus, 1918 | Brazil (Bahia (new occurrence register), Minas Gerais, Rio de Janeiro, São Paulo) (Jameson & Hawkins 2005) |
| *Leucothyreus flavipes* (Eschscholtz, 1822) | Brazil, Paraguay, Uruguay (Jameson & Hawkins 2005 and present study) |
| *Leucothyreus fluminensis* Ohaus, 1918 | Brazil (Bahia (new occurrence register) and Rio de Janeiro) (Machatschke 1972, Jameson & Hawkins 2005) |
| *Leucothyreus garbei* Ohaus, 1931 | Brazil (Bahia) (Machatschke 1972, Jameson & Hawkins 2005 and present study) |
| *Leucothyreus iridipennis* Ohaus, 1917 | Brazil (Bahia (new occurrence register), Espírito Santo, Santa Catarina) (Jameson & Hawkins 2005) |
| *Leucothyreus kulzeri* Frey, 1976 | Brazil (Bahia) (Jameson & Hawkins 2005) |
| *Leucothyreus lucipetens* Ohaus, 1931 | Brazil (Bahia (new occurrence register), Rio de Janeiro) (Jameson & Hawkins 2005) |
| *Leucothyreus occipitalis* Ohaus, 1931 | Brazil (Bahia (new occurrence register), Rio de Janeiro) (Jameson & Hawkins 2005) |
| *Leucothyreus opacus* (Perty, 1832) | Brazil (Jameson & Hawkins 2005 and present study) |
| *Leucothyreus pallefactus* Ohaus, 1924 | Brazil (Bahia (new occurrence register), Santa Catarina) (Jameson & Hawkins 2005) |
| *Leucothyreus pallidus* Ohaus, 1918 | Brazil (Bahia) (Jameson & Hawkins 2005) |
| *Leucothyreus paulista* Ohaus, 1917 | Brazil (Bahia (new occurrence register), São Paulo) (Jameson & Hawkins 2005) |
| *Leucothyreus punctulatus* Blanchard, 1851 | Brazil (Bahia (new occurrence register), Rio de Janeiro) (Jameson & Hawkins 2005) |
| *Leucothyreus severinus* Ohaus, 1918 | Brazil (Bahia) (Jameson & Hawkins 2005) |
| *Leucothyreus similis* Frey, 1976 | Brazil (Bahia) (Jameson & Hawkins 2005 and present study) |
| *Leucothyreus spinifer* Ohaus, 1918 | Argentina (Salta), Brazil (Bahia, Minas Gerais, Rio de Janeiro), Paraguay (San Pedro) (Jameson & Hawkins 2005 and present study) |
| *Leucothyreus subcupreus* Blanchard, 1851 | Brazil (Bahia) (Jameson & Hawkins 2005) |
| *Leucothyreus suturalis* Laporte, 1840 | Brazil (Bahia (new occurrence register), Espírito Santo, Santa Catarina) (Jameson & Hawkins 2005) |
| *Leucothyreus trochantericus* Ohaus, 1917 | Brazil (Bahia (new occurrence register), Rio de Janeiro) (Jameson & Hawkins 2005) |
| *Leucothyreus verticalis* Ohaus, 1924 | Brazil (Bahia (new occurrence register), Espírito Santo) (Jameson & Hawkins 2005) |
| *Leucothyreus* sp. 1 | Brazil (Bahia (Vitória da Conquista)) |
| *Leucothyreus* sp. 2 | Brazil (Bahia (Mucugê)) |
| *Leucothyreus* sp. 3 | Brazil (Bahia (Santa Terezinha)) |
| *Leucothyreus* sp. 4 | Brazil (Bahia (Maracás)) |
| *Leucothyreus* sp. 5 | Brazil (Bahia (Mucugê, Santa Terezinha, Salvador, Sauípe, Senhor do Bonfim)) |
| *Leucothyreus* sp. 6 | Brazil (Bahia (Mucugê, Lençóis, Palmeiras)) |
| *Leucothyreus* sp. 7 | Brazil (Bahia (Paulo Afonso)) |
| *Leucothyreus* sp. 8 | Brazil (Bahia (Feira de Santana, Maracás, Morro do Chapéu, Mucugê, Paulo Afonso, Santa Terezinha, Sauípe, Vitória da Conquista)) |
| *Leucothyreus* sp. 9 | Brazil (Bahia (Igrapiúna, Ituberá, Santa Terezinha, Porto Seguro)) |
| *Leucothyreus* sp. 10 | Brazil (Bahia (Maracás)) |
| ***Lobogeniates*** Ohaus, 1917 | |
| *Lobogeniates alvinus* Ohaus, 1931 | Brazil (Bahia) (Machatschke 1972, Jameson & Hawkins 2005 and present study) |
| *Lobogeniates nigricans* Ohaus, 1917 | Brazil (Bahia (Povoado Cachimbo)) (Jameson & Hawkins 2005) |
| *Lobogeniates* sp. 1 | Brazil (Bahia (Santa Terezinha)) |
| *Lobogeniates* sp. 2 | Brazil (Bahia (Santa Terezinha)) |
| *Lobogeniates* sp. 3 | Brazil (Bahia (Ituberá)) |
| *Lobogeniates* sp. 4 | Brazil (Bahia (Ituberá)) |
| ***Trizogeniates*** Ohaus 1917 (new occurrence register) | |
| *Trizogeniates planipennis* Ohaus, 1917 | Brazil (Bahia (new occurrence register), Espírito Santo, Minas Gerais, Rio Grande do Sul, Rio de Janeiro, Santa Catarina, São Paulo), Peru (Jameson & Hawkins 2005) |

1912, *Dorysthetus espiritosantensis* Ohaus, 1905, *D. fulgidus* (Waterhouse, 1881), *Leucothyreus acanthurus* Ohaus, 1917, *L. albopilosus* Ohaus, 1917, *L. campestris* Burmeister, 1855, *L. cayapo* Ohaus, 1931, *L. duplopunctatus* Frey, 1976, *L. eligius* Ohaus, 1918, *L. fluminensis* Ohaus, 1918, *L. iridipennis* Ohaus, 1917, *L. lucipetens* Ohaus, 1931, *L. occipitalis* Ohaus, 1931, *L. pallefactus* Ohaus, 1924, *L. paulista* Ohaus, 1917, *L. punctulatus* Blanchard, 1851, *L. suturalis* Laporte, 1840, *L. trochantericus* Ohaus, 1917, *L. verticalis* Ohaus, 1924, *Macraspis cincta* (Drury, 1872), *Paranomala tricostulata* (Ohaus, 1897), *P. violacea* (Burmeister, 1844), *Pseudodorysthetus calcaratus* (Spinola, 1835), and *Trizogeniates planipennis* Ohaus, 1917. The subspecies *Pelidnota unicolor unicolor* (Drury, 1778) was also a new record for Bahia state (Table 1). Gathering this information with the already existing, makes a total of 101 species, and 17 subspecies in 4 tribes and 23 genera (Table 1) only for Bahia. Rutelini presented the greatest richness, with 16 genera, 49 species and 16 subspecies. Geniatini is the second tribe in richness with 5 genera and 46 species (Table 1). Anomalini and Anatistini presented only 1 genera each – *Paranomala* Casey, 1915, with 5 species and 2 subspecies and *Spodochlamys* Burmeister, 1855, with only one species (Table 1).

The richest genera were *Leucothyreus* (Geniatini), with 25 species, and *Pelidnota* (Rutelini) with 19 species and 9 subspecies (Figure 2). *Leucothyreus*, with 164 species described (Jameson & Hawkins 2005), and *Pelidnota*, with 136 species and 60 valid subspecies (Moore et al. 2017, Ferreira et al. 2017), are the richest genera within Rutelinae.

There were recorded Ruteliane species in fifty-seven, taking into account the literature and the examined material, out of a total of 417 Bahian municipalities. Rutelini were found to occur in 41 localities, and Geniatini in 37 (Figure 1), which represents only 13.67% of the total amount of municipalities. Anomalini was recorded in only eight localities in the state and Anatistini only in the municipality of Cachoeira (Figure 1). Rutelini and Geniatini were recorded in all the Biomes, however Rutelini presented a concentration of records in areas of Atlantic Rain Forest near the coast. Geniatini had similar numbers of records in the Caatinga and in the Atlantic Forest (Figure 1). These findings could be attributed to the natural history of these tribes which immatures of Rutelini species occurs in dead wood

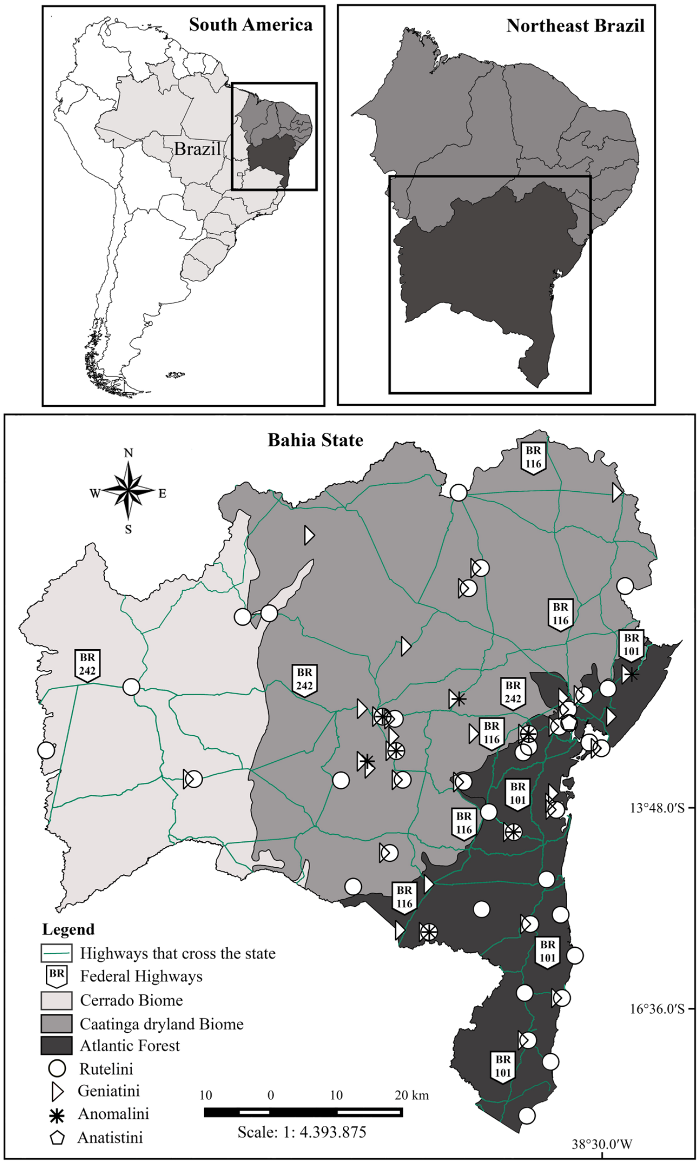

**Figure 1.** Location of the study area and geographic distribution records Rutelinae in the Bahia state.

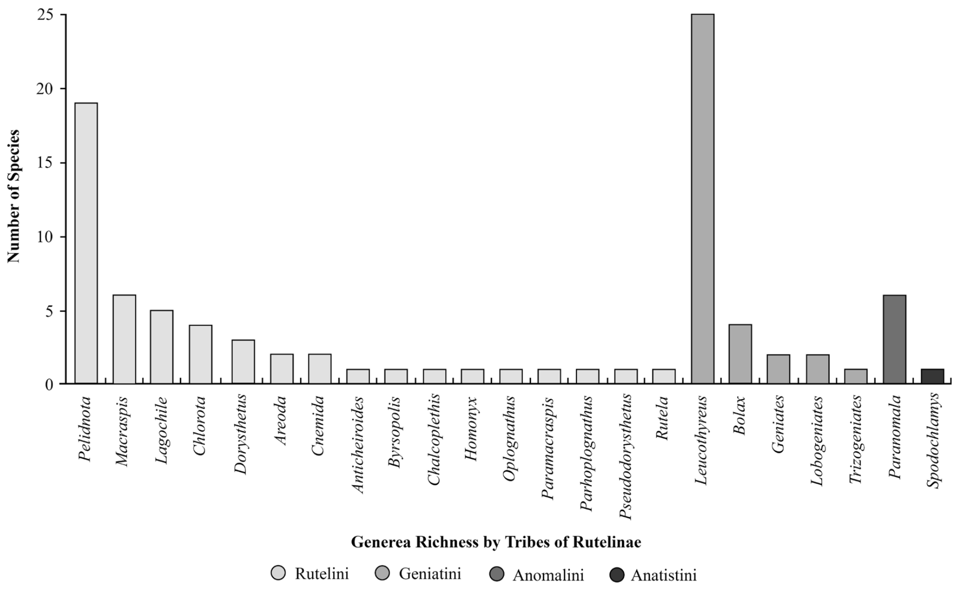

**Figure 2.** Species richness of Rutelinae from Bahia state, gathering the literature data with the results presented in this study.

(Albertoni et al. 2014), while Geniatini species develop mainly in the ground (Furhmann 2013).

The distribution of the Rutelinae species in Bahia has had, in part, direct correlation with the collection trips of the Projeto de Pesquisa em Biodiversidade do Semiárido (PPBio/Ministério da Ciência, Tecnologia, Inovações e Comunicações, MCTIC) since 2005. The ruteline specimens of PPBio Semiarido were deposited in the MZFS and these represent 72.8% (1,064 specimens) of all specimens examined in this study, with 68 species and 5 subspecies. However, although the PPBio has contributed significantly to expand the records of the Rutelinae from Bahia, there are still significant gaps to be explored in the state. The west, southwest and north regions of Bahia present the largest gaps (Figure 1). Certainly, there are many species to be discovered in these regions of the state, which demonstrates the need of a greater collection effort in the regions mentioned above (Oliveira et al. 2016). In addition to the mentioned issues, many of the subfamily distribution records in the state are located in areas near the highways that cross Bahia (Figure 1). Oliveira et al. (2016) report that species composition decreases as distance from access routes increases, and they suggest that collection localities distant from access routes could increase the possibility of new geographic records as well as records of new species. Most of the records for the south region of Bahia, in Belmonte, Barrolândia, Camacan, Itamaraju, Mucuri, Porto Seguro, Prado and Una, and two localities in the southern region: Encruzilhada and Cândido Sales, are the result of material deposited at MNRJ, CERPE and EPGC (Suplementary Material). Similarly, the collection points located in the north of the state are also from material deposited in MNRJ (examined material). The records for the southern region, Aracatu and Vitória da Conquista (examined material), are deposited in the MFS and were collected by the author.

Among the biomes present in Bahia, the Atlantic Forest has the highest representativity of Rutelinae records, with 32 localities of occurrence: Caatinga with 20 (with the largest collects gap in the southwest, and especially in the north of the state (Figure 1)) and the Cerrado, with only 5 points of records, representing the largest collects gap of all biomes (Figure 1). Atlantic Forest originally accounted for 1,300,000 km$^2$ throughout 17 Brazilian states, with 120 million people living in this biome. However, only 22% of the original cover remains, and only 8.5% is in well preserved protection areas, on fragments of over 100 hectares (MMA 2017). Caatinga covers 844,453 km$^2$, representing 11% of the national territory, and is present in nine states of Northeastern Brazil and in the north of Minas Gerais state (MMA 2017). The Caatinga and the Cerrado has been deforested in an accelerated way, especially in the last years, and 46% of the Caatinga total original cover has been deforested (Flores et al. 2012, MMA 2017). Cerrado has been historically transformed in extensive crop plantations in Brazil, causing an increasing reduction of the vegetal cover due to the progressive increase in agricultural economic activity in areas in its domain (Flores et al. 2012). This reduction in vegetal cover has, in turn, generated direct consequences for biodiversity loss (Queiroz 2009, MMA 2017). However, only 7.6% of the total area of the Caatinga is in the protection area, and only 1% of this area is designated as Units of Integral Protection (MMA 2017). In addition, approximately 30% of the Caatinga has already been altered due to human action, and especially due to agriculture. In view of these factors, there is a risk of the rapid loss of unique species in this biome (Araújo et al. 2005), many of which are yet unknown to science. The Cerrado biome presents the largest collects gap of Rutelinae in Bahia state. Cerrado covers 2,036,448 km$^2$ (representing 22% of the national territory), and is present in 12 Brazilian states. It is considered a hotspot of world biodiversity, with an extreme abundance of endemic species (MMA 2017). However, the Cerrado is the biome with the lowest percentage of areas of integral protection. Only 8.21% of the total territory is legally protected by Units of Conservation; of this total, 2.85% are Units of Conservation of Integral Protection and 5.36% are Units of Conservation of Sustainable Use, including Particular Reserve of Natural Heritage – RPPNs (0.07%) (MMA 2017). The findings presented above demonstrate the need to make more collects in the state, especially in Cerrado in the west region of the state, to enable a better understanding of the distribution, expanding the knowledge of the group.

With the results presented here there was an expressive increase, both in the richness of genera and species. After this study the number of genera increased to 23, with the new records of *Byrsopolis* Burmeister, *Pseudodorysthetus* Soula and *Trizogeniates* Ohaus; new distributional records of 30 species and 1 subspecies from Bahia state, and with 14 species, that will be described in subsequent papers, 10 of *Leucothyreus* (according to the consultation with a researcher, Seidel M., who is conducting the review of the genus), 2 of *Lobogeniates* (a genus in process of review by ASF) and 1 of *Byrsopolis* and *Pelidnota*. With respect to the number of registered species of Rutelinae in Bahia, was increased in more than a half, reaching 101 species and 17 subspecies.

This increase in the number of registered Rutelinae species demonstrates the importance of conducting inventories for group knowledge. In addition, the distribution of the Rutelinae locality records in the Bahia state in only 57 registered municipalities, which is equivalent to 13.67% of the total municipalities in the state, plus the gaps seen in the most richest and poorly known biomes, emphasizes the imminent need for new studies involving the Rutelinae for a better knowledge of fauna, not only in the biomes of this state, but in Brazil as a whole.

## Supplementary material

The following online material is available for this article:
Supplementary material

## Acknowledgments

The authors would like to thank to the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for the master's fellowship to the first author (ASF), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the research fellowship awarded to LMA (306772/2006-0) and FB (305055/2012-7), Dra. Marcela Monné and Dr. Miguel A. Monné (MNRJ), Dra. Jane Costa and Dr. Márcio Félix (CEIOC–RJ), Dr. Everardo J. Grossi (EPGC), and Dra. Favízia F. Oliveira (MHNBA/MZUFBA) for allowing the study of material, the PPBio Semiarido project (Programa de Pesquisa em Biodiversidade do Semiárido) (agreement CNPq/MCTI – Ministério da Ciência, Tecnologia e Inovação n.º: 457471/2012-3) for financial support for collections and for supporting to visit of Paschoal Grossi visit to the collections at MZFS.

## Authors Contributions

André da Silva Ferreira: Contribution to data collection, contribution to data analysis and interpretation, contribution to manuscript preparation and contribution to critical revision, adding intellectual content.

Lúcia M. Almeida and Freddy Bravo: Contribution to critical revision, adding intellectual content.

Paschoal Coelho Grossi: Contribution to data collection, critical revision, adding intellectual content.

## Conflicts of interest

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

## References

ALBERTONI, F.F., FUHRMANN, J. & IDE, S. 2014. *Lagochile emarginata* (Gyllenhal): morphology of immature and imago, and biological records (Coleoptera, Scarabaeidae, Rutelinae). Revista Brasileira de Entomologia 58(1): 32-46.

ARAÚJO, F.S.; RODAL, M.J.N. & BARBOSA, M.R.V. 2005. Análise das variações da biodiversidade do bioma Caatinga: suporte a estratégias regionais de conservação. Ministério do Meio Ambiente, DF. Brasília.

BAHIA. 2013. Meio Ambiente na Bahia. Secretaria de Indústria, Comércio e Mineração/Companhia Baiana de Pesquisa Mineral. http://www.cbpm.com.br/paginas/meio_bahia.php (last access at 14/09/2015).

BATES, F. 1904. A revision of the sub-family Pelidnotinae of the coleopterous family Rutelidae, with descriptions of new genera and species. Transactions of the Entomological Society of London 1904: 249-276.

BLANCHARD, C.E. 1850 (1851). Ordre des Coleoptera. In Muséum d'Histoire Naturelle de Paris. Catalogue de la Collection Entomologique. Classe des Insectes, Vol. 1, Part 2. (H. Milne-Edwards, C.E. Blanchard & H. Lucas. eds.). Gide and Baudry, Paris, p.129-240.

BLACKWELDER, R.E. 1944. Checklist of the Coleopterous Insects of Mexico, Central America, the West Indies, and South America. United States National Museum Bulletin 185: 189-265.

BOUCHARD, P., BOUSQUET, Y., DAVIES, A. E., ALONSO-ZARAZAGA, M. A., LAWRENCE, J. F., LYAL, C. H., NEWTON, A. F., REID, C. A., SCHMITT, M., SLIPIŃSKI, S. A. & SMITH, A. B. 2011. Family-group names in Coleoptera (Insecta). ZooKeys 88: 1-972.

BURMEISTER, H. 1844. Handbuch der Entomologie. (Coleoptera Lamellicornia Anthobia et Phyllophaga Systellochela), Vol. 4, Pt. 1. Berlin.

BURMEISTER, H. 1855. Handbuch der Entomologie. (Coleoptera Lamellicornia Anthobia et Phyllophaga Systellochela), Vol. 4., Pt. 2. Berlin.

CHERMAN, M.A. & MORÓN, M.A. 2014. Validación de la Família Melolonthidae Leach, 1819 (Coleoptera: Scarabaeoidea). Acta Zoológica Mexicana (n.s.) 30(1): 201-220.

ENDRÖDI, S. 1966. Monographie der Dynastinae I Teil 1 Tribus Cyclocephalini. Entomologische Abhandlungen Staatlichen Museum für Tierkunde, Dresden 33: 1-145.

EVANS, A.V. 2002. Melolonthinae. In American Beetles Volume 2. Polyphaga: Scarabaeoidea through Curculionoidea. (R.H. Arnett, M.C. Thomas, P.E. Skelley & J.H. Frank. eds.). CRC Press, Boca Raton, Florida, p.51-60.

FABRICIUS, J.C. 1801. Systema Eleutheratorum Secundum Ordines, Genera, Species: Adiectis Synonymis, Locis, Observationibus, Descriptionibus, volume 2. Impensis Bibliopolii Academici Novi. Kiel, Germany.

FERREIRA, A.S., ALMEIDA, L.M. & BRAVO, F. 2017. Three new species of *Pelidnota* MacLeay (Coleoptera, Scarabaeidae, Rutelinae) and new distributional records from northeast Brazil. Revista Brasileira de Entomologia 61: 208-223. http://doi.org/10.1016/j.rbe.2017.04.004.

FILIPPINI, V., MICÓ, E. & GALANTE, E. 2016. Checklist and identification key of Anomalini (Coleoptera, Scarabaeidae, Rutelinae) of Costa Rica. ZooKeys 621: 63-136. http://doi:10.3897/zookeys.621.7565.

FLORES, M.P., GUIMARÃES, R.F., CARVALHO JÚNIOR, O.A. & GOMES, R.A.T. 2012. Multitemporal Analysis of Agricultural Expansion in the Barreiras Municipality - Bahia. Campo-Território: revista de geografia agrária 7(14): 1-19.

FREY, G. 1976. Neue Sudamerikanischen Ruteliden. Entomologische Arbeiten aus dem Museum 27: 344-356.

FUHRMANN, J. 2013. Description of the third larval instar and pupa of *Geniates barbatus* Kirby (Coleoptera, Scarabaeidae, Rutelinae). Revista Brasileira de Entomologia 57(1): 40-46.

GARCIA, F.P., RODRIGUES, S.R., BAGNARA, C.A.C., DE OLIVEIRA, D.S. 2013. Survey of saproxylophagous Melolonthidae (Coleoptera) and some biological aspects in Aquidauana, MS. Biota Neotropica 13 (3): 38-43.

GERMAR, E.F. 1824. Insectorum species novae aut minus cognitae, descriptionibus illustratae. Halle.

GORY, H.L. 1833. Description de deux Coléoptères nouveaux des genres *Rutela* et *Buprestis*. Annales de la Société entomologique de France 2: 67-68.

GRAY, G. R. 1832. Supplement on the Lamellicornes. In The Class Insecta Arranged by the Baron Cuvier, with Supplementary Additions to each Order, Volume 1. Whittaker, Treacher, and Co. (E. Griffith & E. Pidgeo. eds.). London, UK, p.504-537.

GROSSI, P.C. & VAZ-DE-MELLO, F.Z. 2016. Rutelinae in Catálogo Taxonômico da Fauna do Brasil. PNUD. http://fauna.jbrj.gov.br/fauna/faunadobrasil/126897 (last access at 10/09/2016).

GUÉRIN-MÉNEVILLE, F.É. 1834. Iconographie du Règne Animal de G. Cuvier, ou Représentation d'Après Nature de L'une des Espèces les Plus Remarquables, et Souvent non Encore Figurées, de Chaque Genre d'Animaux. Avec un texte descriptif mis au courant de la science. Ouvrage Pouvant Servir d'Atlas à Tous les Traités de Zoologie. Insectes. Vol. 7. J. B. Baillière, Paris, 576 pp. [+ 110 plates].

GUIMARÃES, L.R. 1944. Rutelidae, Cetonidae, Melolonthidae e Dynastidae de Monte Alegre. Papéis Avulsos do Departamento de Zoologia (São Paulo) 6: 93-102.

GUTIÉRREZ, A.R. 1951. Notas sobre Scarabaeidae neotrópicos II (Coleopt. Lamellic.). Anales de la Sociedad Científica Argentina 151: 106-125.

HARDY, A.R. 1975. A revision of the genus *Pelidnota* of America north of Panama (Coleoptera: Scarabaeidae: Rutelinae). University of California Publications in Entomology 78: 1-43.

HARDY, A. 1991. A Catalog of the Coleoptera of America North of Mexico - Family: Scarabaeidae, Subfamilies: Rutelinae and Dynastinae. California, United States - Department of Agriculture, Agriculture Handbook.

HAROLD, E. 1869. Scarabaeidae. In Catalogus Coleopterorum Hucusque Descriptorum Synonymicus et Systematicus, Vol. 4. E. H. Gummi (M. Gemminger & E. Harold. eds.). Munich, p.979-1346.

HAWKS, D.C. 2017. Five new species of *Chrysina* Kirby (Coleoptera: Scarabaeidae: Rutelinae). Insecta Mundi 0544: 1-9.

HERBST, J.F.W. 1790. Natursystem aller bekannten in- und ausländlischen Insekten, als eine Fortsetzung der von Büffonschen Naturgeschichte. Der Käfer dritter Theil. Pauli, Berlin.

HUNT, T., BERGSTEN, J., LEVKANICOVA, Z., PAPADOPOULOU, A, ST. JOHN, O., WILD, R., HAMMOND, P.M., AHRENS, D., BALKE, M., CATERINO, M.S., GÓMEZ-ZURITA, J., RIBERA, I., BARRACLOUGH, T.G., BOCAKOVA, M., BOCAK, L. & VOGLER, A.P. 2007. A Comprehensive Phylogeny of of Beetles Reveals the Evolutionary Origins of a Superradiation. Science 318: 1913-1919.

IBGE–INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. 2013. Área Territorial Brasileira: Consulta por Unidade de Federação. http://www.ibge.gov.br/home/geociencias/areaterritorial/principal.shtm (las access at 14/09/2015).

JAMESON, M.L. 1996. Revision and Phylogeny of the Neotropical genus *Cnemida* (Coleoptera: Scarabaeidae: Rutelinae). Insecta Mundi 10(1-4): 285-315.

JAMESON, M. L. 2002. Rutelinae MacLeay 1819. In American Beetles Volume 2. Polyphaga: Scarabaeoidea through Curculionoidea. (R.H. Arnett, M.C. Thomas, P.E. Skelley & J.H. Frank eds.). CRC Press, Boca Raton, Florida, p.60-64.

JAMESON, M.L. 2008. Review of the genus *Microchilus* Blanchard (Coleoptera: Scarabaeidae: Rutelinae: Geniatini). Insecta Mundi 0025: 1-14.

JAMESON, M.L. & HAWKINS, S.J. 2005. Synopsis of the genera of Geniatini (Coleoptera: Scarabaeidae: Rutelinae) with an annotated catalog of species. Zootaxa 874: 1-76.

JAMESON, M.L. & RATCLIFFE, B.C. 2011. The Neotropical Scarab Beetle Tribe Anatistini (Coleoptera: Scarabaeidae: Rutelinae). Bulletin of the University of Nebraska State Museum 26: 1-100.

KOHLMANN, B. & MORÓN, M. A. 2003. Análisis histórico de la clasificación de los Coleoptera Scarabaeoidea o Lamellicornia. Acta Zoológica Mexicana (n.s.) 90: 175-280.

KRAJCIK, M. 2008. Checklist of Scarabaeoidea of the World: Rutelinae (Coleoptera: Scarabaeidae: Rutelinae), Vol. 2. Animma. X Supplement 4, Plzen Milan Krajcik.

LAPORTE [=CASTELNAU] FLNCde. 1840. Histoire naturelle des insectes Coléoptères; avec une introduction renfermant l'anatomie et la physiologie des animaux articulés, par M. Brullé. Tome premier. Histoire naturelle des animaux articulés, annélides, crustacés, arachnides, myriapodes et insectes Tome troisième. P. Duménil, Paris, 324p. [+ 19 plates].

LAWRENCE, J.F. & NEWTON, A.F. 1995. Families and subfamilies of Coleoptera (with selected genera, notes and references, and data on family-group names). In Biology, Phylogeny, and Classification of Coleoptera: Papers Celebrating the 80th Birthday of Roy A. (J. Pakaluk & S.A. Slipinski. eds.). Crowson, Warsaw: Muzeum i Instytut Zoologii PAN, p.779-1006.

LAWRENCE, J.F., ŚLIPIŃSKI, A., SEAGO, A. E., THAYER, M.K., NEWTON, A.F. & MARVALDI, A.E. 2011. Phylogeny of the Coleoptera Based on Morphological Characters of Adults and Larvae. Annales Zoologici 61: 1-217.

MACHATSCHKE, J. 1972. Scarabaeidae: Melolonthidae, Rutelinae. Coleopterum Catalogus Supplementa 66(1-2): 1-429.

MMA–MINISTÉRIO DO MEIO AMBIENTE. 2017. Mata Atlântica. http://www.mma.gov.br/biomas/mata-atlantica (last access at 06/06/2017).

MOORE, M.R., JAMESON, M.L., GARNER, B.H., AUDIBERT, C., SMITH, A.B.T. & SEIDEL, M. 2017. Synopsis of the pelidnotine scarabs (Coleoptera, Scarabaeidae, Rutelinae, Rutelini) and annotated catalog of the species and subspecies. ZooKeys 666: 1-349.

MORÓN, M.A. 1990. The Beetle of the World: Rutelini. Sciences Nat. 10: 1-206.

MORÓN, M. A. 2004. Melolontídeos edafícolas. In Pragas de solo no Brasil. (J.R. Salvadori, C.J. Ávila & M.T.B. Silva. eds.). Passo Fundo: Embrapa Trigo; Dourados: Embrapa Agropecuária Oeste; Cruz Alta: Fundacep Fecotrigo, p.41-68.

MORÓN, M.A. & RAMÍREZ-PONCE, A. 2012. Mesoamerican genera of Anomalini (Coleoptera: Melolonthidae: Rutelinae): A brief review. Trends in Entomology 8: 97-114.

MORÓN, M.A., RATCLIFFE, B.C. & DELOYA, C. 1997. Atlas de los Escarabajos de México. Coleoptera: Lamellicornia. Vol. 1: Família Melolonthidae. Subfamílias Rutelinae, Dynastinae, Cetoniinae, Trichiinae, Valginae y Melolonthinae. Sociedad Mexicana de Entomologia, A.C., Mexico.

OHAUS, F. 1897. Stettiner Entomologische Zeitung, LVIII.

OHAUS, F. 1905. Revision der Amerikanischen Anoplognathiden (Coleoptera Lamellicornia). Stettiner Entomologische Zeitung 1905: 120-167.

OHAUS, F. 1908. Die Ruteliden meiner Sammelreisen in Südamerika (Col.). Deutsche Entomologische Zeitschrift 1908: 239-262.

OHAUS, F. 1912. Beiträge zur Kenntnis der Ruteliden. X. Stettiner Entomologische Zeitung 73: 273-319.

OHAUS, F. 1913. XI. Beitrag zur Kenntnis der Ruteliden. (Col.). Deutsche Entomologische Zeitschrift 1913: 487-511.

OHAUS, F. 1917. Neue Geniatinen (Col. lamell. Rutelin.). Stettiner Entomologische Zeitung 78: 3-53.

OHAUS, F. 1918a. Scarabaeidae: Euchirinae, Phaenomerinae, Rutelinae. Coleopterum Catalogus 20: 1-124.

OHAUS, F. 1918b. Neue Geniatinen II (Col. lamell. Rutelin.). Stettiner Entomologische Zeitung 79: 350-365.

OHAUS, F. 1924. Neue Geniatinen III. Stettiner Entomologische Zeitung 84: 179-186.

OHAUS, F. 1926. Three new species of Rutelinae (Coleoptera lamellicornia) in the Carnegie Museum. Annals of the Carnegie Museum 17: 87-89.

OHAUS, F. 1928. Beitrag zur Kenntnis der Ruteliden (Col. lamell.). Deutsche Entomologische Zeitschrift 1928(1929): 385-406.

OHAUS, F. 1930. XXVI. Beitrag zur Kenntnis der Rutelinen (Col. amell.). Deutsche Entomologische Zeitschrift 1930: 138-158.

OHAUS, F. 1931. Neue Geniatinen IV. Stettiner Entomologische Zeitung. Stettin 92: 227-258.

OLIVEIRA, U., PAGLIA, A.P., BRESCOVIT, A.D., CARVALHO, C.J.B., SILVA, D.P., REZENDE, D.T., LEITE, F.S.F., BATISTA, J.A.N., BARBOSA, J.P.P.P., STEHMANN, J.R., ASCHER, J.S., VASCONCELOS, M.R., MARCO JR., P., LÖWENBERG-NETO, PP., DIAS, P.G., FERRO, V.G. & SANTOS, A.J. 2016. The strong influence of collection bias on biodiversity knowledge shortfalls of Brazilian terrestrial biodiversity. Diversity and Distributions 2016: 1-13.

OLIVIER, A.G. 1789. Entomologie, ou Histoire Naturelle des Insectes, avec leurs Caractères Génériques et Spécifiques, leur Description, leur Synonymie, et leur Figure Enluminée. Coléoptères, Tome Premier (genera separately paged). Baudouin, Paris, 432p. [xix + 2 pp].

OLIVIER, A.G. 1802. Entomologie oder Naturgeschichte der Insekten mit ihren Gattungs- und Art-Mekmalen, ihrer Beschreibung und Synonymie. Käfer. Zweiter Theil. Mit Kupfern. Karl Reichard, Braunschweig.

PARDO-LOCARNO, L.C., RAMÍREZ-PAVA, B., VILLOTA, H., VILLANUEVA, O. & BAHAMÓN, W. 2011. Ensamblaje de escarabajos Melolonthidae (Coleoptera: Scarabaeoidea) asociados con pasturas en el departamento del Caquetá y su posible relación con la salubridad edáfica. Acta Agronómica 60 (3): 1-12.

PAUCAR-CABRERA, A. 2003. Systematics and phylogeny of the genus *Epectinaspis* Blanchard (Coleoptera: Scarabaeidae: Rutelinae) and description of a new genus of Anomalini from Mexico. Coleopterists Society Monographs 2: 1-60.

PEREIRA, A.F., RODRIGUES, S.R. & MORÓN, M.A. 2013. Biological aspects of *Leucothyreus alvarengai* Frey and *Leucothyreus* aff. *semipruinosus* Ohaus

(Coleoptera, Melolonthidae, Rutelinae) in crop succession at central Brazil. Revista Brasileira de Entomologia 57 (3): 323-228.

PERTY, J.A.M. 1830. Insecta Brasiliensia. In Delectus animalium articulatorum, quae in itinere per Brasilliam annis MDCCCXVII-MDCCCXX jussu et auspiciis Maximilliani Josephi I. Bavariae regis augustissimi peracto. (J. Spix & C. Martius. eds.). Frid. Fleicher, Monachii [München], p.1-60.

PUKER, A., RODRIGUES, S.R., TIAGO, E.F. & SANTOS, W.T. 2009. Phytophagous species of Scarabaeidae (Insecta: Coleoptera) associated with the root system of *Acrocomia aculeata* (Jacq.) Loddi. ex Mart. (Arecaceae). Biota Neotropica 9 (3): 105-109.

QUEIROZ, F.A. 2009. Impacts of the international trade of soybeans on the biodiversity of Cerrado Savannah. Sociedade & Natureza, Uberlândia 21 (2): 193-209.

RATCLIFFE, B.C. & JAMESON, M.L. 1989. A Synopsis of the Genus *Areoda* (Coleoptera: Scarabaeidae: Rutelinae). The Coleopterists Bulletin 43(2): 135-144.

RATCLIFFE, B.C., JAMESON, M.L., FIGUEROA, L., CAVE, R.D., PAULSEN, M.J., CANO, E.B., BEZA-BEZA, C., JIMENEZ-FERBANS. L. & REYES-CASTILLO, R. 2015. Beetles (Coleoptera) of Peru: A survey of families. Scarabaeoidea. The Journal of the Kansas Entomological Society 88: 186-207.

RESTREPO-GIRALDO, H., MORÓN, M.A., VALLEJO, F., PARDO-LOCARNO, L.C. & LÓPEZ-AVILA, A. 2003. Catálogo de Coleoptera Melolonthidae (Scarabaeidae Pleurosticti) de Colombia. Folia Entomológica Mexicana 42: 239-263.

RODRIGUES, S.R., PUKER, A., ABOT, A.R.; BARBOSA, C.L., IDE, S. & COUTINHO, G.V. 2008. Ocorrência e aspectos biológicos de *Anomala testaceipennis* Blanchard (Coleoptera, Scarabaeidae). Revista Brasileira de Entomologia 52 (1): 68-71.

RODRIGUES, S.R. & DA SILVA FALCO, J. 2011. Aspectos biológicos de *Pelidnota fulva* Blanchard, 1850 (Coleoptera, Scarabaeidae, Rutelinae). Biota Neotropica 11: 157-160.

RODRIGUES, S.R., MORÓN, M.A., NOGUEIRA, G.A.L. 2012. Description of the third instar of *Pelidnota fulva* Blanchard, 1850 (Coleoptera: Scarabaeidae: Rutelinae). The Coleopterists Bulletin 66 (3): 266-270.

RODRIGUEZ-DEL-BOSQUE, L.A. 1996. Population and adult longevity the *Phyllophaga crinita, Anomala flavipennis* and *A. forminosa* Coleoptera (Scarabaeidae). Southwestern Entomologist 21 (1): 55-58.

RODRIGUEZ-DEL-BOSQUE, L.A. 1998. A sixteen-year study on the bivoltinism of *Anomala flavipennis* (Coleoptera: Scarabaeidae) in Mexico. Environmental Entomology 27: 248-252.

SEIDEL, M., JAMESON, M.L. & STONE, R.L. 2017. A new cryptic species and review of the east-Andean leaf chafer genus *Mesomerodon* Ohaus, 1905 (Coleoptera, Scarabaeidae, Rutelinae). ZooKeys 671: 61-85. http://doi.org/10.3897/zookeys.671.11815.

SIERRA, J.M. 2017. Four new species of *Chrysina* Kirby (Coleoptera: Scarabaeidae: Rutelinae) from Guatemala and Honduras. Insecta Mundi 0543: 1-12.

SMITH, A.B.T., HAWKS, D.C. & HERATY, J.M. 2006. An Overview of the Classification and Evolution of the Major Scarab Beetle Clades (Coleoptera: Scarabaeoidea) Based on Preliminary Molecular Analyses. Coleopterists Society Monograph 5: 35-46.

SOULA, M. 1998. Les Coléoptères du Nouveau Monde. Rutelini 2. Revision Des Anticheirina 1. Hillside Books, Canterbury 26 (1): 1-116.

SOULA, M. 2002a. Les Coléoptères du Nouveau Monde. Rutelini 2. Hillside Books, Canterbury 26: 1-98.

SOULA, M. 2002b. Les Coléoptères du Nouveau Monde. Rutelini 2. Hillside Books, Canterbury 26 (2): 117-296.

SOULA, M. 2003. Les Coléoptères du Nouveau Monde. Rutelini 3. Hillside Books, Canterbury 29: 1-76.

SOULA, M. 2005. Les Coléoptères du Nouveau Monde. Rutelini 3. Révision Des Anticheirina 3. Hillside Books, Canterbury 26 (3): 294-409.

SOULA, M. 2006. Les Coléoptères du Nouveau Monde. Rutelini 1. Révision des Pelidnotina 1 Et des Lasiocalina. Besoiro Suplement 1: 1-176.

SOULA, M. 2008. Les Coléoptères du Nouveau Monde. Rutelini 2. Révision des Pelidnotina 2, Besoiro, 2: 1-40.

SOULA, M. 2009. Les Coléoptères du Nouveau Monde. Rutelini 3. Révision des Pelidnotina 3, Besoiro 3: 1-139.

SOULA, M. 2010. Les Coléoptères du Nouveau Monde. Rutelini 4. Révision des Pelidnotina 4, Besoiro 4: 1-66.

SOULA, M. 2011. Les Coléoptères du Nouveau Monde. Rutelini 5. Geniatini 1, Révision du genre *Bolax*, Besoiro 5: 1-85.

VIANA, C.H.P., MARQUES, O.M. & CARVALHO, C.A.L. 2001. Rutelinae (Coleoptera: Scarabaeidae) Coletados em Armadilha Luminosa em Cruz das Almas, Bahia. Magistra, Cruz Das Almas-Bahia 13 (1): 1-7.

VIGORS, N.A. 1825. Descriptions of some rare, interesting, or hitherto uncharacterized subjects of zoology. The Zoological Journal 1: 526-542.

*Received: 30/10/2017*
*Revised: 29/01/2018*
*Accepted: 31/01/2018*

Biota Neotropica 18(2): e20180514, 2018
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
Article

# Temporal and spatial variation of Myriapoda (Diplopoda and Chilopoda) assemblages in a Neotropical floodplain

*Lorhaine Santos-Silva*[1]*, *Tamaris Gimenez Pinheiro*[2], *Amazonas Chagas-Jr*[3], *Marinêz Isaac Marques*[3] & *Leandro Dênis Battirola*[1]

[1]*Universidade Federal de Mato Grosso, Instituto de Ciências Naturais, Humanas e Sociais, Programa de Pós-Graduação em Ciências Ambientais, Av. Alexandre Ferronato 1.200, Setor Industrial, 78557-267, Sinop, MT, Brasil*
[2]*Universidade Federal do Piauí, Avenida Cícero Eduardo, s/n, Junco, 64607-675, Picos, PI, Brasil*
[3]*Universidade Federal de Mato Grosso, Instituto de Biociências, Departamento de Biologia e Zoologia, Avenida Fernando Corrêa da Costa 2.367, Boa Esperança, 78060-900, Cuiabá, MT, Brasil*
**Corresponding author: Lorhaine Santos-Silva, e-mail: lorhaine.silva@gmail.com*

SANTOS-SILVA, L., PINHEIRO, T.G., CHAGAS-JR, A., MARQUES, M.I., BATTIROLA, L.D. **Temporal and spatial variation of Myriapoda (Diplopoda and Chilopoda) assemblages in a Neotropical floodplain**. Biota Neotropica 18(2): e20180514. http://dx.doi.org/10.1590/1676-0611-BN-2018-0514

***Abstract:*** Myriapods constitute important edaphic macrofauna taxa which dwell in different trophic levels and influence the dynamics of these environments. This study evaluated the variation in composition, richness and abundance of edaphic myriapod assemblages as a function of the distribution and structure of flooded and non-flooded habitats (spatial variation) and hydrological seasonality (temporal variation) in a floodplain of the northern Pantanal region of Mato Grosso, Brazil. Sampling was carried out in three areas of the Poconé Pantanal, along an altitudinal and inundation gradient consisting of inundated and non-inundated habitats and different vegetation formations. Three quadrats (10 x 10 m) were delimited within each habitat type, where sampling was performed using pitfall traps and mini-Winkler extractors during the dry, rising water, high water and receding water periods of two hydrological cycles within the Pantanal (2010/2011 and 2011/2012). A total of 549 millipedes were collected, consisting of 407 Diplopoda and 142 Chilopoda distributed in six orders, 12 families and 20 species. The assemblages composition varied throughout the seasonal periods, indicating that the rising water and dry periods differed from the high water and receding water periods. In addition to the variation between seasonal periods, myriapod richness and abundance also varied in relation to areas consisting of different vegetation formations. Thus, it can be concluded that the hydrological seasonality associated with the inundation gradient and different vegetation types were determinant in the heterogeneous spatial and temporal distribution of myriapod assemblages, validating that the conservation of these invertebrates in the Pantanal is directly linked to the preservation of vegetation, and consequently, ecosystem integrity.

***Keywords:*** *Biodiversity, conservation, myriapods, seasonality, wetlands.*

# Variação temporal e espacial da assembleia de Myriapoda (Diplopoda e Chilopoda) em uma planície de inundação Neotropical

***Resumo:*** Os miriápodes constituem importantes táxons da macrofauna edáfica atuando em diferentes níveis tróficos, influenciando a dinâmica desses ambientes. Este estudo avaliou a variação na composição, riqueza e abundância da assembleia de miriápodes edáficos em função da distribuição e estrutura de habitats inundáveis e não inundáveis (variação espacial) e da sazonalidade hidrológica (variação temporal) em uma planície de inundação na região norte do Pantanal de Mato Grosso, Brasil. As amostragens foram realizadas em três áreas no Pantanal de Poconé, em um gradiente altitudinal e de inundação, constituídas por habitats inundáveis e não inundáveis e por diferentes formações vegetacionais. Em cada tipo de habitat foram delimitados três quadrantes (10 x 10 m), onde foram efetuadas amostragens com armadilhas pitfall e Extrator mini-Winkler, ao longo dos períodos de seca, enchente, cheia e vazante, durante dois ciclos hidrológicos do Pantanal (2010/2011 e 2011/2012). Foram amostrados 549 miriápodes, dos quais 407 Diplopoda e 142 Chilopoda, distribuídos em seis ordens, 12 famílias e 20 espécies. A composição da assembleia variou ao longo dos períodos sazonais, indicando que a enchente e seca diferem da cheia e vazante. Além da variação entre os períodos sazonais, a riqueza e abundância de miriápodes variaram também em relação às áreas, constituídas por diferentes formações vegetacionais. Assim, pode-se concluir que a sazonalidade hidrológica associada ao gradiente de inundação e os diferentes tipos vegetacionais foram determinantes para a distribuição espacial e temporal heterogênea da assembleia de miriápodes, evidenciando que a conservação destes invertebrados no Pantanal está diretamente ligada à preservação da vegetação e, consequentemente, de sua integridade ecossistêmica.

***Palavras-chave:*** *Áreas úmidas, biodiversidade, conservação, miriápodes, sazonalidade.*

## Introduction

The distribution patterns in the richness and diversity of animal species in tropical environments are strongly related to the richness, composition and structure of plant communities. Heterogeneous environments possessing greater vegetation complexity associated with seasonal abiotic variations generally provide a greater variety of resources and niches for fauna (e.g. Ferreira & Casatti 2006, Lopes et al. 2011, Miranda et al. 2013), factors considered determinant for the coexistence of species (Tews et al. 2004, Freitas et al. 2006, Giacomini 2007).

Like other wetlands, the Pantanal of Mato Grosso is considered a spatially and temporally complex ecosystem (Heckman 1998). The temporal variation in water level is one of its main characteristics, making periodic flooding a determinant in its ecological processes (Junk 1993, Junk & Nunes-da-Cunha 2005, Junk et al. 2015). The local differences in flood intensity and duration, as well as the characteristic topographic variations of the Pantanal, shape the landscape and, consequently, the distribution of the phytophysiognomic units, forming a mosaic of habitats (Silva et al. 2000, Rebellato & Nunes-da-Cunha 2005, Nunes-da-Cunha et al. 2007, Fantin-Cruz et al. 2010, Machado et al. 2012) consisting of forests, fields, and monodominant patches (Arieira & Nunes-da-Cunha 2006, Nunes-da-Cunha & Junk 2011, 2015). This variety of habitats is responsible for maintaining rich and abundant fauna (Junk et al. 2006, Alho & Sabino 2011), including rarely studied taxa such as the arthropod group Myriapoda (Golovatch et al. 2005, Battirola et al. 2009, 2017c).

Although they play a vital role in the dynamics of ecosystems and represent an important part of edaphic macrofauna, Myriapoda constitute a group that has been the subject of little studies in relation to its diversity and ecology (Golovatch et al. 1995, Adis & Harvey 2000, Brewer et al. 2012). Among Myriapoda, Chilopoda and Diplopoda are the most abundant and species rich classes. Chilopoda comprises five orders and approximately 3,300 species. They are exclusively predators and, in most cases, feed on other arthropods and small vertebrates proportional to their size (Edgecombe & Giribet 2007, Noronha et al. 2015, Guizze et al. 2016). Diplopoda are distributed in approximately 16 orders with 140 families and more than 11,000 species (Enghoff et al. 2015). They are detritivores, participating in the decomposition, reduction and fragmentation of organic material (Golovatch et al. 1995, Hoffman et al. 2002, Battirola et al. 2011, Minelli & Golovatch 2013).

In seasonally flooded areas, stress derived from inundation causes myriapods to develop specific survival strategies (Adis 1997). In the Pantanal of Mato Grosso, adaptations and survival strategies are known for the diplopods *Plusioporus salvadorii* Silvestri, 1895 (Spirostreptidae) and *Pantanalodesmus marinezae* Hoffman, 2000 (Chelodesmidae), terrestrial species that migrate to the trunks of trees during flooding, where they remain until the end of the inundation period (Adis et al. 2001), *Poratia salvator* Golovatch & Sierwald, 2000 (Pyrgodesmidae) and *Promestosoma boggianii* (Silvestri, 1898) (Paradoxosomatidae), both of which synchronize their life cycles and phenology to that of the region's flood cycles (Pinheiro et al. 2009, 2011, Wantzen et al. 2016, Battirola et al. 2017c, Santos-Silva et al. 2018), and also Polyxenida, which has a distribution pattern between soil and tree canopy influenced by seasonal variations (Battirola et al. 2009).

Considering the importance of studies on biodiversity and its maintenance mechanisms, as well as the relationship between species and their habitats, particularly in priority conservation areas such as the Pantanal of Mato Grosso, this study aimed to: (i) evaluate the composition of Myriapoda assemblages (Chilopoda and Diplopoda) in a floodplain of the northern Pantanal of Mato Grosso; and (ii) to analyze the influence of habitat structure (flooded and non-flooded) and seasonality on the abundance and richness of myriapods, thus contributing to the knowledge of distribution patterns of these taxa in wetlands.

## Material and Methods

### 1. *Study Area*

Sampling was performed in inundated (I) and non-inundated (NI) habitats in three sample areas (A1, A2, A3), distributed across an altitudinal and inundation gradient along the Porto Cercado road, located between the Bento Gomes and Cuiabá rivers, in the Poconé Pantanal, Mato Grosso, Brazil (16º20'56"S 056º29'69"W and 16º29'82"S 056º23'95"W) (Figure 1). The local climate is classified as tropical savannah AW under the Köppen Classification system, characterized by dry winters and rainy summers, with temperature ranging between 22 and 32ºC (Hasenack et al. 2003). Annual rainfall ranges from 1,000 to 1,500 mm, with rainfall below 10 mm occurring during the dry season (Radambrasil 1982). Sampling occurred throughout the four seasonal periods typical of the region; dry (July to September), rising water (October to December), high water (January to March) and receding water (April to June) during two annual cycles (2010/2011 and 2011/2012), characterized according to Heckman (1998).

Area A1 represents a higher elevation with low flood amplitude (0.1 m of depth), and is located next to the Bento Gomes River; area A2 is located at a mid-point along the gradient, with intermediate elevation and flood amplitude (0.25 m depth); area A3 is located near the Cuiabá River, and is the area with least elevation and therefore susceptible to a greater flood amplitude (0.5 m depth) (Figure 1).

http://dx.doi.org/10.1590/1676-0611-BN-2018-0514

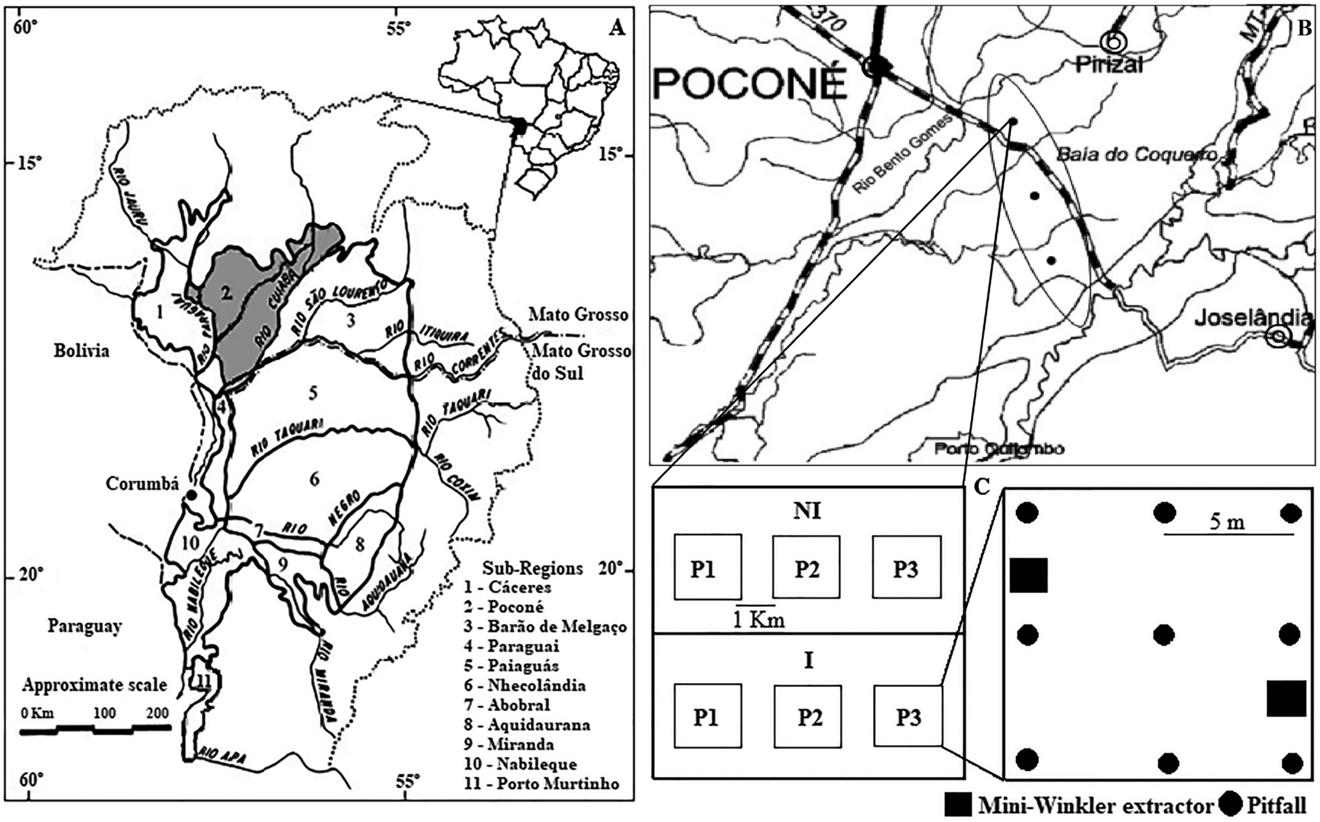

**Figure 1.** (A) The Pantanal and its 11 sub-regions, with emphasis on the Pantanal of Poconé, Mato Grosso, Brazil. (B) Study area with the location of the three sample units (A1, A2 and A3), along the Porto Cercado Road, between the Bento Gomes and Cuiabá rivers, within the floodplain of the Poconé Pantanal – MT. (C) Illustration indicating the inundated (I) and non- inundated (NI) habitats, with the three quadrats (P1, P2, P3) and layouts for the pitfall traps and mini-Winkler extractors. (Source: Silva et al. 2000, Meurer 2015, modified).

Due to the location of the inundation gradient, each area contains different vegetation formations. The A1 area is predominantly mountainous in non-flooded areas, characterized by dense savanna tree vegetation (Silva et al. 2000, Nunes-da-Cunha et al. 2007, Fantin-Cruz et al. 2010), while sampling points located within floodplain habitats consist predominately of *murundus* fields (mounds of earth constructed by termites above the flood line). Woody cerrado vegetation is established within these fields due to the absence of flooding (Oliveira-Filho 1992, Nunes-da-Cunha et al. 2007, De Morais et al. 2013).

Area A2 is characterized by the presence of monodominant forest formations of *Callisthene fasciculata* (Spr.) Mart. (Vochysiaceae), with sparse grasses and herbaceous ground covers, and dense stands of *Bromelia balansae* Mez. and *Ananas ananassoides* (Baker) L.B. SM. (Bromeliaceae) (Nunes-da-Cunha et al. 2007). Sampling points within inundated areas correspond to fields dominated by *Axonopus purpusii* (Mez.). Chase and *Reimarochloa brasilienses* (Spreng.) (Poaceae), recognized for its high palatability and nutritional value to herds (Santos et al. 2012, Nunes-da-Cunha & Junk 2015).

Area A3 contains stands of *Attalea phalerata* Mart. (Arecaceae) at the non-flooded sampling points (Santos et al. 2003, Nunes-da-Cunha et al. 2007), while the sampling points located within flooded areas correspond to mixed formations of evergreen flooded forests known as *landizais* and *cerradões* (Silva et al. 2000, Nunes-da-Cunha et al. 2007, Fantin-Cruz et al. 2010).

## 2. *Experimental Design*

Each sample area (A1, A2 and A3) was composed of two treatments; inundated (I) and non-inundated (NI) habitats. Within each habitat type, three quadrats (10 m x 10 m) were delimited, considered sample points (P1, P2 and P3), where sampling was performed using pitfall traps (Adis 2002) and mini-Winkler extractors (Bestelmeyer et al. 2000).

At each sample point, nine pitfall traps were distributed five meters apart, totaling 27 pitfall traps per habitat type, 54 per area, and 162 traps per seasonal cycle consisting of the dry, rising water and receding water periods. During the high water period, only non-inundated habitats (NI) were sampled, as sampling in flooded areas (I) during inundation was considered unfeasible, thus 27 pitfall traps per area were used during the high water period, totaling 81 traps. The pitfall traps consisted of a polyethylene vial 20 cm in length, with a 5-6 cm diameter opening and contained 250 ml of 4% formalin solution. Plastic protective covers (20 x 20 cm) were used to shield the traps from rain and debris. All traps were buried at ground level to intercept moving arthropods and remained open in the field for seven days.

Mini-Winkler collectors were used to sample 2 $m^2$ of leaf litter and superficial soil from each quadrat, totaling 6 $m^2$ per habitat type, 12 $m^2$ per area, and 36 $m^2$ per seasonal cycle consisting of the dry, rising water and receding water periods. During the high water period, only non-inundated habitats (NI) were sampled, as sampling in flooded areas (I) during inundation was considered unfeasible, thus 6 $m^2$ of leaf litter was sampled per area during the high water period, totaling 18 $m^2$ during this period. Samples from the mini-Winkler collectors were taken to the laboratory, where they remained suspended for 72 hours in an air-conditioned environment for desiccation and, consequently, collection of arthropods from the collection flasks containing 70% alcohol.

The myriapods were separated from other arthropods in the laboratory, quantified and identified at the lowest possible taxonomic level by their respective specialists Amazonas Chagas Jr. (Chilopoda), Tamaris G. Pinheiro and Sergei Golovatch (Diplopoda). Specimens were placed into containers containing 70% alcohol. All sample material was deposited at the Biological Collection of Southern Amazonia (*Acervo Biológico da Amazônia Meridional*–ABAM), Federal University of Mato Grosso, Sinop-MT, Brazil. Sample data from the pitfall traps and mini-Winkler collectors was combined for analysis.

### 3. *Data Analysis*

The distribution of Myriapoda assemblages (Chilopoda and Diplopoda) was evaluated by entering the two annual hydrological cycles in the same data block. The Shapiro-Wilk test was used to evaluate the normality of the data. The variation in the composition of Myriapoda (Chilopoda and Diplopoda) assemblages between the seasonal periods (dry, rising water, high water and receding water) was evaluated through a Principal Coordinates Analysis (PCoA), based on the specie's abundance data matrix (log x+1), using the Bray-Curtis similarity index. Subsequently, the two axes resulting from the ordination were analyzed using a Multivariate Analysis of Variance (MANOVA), adopting the Pillai Trace test.

To evaluate the temporal variation in Myriapoda species richness between the seasonal periods (dry, rising water, high water, receding water), sample areas (A1, A2 and A3), as well as between inundated (I) and non-inundated habitats, Generalized Linear Models (GLMs) with Poisson distribution for richness and Negative Binomial for abundance (based on Aikake and Bayesian evaluation criteria) were used. Species richness and its association to sampling was evaluated using the Jackknife 1 estimator. In all analyses, the adopted significance level was 0.05, using the R 3.4.1 program (R Development Core Team version 2017) Vegan package (Oksanen et al. 2017).

## Results

### 1. *Assemblage Composition*

A total of 549 myriapods were collected; 407 Diplopoda and 142 Chilopoda, which were distributed among six orders, 12 families and 20 species (Table 1). Diplopoda is represented by three orders, seven families and 11 species, while three orders, five families and nine species make up the collected Chilopoda.

Diplopoda was predominated by Polydesmida (339 ind.; 83.1%). *Promestosoma boggianii* (Silvestri, 1898) (295 ind.; 87%) and *Brasilodesmus* sp. (37 ind.; 10.9%) were most abundant. Cyrtodesmidae sp. (3 ind.; 0.9%), Fuhrmannodesmidae sp. and *Poratia salvator* (1 ind.; 0.6% each) were poorly representated. The Spirostreptida Order was the second largest group among Diplopoda (67 ind.; 16.6%), represented primarily by *Trichogonostreptus* (*Oreastreptus*) *mattogrossensis* (Silvestri, 1902) (44 ind.; 65.7%) and *Plusioporus salvadorii* (19 ind.; 28.4%). *Orthoporus* (aff.) *americanus* (Silvestri, 1895) (2 ind.; 3%), *Urostreptus tampiitauensis* (Schubart, 1947) and *Urostreptus* sp.1 (1 ind.; 1.5% each) revealed low abundance. Polyxenida also presented low abundance (Table 1).

Lithobiomorpha were the predominate Chilopoda, represented by *Lamyctes* sp. (93 ind.; 65.5%), and followed by Scolopendromorpha (38 ind.; 26.8%), principally *Rhysida celeris* (Humbert & Saussure, 1870) (25 ind.; 65.8%) and *Otostigmus tidius* Chamberlin, 1914 (Scolopendridae) (5 ind,; 13.2%). Geophilomorpha were the least abundant chilopods, with only 11 specimens of *Schendylops inquilinus* Pereira et al. 2007 (Schendylidae) (7.7%) (Table 1).

The 20 species obtained corresponded to 80% of the Jackknife 1 estimator expected richness (25.9 spp.), showing sampling efficiency. The composition of myriapod assemblages varied throughout the seasonal periods. The two Principal Components Analysis (PCoA) axes captured 78% of the variation in assemblage composition. The ordination of myriapod species abundance between seasonal periods showed temporal variation in assemblage structure (MANOVA, F = 4.875; df = 3; P < 0.001). This ordination indicated that the rising water and dry periods differed from the high water and receding water periods in relation to the composition of Myriapoda assemblages (Figure 2). The greatest variations in relation to abundance were found during the dry and rising water periods (87.8% of sampled individuals), compared to the high water and receding water periods (12.2% of assemblage abundance).

### 2. *Assemblage Richness and Abundance*

The species richness of Myriapoda assemblages varied between the seasonal periods (GLM, Z = -2.72, P < 0.001) (Figure 3A). No variation was observed in relation to the abundance of myriapods (GLM, Z = -1.68, P = 0.09) (Figure 3 B). The rising water (13 spp.; 30.2%), dry (12 spp.; 27%) and high water (11 spp.; 25.6%) seasonal periods corresponded to the highest species richness, while the receding water period revealed just seven species (16.3%). In relation to abundance, the rising water (269 ind.; 49%) and dry (213 ind.; 38.8%) periods had the highest number of individuals, while the receding water (48 ind.; 8.7%) and dry (19 ind.; 3.5%) periods registered the least records (Figure 3 B).

Considering the seasonal periods, it was observed that *R. celeris*, *S. inquilinus*, *Lamyctes* sp. and *T. (O.) mattogrossensis* occurred throughout the year. However, *Newportia (Tidops) balzanii* Silvestri, 1895 (Scolopocryptopidae), *Scolopendra viridicornis* Newport, 1844 (Scolopendridae) and Fuhrmannodesmidae sp. were sampled only during the high water period. Other taxa such as *Newportia (Tidops)* sp., *P. salvator* and Polyxenida were sampled only during the rising water period, while *Urostreptus* sp. and *U. tampiitauensis*, were sampled exclusively in the dry period. During the receding water period there was no record of exclusive occurrence for any of the myriapod species.

Myriapod richness was different between areas A1, A2 and A3 (GLM, Z = 1.89, P = 0.05) (Figure 3A), similar to that observed in relation to species abundance (GLM, Z= 4.30, P < 0.001) (Figura 3 B). For the A1 area a large number of exclusive species were found, including *S. viridicornis, Urostreptus* sp., *U. tampiitauensis, O.* (aff.) *americanus* and Polyxenida. *Brasilodesmus* sp., Cyrtodesmidae sp., Fuhrmannodesmidae sp., and *Newportia (Tidops)* sp. were sampled only in area A3. Area A2 showed a greater abundance of individuals

**Table 1.** Abundance distribution of Diplopoda and Chilopoda between seasonal periods (DS = Dry season, RW = Rising water, HW = High water, RE = Receding water), inundated (I) and non-inundated (NI) habitats, as well as between the different phytophysiognomies (AC = *Attalea phalerata* stands, CL = Field, CM = Murundu Field, CR = *Callisthene fasciculata* Forest, CE = Cerradão, LM = Landizal); and indication of the collection methodology (EMW = Mini-Winkler collector and PTR = pitfall traps) used in a floodplain of the northern Pantanal region of Mato Grosso, Brazil.

| **Táxon** | **Seasonal Periods** | | | | **Habitats** | | **Phytophysiognomies** | | | | | | | **Collection Methodology** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **DS** | **RW** | **HW** | **RE** | **I** | **NI** | **CO** | **CM** | **CR** | **CL** | **AC** | **CE** | **LM** | |
| Diplopoda | | | | | | | | | | | | | | |
| Polydesmida | | | | | | | | | | | | | | |
| Chelodesmidae | | | | | | | | | | | | | | |
| *Brasilodesmus* sp.⁽¹⁾ | 36 | 1 | - | - | 18 | 19 | - | - | - | - | 19 | 18 | - | EMW, PTR |
| Cyrtodesmidae | | | | | | | | | | | | | | |
| Cyrtodesmidae sp.⁽²⁾ | 2 | 1 | - | - | 1 | 2 | - | - | - | - | 2 | - | 1 | PTR |
| Fuhrmannodesmidae | | | | | | | | | | | | | | |
| Fuhrmannodesmidae sp.⁽³⁾ | - | - | 2 | - | - | 2 | - | - | - | - | 2 | - | - | EMW |
| Paradoxosomatidae | | | | | | | | | | | | | | |
| *Promestosoma boggianii* (Silvestri, 1898)⁽⁴⁾ | 76 | 209 | - | 10 | 182 | 113 | 1 | 3 | 79 | 147 | 33 | 23 | 9 | EMW, PTR |
| Pyrgodesmidae | | | | | | | | | | | | | | |
| *Poratia salvator* Golovatch & Sierwald, 2001⁽⁵⁾ | - | 2 | - | - | 2 | - | - | - | - | 1 | - | - | 1 | EMW |
| Polyxenida⁽²⁾ | | | | | | | | | | | | | | |
| Polyxenidae⁽⁶⁾ | - | 1 | - | - | 1 | - | - | 1 | - | - | - | - | - | PTR |
| Spirostreptida | | | | | | | | | | | | | | |
| Spirostreptidae | | | | | | | | | | | | | | |
| *Orthoporus* (aff.) *americanus* (Silvestri, 1895)⁽⁷⁾ | 1 | - | 1 | - | - | 2 | 2 | - | - | - | - | - | - | PTR |
| *Plusioporus salvadorii* Silvestri, 1895⁽⁸⁾ | 7 | 12 | - | - | 1 | 18 | - | - | 17 | 1 | 1 | - | - | EMW, PTR |
| *Trichogonostreptus (Oreastreptus) mattogrossensis* (Silvestri, 1902)⁽⁹⁾ | 28 | 6 | 4 | 6 | 18 | 26 | 4 | 7 | 18 | 8 | 4 | 2 | 1 | EMW, PTR |
| *Urostreptus* sp.⁽¹⁰⁾ | 1 | - | - | - | - | 1 | 1 | - | - | - | - | - | - | PTR |
| *Urostreptus tampiitauensis* (Schubart, 1947)⁽¹¹⁾ | 1 | - | - | - | 1 | - | 1 | - | - | - | - | - | - | PTR |
| Chilopoda | | | | | | | | | | | | | | |
| Scolopendromorpha | | | | | | | | | | | | | | |
| Cryptopidae | | | | | | | | | | | | | | |
| *Cryptops* sp.⁽¹²⁾ | - | 1 | 1 | - | - | 2 | 1 | - | - | - | 1 | - | - | EMW |
| Scolopocryptopidae | | | | | | | | | | | | | | |
| *Newportia (Tidops) balzanii* Silvestri, 1895⁽¹³⁾ | - | - | 2 | - | - | 2 | 1 | - | - | - | 1 | - | - | EMW |
| *Newportia (Tidops)* sp.⁽¹⁴⁾ | - | - | 1 | - | - | 1 | - | - | - | - | 1 | - | - | EMW |
| Scolopendridae | | | | | | | | | | | | | | |
| *Otostigmus* sp.⁽¹⁵⁾ | - | - | 1 | 1 | 1 | 1 | 1 | - | - | - | - | 1 | - | PTR |
| *Otostigmus tidius* Chamberlin, 1914⁽¹⁶⁾ | 2 | 2 | - | 1 | 1 | 4 | 2 | 1 | 1 | - | 1 | - | - | PTR |
| *Rhysida celeris* (Humbert & Saussure, 1870)⁽¹⁷⁾ | 19 | 2 | 2 | 2 | 5 | 20 | 14 | 4 | 6 | - | - | 1 | - | EMW, PTR |
| *Scolopendra viridicornis* Newport, 1844(18) | - | - | 1 | - | - | 1 | 1 | - | - | - | - | - | - | PTR |
| Geophilomorpha⁽⁵⁾ | | | | | | | | | | | | | | |
| Schendylidae | | | | | | | | | | | | | | |
| *Schendylops inquilinus* Pereira et al., 2007⁽¹⁹⁾ | 3 | 3 | 2 | 3 | 2 | 9 | 5 | 1 | 2 | 1 | 1 | - | 1 | EMW |
| Lithobiomorpha⁽⁶⁾ | | | | | | | | | | | | | | |
| Henicopidae | | | | | | | | | | | | | | |
| *Lamyctes* sp.⁽²⁰⁾ | 37 | 28 | 3 | 25 | 57 | 36 | 2 | 20 | 16 | 30 | 18 | 4 | 3 | EMW, PTR |
| Total | 213 | 269 | 19 | 48 | 289 | 260 | 36 | 37 | 139 | 188 | 84 | 49 | 16 | |
| | 549 | | | | 549 | | 549 | | | | | | | |

Registration number in ABAM: (1) - Abam/Diplopoda/0287; (2) - Abam/Diplopoda/0288; (3) - Abam/Diplopoda/0289; (4) - Abam/Diplopoda/0290; (5) - Abam/Diplopoda/0291; (6) - Abam/Diplopoda/0292; (7) - Abam/Diplopoda/0293; (8) - Abam/Diplopoda/0294; (9) - Abam/Diplopoda/0295; (10) - Abam/Diplopoda/0296; (11) - Abam/Diplopoda/0297; (12) - Abam/Chilopoda/0002; (13) - Abam/Chilopoda/0003; (14) - Abam/Chilopoda/0004; (15) - Abam/Chilopoda/0005; (16) - Abam/Chilopoda/0006; (17) - Abam/Chilopoda/0007; (18) - Abam/Chilopoda/0008; (19) - Abam/Chilopoda/0009; (20) - Abam/Chilopoda/0010.

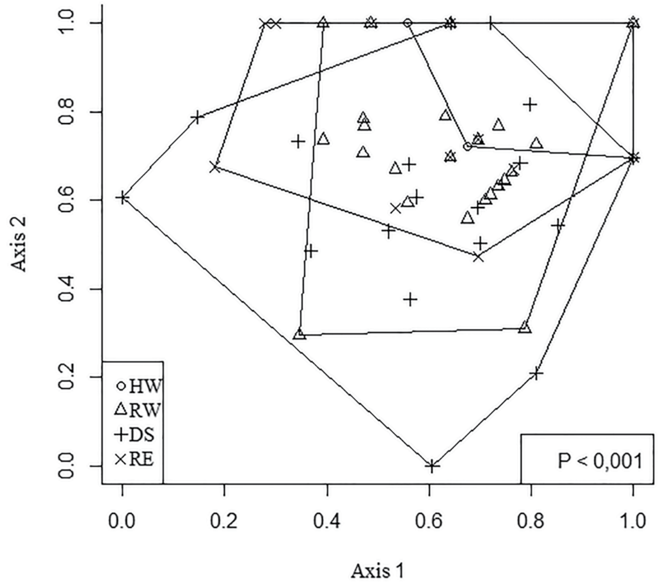

**Figure 2.** Principal Component Analysis (PCoA) of myriapod composition (Chilopoda and Diplopoda), arranged in two axes, considering the four seasonal periods (DS = Dry season, RW = Rising water, HW = High water and RE = Receding water) of the northern Pantanal region of Mato Grosso, Brazil.

(327 ind.; 59.6%), followed by area A3 (149 ind.; 27.1%) and area A1 (73 ind.; 13.3%). *Otostigmus tidius*, *R. celeris, S. inquilinus, Lamyctes* sp. and *P. boggianii* were found in all sampled areas.

The inundated and non-inundated habitats did not vary between species, both in regards to species richness (GLM, Z = - 0.19, P = 0.8) and myriapod abundance (GLM, Z = - 0.98, P = 0.3). Although not varied, the number of individuals in inundated habitats (289 ind.; 52.6%) was higher than that observed in non-inundated habitats (260 ind.; 47.4%) (Table 1). Comparing the species found between inundated and non-inundated habitats, it was observed that nine species were common to both environments, nine were sampled only in non-inundated habitats, and two only in inundated environments (Table 1).

In regards to the different vegetation formations present in the sample areas, it was observed that the fields (188 ind.; 34.2%) and *C. fasciculata* forests (139 ind.; 25.3%) were more abundant, followed by areas of *A. phalerata* stands (84 ind.; 15.3%), *cerradão* (49 ind.; 8.9%), *murundu* fields (37 ind.; 6.7%), mountain ranges (36 ind.; 6.6%) and *landizal* (16 ind.; 2.9%). Evaluating the distribution of the constituent species of these assemblages, only *P. boggianii, Lamyctes* sp. and *T. (O.) mattogrossensis* were recorded in all vegetation types. *Scolopendra viridicornis*, *Urostreptus* sp., and *U. tampiitauensis, O.* (aff.) *americanus* occurred exclusively in mountainous areas. Fuhrmannodesmidae sp.

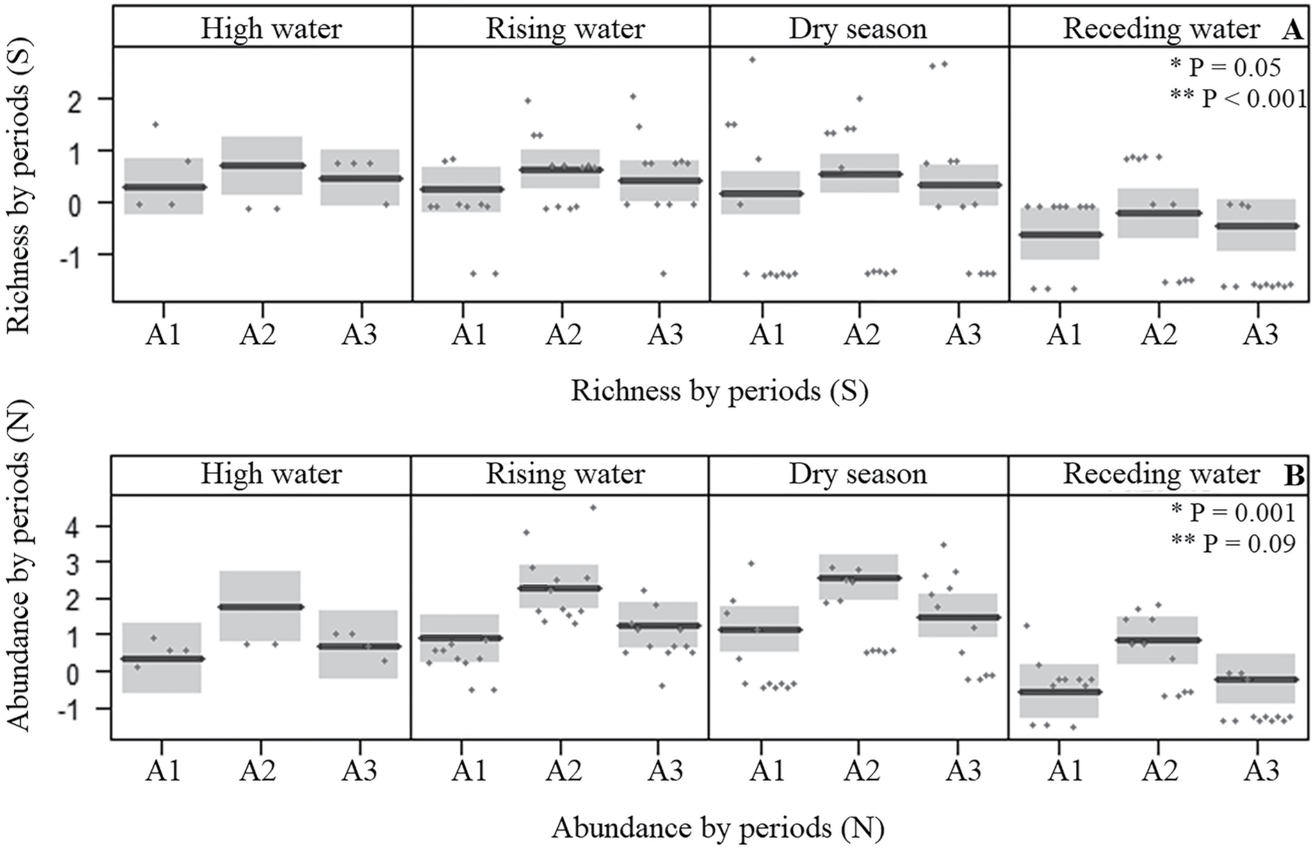

**Figure 3.** Myriapod distribution (Diplopoda and Chilopoda) in relation to seasonal periods, sample areas and richness (A), seasonal periods, sample areas and abundance (B), in a floodplain of the northern Pantanal region of Mato Grosso, Brazil. * Value of P for area, ** value of P for seasonal period.

and *Newportia (Tidops)* sp. were recorded only in areas of *A. phalerata* (Table 1).

## Discussion

Myriapod assemblages and their structure are still poorly explored in Neotropical region, particularly in wetlands such as the Pantanal (e. g. Adis et al. 2001, Golovatch et al. 2005, Pereira et al. 2007, Pinheiro et al. 2009, 2011, Battirola et al. 2009, Wantzen et al. 2016). In the present study, 20 species of Chilopoda and Diplopoda were sampled, a value higher than that obtained in other surveys conducted in the same region of the Pantanal (Golovatch et al. 2005, Battirola et al. 2017c, Battirola et al. 2009), and similar to those found in the Amazon of Mato Grosso (Battirola et al. 2011, 2016a). The knowledge gap in regards to these invertebrates is confirmed by the new records of two families of Polydesmida (Diplopoda), Cyrtodesmidae and Fuhrmannodesmidae sampled for the first time in the Mato Grosso Pantanal, expanding the list of known Myriapoda taxa for this region. Cyrtodesmidae and Fuhrmannodesmidae species correspond to small and common diplopods in the wetlands of central Amazonia (Golovatch 2001, Adis et al. 2002, Hoffman et al. 2002).

The results obtained allow the inference that the composition, richness and abundance of myriapod assemblages vary according to the region's hydrological seasonality, as well as the structural conditions provided by the different habitats present in this floodplain in the northern Pantanal region of Mato Grosso. The dry and rising water phases corresponded to the seasonal periods of greater abundance and movement of myriapods between inundated and non-inundated habitats, as well as the periods with the highest recorded species richness. This pattern of movement, with a considerable increase in the abundance and richness of myriapod fauna in the dry and rising water periods is a result of the influence of environmental changes which occur between the end of the dry season and the beginning of the rainy (rising water) season, providing greater moisture availability and, consequently, better survival conditions and resources for myriapods in these environments (e. g. Adis et al. 2001, Pinheiro et al. 2009, 2011, Marques et al. 2011, Battirola et al. 2009). This variation substantiates the specificity of flooded ecosystems and their dependence on seasonal hydrological changes (e.g. Junk 1993).

An additional relevant factor that contributes to this pattern of movement and occurrence is the hydrological stress caused by seasonal flooding during the rising water and high water periods, when most of the terrestrial habitats present in the floodplain are affected at different flood levels, altering the structural conditions of these environments and hindering the survival of invertebrate fauna in the edaphic environment (Castilho et al. 2005; Signor et al. 2010; Marques et al. 2014; Junk et al. 2015; Battirola et al. 2017a,b). This variation substantiates the specificity of flooded ecosystems and their dependence on seasonal hydrological changes (e.g. Junk 1993).

The effect of periodic changes to habitat structure caused by the hydrological regime can be verified in the present study by the distribution of *P. boggianii* abundance throughout the different seasonal periods, enabling the assumption that this species migrates between inundated and non-inundated habitats to favorable environmental conditions. The *Promestosoma boggianii* population is seasonally distributed, occupying primarily inundated and non-inundated habitats during dry and rising water periods, and decreasing severely in numbers in these areas during the receding water and high water periods. This pattern of habitat occupation between seasonal periods can be interpreted as a survival strategy developed by this species in response to the sudden changes in environmental conditions which alter the distribution of resources, such as the variety and quantity of leaf litter, breeding habitat, shelter against flooding or desiccation during dry periods, aspects considered to be influencing factors on these invertebrates (Adis et al. 2001, Battirola et al. 2009, Pinheiro et al. 2009, 2011, Marques et al. 2011).

These temporary displacements between habitats and the synchronism in life cycle development of some species according to the hydrological conditions of the northern Pantanal region were recorded for the diplopods *P. salvator* and *P. boggianii,* which adapted their life cycle, reproduction and phenology to the region's flood cycles (Pinheiro et al. 2009, 2011, Wantzen et al. 2016, Santos-Silva et al. 2018), as well as for the chilopods *R. celeris* and *S. inquilinus* (Battirola et al. 2017c), and other groups of terrestrial arthropods (Adis et al. 2001, Castilho et al. 2005, Marques et al. 2014, Yamazaki et al. 2015).

In other wetlands such as Central Amazonia, several known survival strategies are employed by myriapods such as the vertical migration from soil to tree trunks and canopy at the beginning of the flooding period, which have been recorded for *Epinannolene exilio* (Brölemann, 1904) (Pseudonannolenidae) and *Poratia insularis* (Kraus, 1960) (Pyrgodesmidae) (Golovatch et al. 1997, Bergholz et al. 2004), and *Myrmecodesmus adisi* (Hoffman 1985) (Pyrgodesmidae), a semi-aquatic species that has a morphological adaptation which renders it resistant to flooding, enabling it to survive submerged in the forest substrate for long periods (Adis 1986, Golovatch 1999, Adis et al. 2003). *Lamyctes adisi* Zalesskaja, 1994 (Henicopidae) developed eggs resistant to submersion, which allows it to synchronize its reproduction with dry and inundated periods, ovipositing in the soil before flooding, so that hatching occurs soon after the receding water period (Adis 1992, Foddai et al. 2002).

In addition to the influence of the region's seasonality on the temporal distribution of Chilopoda and Diplopoda assemblages, the conditions of the different habitats present in the inundation gradient and their vegetative characteristics can be considered important factors in the occupation of these areas by myriapods. It was observed that the different species of myriapods that inhabit this flood plain occupy the most varied habitats available, however, significant variations are evidenced in their abundance patterns between habitats, allowing the assumption that the structure of the environment has a greater influence on the population's abundance than the number of myriapod species in this gradient.

Despite the high similarity between inundated and non-inundated environments, myriapods were more abundant in inundated habitats. Areas A2 and A3, susceptible to a greater flood amplitude, also had a higher number of myriapods in comparison to area A1, indicating that habitats which are wetter for longer periods throughout the year provide better conditions of permanence and reproduction for these individuals. These results demonstrate that non-inundated areas, due to their structure and different vegetation types, can function as refuge, shelter, breeding and feeding sites for certain species of Chilopoda and Diplopoda during periods when the lower parts of the plains in the Pantanal are subject to inundation, as was observed for other arthropods adapted to these seasonal conditions (Battirola et al. 2010, 2016b, 2017a,b, Aranda 2013, Marques et al. 2011, 2014, Meurer et al. 2015, Yamazaki et al. 2015).

In general, these results conclude that the composition, richness and abundance of myriapod assemblages associated with this floodplain are susceptible to the temporal and spatial variations of this ecosystem, due to the seasonal hydrological conditions and their specific effects on the structure of the environment in both inundated and non-inundated habitats characteristic of this important wetland. In addition, seasonally flooded areas such as the Pantanal of Mato Grosso play an important role in the maintenance of biological diversity, due to the vegetation mosaic which offers various habitats and niches that, combined with the hydrological dynamics, provide a wide variety of fauna resources (e.g. Alho 2008). Consequently, conservation of the Pantanal is directly linked to the preservation of its vegetation structure (Alho & Sabino 2011), which is used by vertebrates and invertebrates such as Chilopoda and Diplopoda for the habitat and resources it provides. Thus, management and environmental protection plans for the Pantanal of Mato Grosso should consider the magnitude of the regional macrohabitats, protecting the structural and functional integrity of the wetlands, as well as their biodiversity.

## Acknowledgement

We thank the Pantanal Research Center (*Centro de Pesquisas do Pantanal* – CPP), the National Institute of Science and Technology in Wetlands (*Instituto Nacional de Ciência e Tecnologia em Áreas Úmidas* – INAU/UFMT/CNPq), the Mato Grosso Foundation for Research Support (*Fundação de Amparo à Pesquisa do Estado de Mato Grosso* – FAPEMAT) (Process PRONEX/FAPEMAT/CNPq 838265/2009) and the National Council for Scientific and Technological Development (*Conselho Nacional de Desenvolvimento Científico e Tecnológico* – CNPq) (Process 472215/2013-2) for their financial assistance and provision of logistics to the study. The Coordination of Improvement of Higher Education Personnel (*Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* – CAPES) for the granting of a scholarship to LSS. The Federal University of Mato Grosso, specifically, the Graduate Program in Environmental Sciences (*Universidade Federal de Mato Grosso* – UFMT, Sinop).

## Authors' Contributions

Leandro Dênis Battirola and Marinêz Isaac Marques: substantial contribution in the concept and design of the study;

Leandro Dênis Battirola, Marinêz Isaac Marques and Lorhaine Santos-Silva: contribution to data collection;

Tamaris Gimenez Pinheiro and Amazonas Chagas-Jr: contribution to identified Diplopoda and Chilopoda;

Lorhaine Santos-Silva and Leandro Dênis Battirola: contribution to data analysis and interpretation;

Lorhaine Santos-Silva and Leandro Dênis Battirola: contribution to manuscript preparation;

Tamaris Gimenez Pinheiro, Amazonas Chagas-Jr and Marinêz Isaac Marques: contribution to critical revision, adding intellectual content.

## Conflicts of interest

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

## References

ADIS, J. 1986. An "aquatic" millipede from a Central Amazonian inundation forest. Oecologia 68:347-349. https://doi.org/10.1007/BF01036737

ADIS, J. 1992. How to survive six months in a flooded soil: Strategies in Chilopoda and Symphyla from Central Amazonian floodplains. Stud. Neotrop. Fauna E. 27:(2-3)117-129. http://dx.doi.org/10.1080/01650529209360872

ADIS, J. 1997. Estratégias de sobrevivência de invertebrados terrestres em florestas inundáveis da Amazônia Central: Uma resposta à inundação de longo período. Acta Amaz. 27:43-54. 1809-4392-aa-27-1-0043

ADIS, J. 2002. Recommended sampling techniques. In Amazonian Arachnida and Myriapoda (J. Adis ed.). Pensoft Publishers, Sofia, p. 555-576.

ADIS, J. & HARVEY, M.S. 2000. How many Arachnida and Myriapoda are there world-wide and in Amazonia. Stud. Neotrop. Fauna E. 35:139-141. http://hdl.handle.net/11858/00-001M-0000-000F-E060-1

ADIS, J., MARQUES, M.I. & WANTZEN, K.M. 2001. First observations on the survival strategies of terriculous arthropods in the northern Pantanal wetland of Brazil. Andrias 15:127-128.

ADIS, J., FODDAI, D., GOLOVATCH, S.I., HOFFMAN, R.L., MINELLI, A., DE MORAIS, J.W., PEREIRA, L.A., SCHELLER, U., SCHILEYKO, A.A. & MÜRMLI, M. 2002. Myriapoda at 'Reserva Ducke', Central Amazonia/ Brazil. Amazoniana 17(1-2):14-25.

ADIS, J., GOLOVATCH, S.I. & MESSNER, B. 2003. Morphological structures in some Neotropical *Myrmecodesmus* species (Diplopoda: Polydesmida: Pyrgodesmidae) reveal the ability for plastron respiration. Arthropoda Sel. 12(1):17-21.

ALHO, C.J.R. 2008. Biodiversity of the Pantanal: Response to seasonal flooding regime and to environmental degradation. Braz. J. Biol. 68(4):957-966. 10.1590/S1519-69842008000500005

ALHO, C.J.R. & SABINO, J. 2011. A conservation agenda for the Pantanal's biodiversity. Braz. J. Biol. 71(1):327-335. 10.1590/S1519-69842011000200012

ARANDA, R. 2013. Capões como ilhas para artrópodes no Pantanal. EntomoBrasilis 6(3):173-177. 10.12741/ebrasilis.v6i3.331.

ARIEIRA, J. & NUNES-DA-CUNHA, C. 2006. Fitossociologia de uma floresta inundável monodominante de *Vochysia divergens* Pohl. (Vochysiaceae), no Pantanal Norte, MT, Brasil. Acta Bot. Bras. 20(3):569-580. 10.1590/ S0102-33062006000300007

BATTIROLA, L.D., MARQUES, M.I., ROSADO-NETO, G.H., PINHEIRO, T.G. & PINHO, N.G.C. 2009. Vertical and time distribution of Diplopoda (Arthropoda, Myriapoda) in a monodominant forest in Pantanal of Mato Grosso, Brazil. Zoologia 26:479-487. 10.1590/S1984-46702009005000008

BATTIROLA, L.D., MARQUES, M.I., BRESCOVIT, A.D., ROSADO NETO, G.H. & ANJOS, K.C. 2010. Comunidade edáfica de Araneae (Arthropoda, Arachnida) em uma floresta sazonalmente inundável na região norte do Pantanal de Mato Grosso, Brasil. Biota Neotropica 10(2) http://www.biotaneotropica.org.br/v1 0n2/pt/abstract?inventory+bn00210022010

BATTIROLA, L.D., BRESCOVIT, A.D., PENA-BARBOSA, J.P.P., PINHEIRO, T.G. & BATISTELLA, D.A. 2011. Diplopoda (Myriapoda, Arthropoda) da Fazenda São Nicolau, Cotriguaçu-MT. In Descobrindo a Biodiversidade da Fazenda São Nicolau (D.J. Rodrigues, T.J. Izzo & L.D. Battirola, eds.). Pau e Prosa Comunicação Ltda, Cuiabá, p. 35-46.

BATTIROLA, L.D., SANTOS-SILVA, L., ALMEIDA, F.M., BATISTELLA, D.A., PENA-BARBOSA, J.P.P., CHAGAS-JUNIOR, A. & BRESCOVIT, A.D. 2016a. Artrópodes de solo do Parque Estadual do Cristalino, Mato Grosso. In Biodiversidade do Parque Estadual Cristalino (D.D.J. Rodrigues, J.D.C.D. Noronha, V.F. Vindica & F.R. Barbosa, eds.). Áttema Editorial, Santo André-SP, p. 165-177.

BATTIROLA, L.D., BATISTELLA, D.A., ROSADO-NETO, G.H., BRESCOVIT, A.D. & MARQUES, M.I. 2016b. Spider assemblage (Arachnida: Araneae) associated with canopies of *Vochysia divergens* (Vochysiaceae) in the northern region of the Brazilian Pantanal. Zoologia 33(4):1-9. 10.1590/S1984-4689zool-20150170

BATTIROLA, L.D., ROSADO-NETO, G.H., BATISTELLA, D.A., MAHNERT, V., BRESCOVIT, A.D. & MARQUES, M.I., 2017a. Vertical and time distribution of Pseudoscorpiones (Arthropoda: Arachnida) in a floodplain forest in the Brazilian Pantanal. Rev. Biol. Trop. 65(2): 445-459. https://doi.org/10.15517/rbt.v65i2.24134

BATTIROLA, L.D., SANTOS, G.B., MEURER, E., CASTILHO, A.C.C., MAHNERT, V., BRESCOVIT, A.D. & MARQUES, M.I. 2017b. Soil and canopy Pseudoscorpiones (Arthropoda, Arachnida) in a monodominant forest of *Attalea phalerata* Mart. (Arecaceae) in the Brazilian Pantanal. Stud. Neotrop. Fauna E. 52 (2):1-8. http://dx.doi.org/10.1080/01650521.2017.1282210

BATTIROLA, L.D., GOLOVATCH, S.I., PINHEIRO, T.G., BATISTELLA, D.A., ROSADO-NETO, G.H., CHAGAS JR, A., BRESCOVIT, A.D. & MARQUES, M.I. 2017c. Myriapod (Arthropoda, Myriapoda) diversity and distribution in a floodplain forest of the Brazilian Pantanal. Stud. Neotrop. Fauna E. http://dx.doi.org/10.1080/01650521.2017.1397978

BERGHOLZ, N.G.R., ADIS, J. & GOLOVATCH, S.I. 2004. The millipede *Poratia insulares* (Kraus, 1960) new to the fauna of Brazil (Diplopoda: Polydesmida: Pyrgodesmidae). Arthropoda Sel. 13(3):123-127.

BESTELMEYER, B.T., AGOSTI, D., LEEANNE, F., ALONSO, T., BRANDÃO, C.R.F., BROWN, W.L., DELABIE, J.H.C. & SILVESTRE, R. 2000. Field techniques for the study of ground-living ants: An Overview, description, and evaluation. In Ants: standart methods for measuring and monitoring biodiversity (D. Agosti, J.D. Majer, A. Tennant & T. de Schultz, eds.). Smithsonian Institution Press, Washington, p. 122-144.

BREWER, M.S., SIERWALD, P. & BOND, J.E. 2012. Millipede taxonomy after 250 years: Classification and taxonomic practices in a mega-diverse yet understudied arthropod group. Plos One 7(5):e3724. 10.1371/journal.pone.0037240

CASTILHO, A.C.C., MARQUES, M.I., ADIS, J. & BRESCOVIT, A.D. 2005. Distribuição sazonal e vertical de Araneae em área com predomínio de *Attalea phalerata* Mart. (Arecaceae), no Pantanal de Poconé, Mato Grosso, Brasil. Amazoniana 18: 215-239. http://hdl.handle.net/11858/00-001M-0000-000F-D965-3

DE MORAIS, R.F., DA SILVA, E.C.S., METELO, M.R.L. & DE MORAIS, F.F. 2013. Composição florística e estrutura da comunidade vegetal em diferentes fitofisionomias do Pantanal de Poconé, Mato Grosso. Rodriguésia 64(4):775-790. http://dx.doi.org/10.1590/S2175-78602013000400008.

EDGECOMBE, G.D. & GIRIBET, G. 2007. Evolutionary biology of centipedes (Myriapoda: Chilopoda). Annu. Rev. Entomol. 52:151-70. 10.1146/annurev.ento.52. 110405.091326

ENGHOFF, H., GOLOVATCH, S., SHORT, M., STOEV, P. & WESENER, T. 2015. Diplopoda, taxonomic overwiew. In The Myriapoda 2 (A. Minelli ed.). Koninklijke Brill NV, Leiden, p. 363-453.

FANTIN-CRUZ, I., GIRARD, P., ZEILHOFER, P., COLLISCHONN, W. & NUNES-DA-CUNHA, C. 2010. Unidades fitofisionômicas em mesoescala no Pantanal Norte e suas relações com a geomorfologia. Biota Neotropica 10(2) http://www.biotaneotropica.org.br/v10n2/pt/abstract?article+bn00410022010

FERREIRA, C.D.P. & CASATTI, L. 2006. Influência da estrutura do habitat sobre a ictiofauna de um riacho em uma micro-bacia de pastagem, São Paulo, Brasil. Rev. Bras. Zool. 23(3):642-651. 10.1590/S0101-81752006000300006.

FODDAI, D., SCHILEYKO, A.A. & MINELLI, A. 2002. Lithobiomorpha. In Amazonian Arachnida and Myriapoda (J. Adis, ed.). Pensoft Publishers, Sofia, p. 475-478.

FREITAS, A.V.L., LEAL, I.R., UEHARA-PRADO, M. & IANNUZZI, L. 2006. Insetos como indicadores de conservação da paisagem. In Biologia da Conservação (C.F. Rocha, H. Bergalo, M.V. Sluys & M.A. Alves, eds.). Essências, Rima Editora, São Carlos, p. 357-384.

GIACOMINI, H.C. 2007. Os mecanismos de coexistência de espécies como vistos pela teoria ecológica. Oecol. Bras. 11(4):521-543. 10.4257/oeco.2007.1104.05.

GOLOVATCH, S.I. 1999. On six new and some older Pyrgodesmidae from the environs of Manaus, Central Amazonia, Brazil (Diplopoda, Polydesmida). Amazoniana 15: 221-238.

GOLOVATCH, S.I. 2001. Two new polydesmoid millipedes from a white sand forest área near Manaus, Central Amazonia, Brazil (Diplopoda, Polydesmida: Pyrgodesmidae, Fuhrmannodesmidae). Arthropoda Sel. 10(1): 27-30.

GOLOVATCH, S.I., HOFFMAN, R.L., ADIS, J. & DE MORAIS, J.W. 1995. Identification plate for the millipede orders populating the Neotropical region south of Central Mexico (Myriapoda, Diplopoda). Stud. Neotrop. Fauna E. 30:159-164. 10.1080/01650529509360954

GOLOVATCH, S.I., HOFFMAN, R.L., ADIS, J., VOHLAND, K. & MÁRMOL, A. 1997. On the identity of further two millipede species (Diplopoda) from the environs of Manaus, Central Amazonia, Brazil. Amazoniana 14: 301-309.

GOLOVATCH, S.I., HOFFMAN, R.L., ADIS, J., MARQUES, M.I., RAIZER, J., SILVA, F.H.O., RIBEIRO, R.A.K., SILVA, J.L. & PINHEIRO, T.G. 2005. Milipedes (Diplopoda) of the Brazilian Pantanal. Amazoniana 18(3-4):273-288. 11858/00-001M-0000-000F-D961-B

GUIZZE, S.P.G., KNYSAK, I., BARBARO, K.C., KARAM-GEMAEL, M. & CHAGAS-JR, A. 2016. Predatory behavior of three centipede species of the order Scolopendromorpha (Arthropoda: Myriapoda: Chilopoda). Zoologia 33(6): e20160026.10.1590/S1984-4689zool-20160026

HASENACK, H., CORDEIRO, J.L.P. & HOFMANN, G.S. 2003. O clima da RPPN Sesc Pantanal. UFRGS, Porto Alegre.

HECKMAN, C.W. 1998. The Pantanal of Poconé. Biota and ecology in the northern section of the world's largest pristine wetland. Academic Publishers, Kluwer, Dordrecht.

HOFFMAN, R.L., GOLOVATCH, S.I., ADIS, J. & DE MORAIS, J.W. 2002. Diplopoda. In Amazonian Arachnida and Myriapoda (J. Adis, ed.). Pensoft Plubishers, Sofia, p. 505-534.

JUNK, W.J. 1993. Wetlands of tropical South America. In Wetlands of the world, inventory and management (D. Whigham, S. Hejny & D. Dykyjova, eds.). W. Junk Publishers, Dordrecht, p. 679-739.

JUNK, W.J. & NUNES-DA-CUNHA, C. 2005. Pantanal: A large South American wetland at a crossroads. Ecol. Eng. 24:391-401. 10.1016/j.ecoleng.2004.11.012

JUNK, W.J., NUNES-DA-CUNHA, C., WANTZEN, K.M., PETERMANN, P., STRÜSSMANN, C., MARQUES, M.I. & ADIS, J. 2006. Biodiversity and its conservation in the Pantanal of Mato Grosso, Brazil. Aquat. Sci. 68:278-309. 10.1007/s00027-006-0851-4

JUNK, W.J., PIEDADE, M.T.F., LOURIVAL, R., WITTMANN, F., KANDUS, P., LACERDA, L.D., BOZELLI, R.L., ESTEVES, F.A., NUNES-DA-CUNHA, C., MALTCHIK, L., SCHÖNGART, J., SCHAEFFER-NOVELLI, Y., AGOSTINHO, A.A., NOBREGA R.L.B. & CAMARGO, E. 2015. Classificação e delineamento das áreas úmidas brasileiras e de seus macrohabitats. In Definição e classificação das áreas úmidas (AUs) brasileiras, base científica para uma nova política de proteção e manejo sustentável (C. Nunes-da-Cunha, M.T.F. Piedade & W.J. Junk, eds.). INCT-INAU – EdUFMT, Cuiabá, p. 13-76.

LOPES, A., DE PAULA, J.D.A., MARDEGAN, S.F., HAMADA, N. & PIEDADE, M.T.F. 2011. Influência do habitat na estrutura da comunidade de macroinvertebrados aquáticos associados às raízes de *Eichhornia crassipes* na região do Lago Catalão, Amazonas, Brasil. Acta Amaz. 41(4):493-502. 10.1590/S0044-59672011000400007

MACHADO, M.P., PIRES, L.R., SILVA, L.T.P., RIGUETE, J.R. & SILVA, A.G. 2012. Análise de um gradiente fitofisionômico em área de influência de inundação periódica no Pantanal de Poconé, Mato Grosso, Brasil. Natureza On Line 10(2):65-70.

MARQUES, M.I., ADIS, J., BATTIROLA, L.D., SANTOS, G.B. & CASTILHO, A.C.C. 2011. Arthropods associated with a forest of *Attalea phalerata* Mart. (Arecaceae) palm three in the northern Pantanal. In The Pantanal: Ecology, biodiversity and sustainable management of a large neotropical seasonal wetland (W.J. Junk, C.J. Da Silva, C. Nunes-da-Cunha & K.M. Wantzen, eds.). Pensoft Publishers, Sofia, p. 431-468.

MARQUES, M.I., SANTOS, G.B. & BATTIROLA, L.D. 2014. Cerambycidae (Insecta, Coleoptera) associados à *Vochysia divergens* Pohl (Vochysiaceae) na região norte do Pantanal de Mato Grosso, Brasil. EntomoBrasilis 7(2):159-160. 10.12741/ebrasilis.v7i2.317

MEURER, E. 2015. Análise do efeito da inundação e estrutura da vegetação sobre a riqueza e distribuição da assembleia de formigas edáficas, estudo comparativo entre áreas inundáveis e não inundáveis na região norte do Pantanal. Tese de doutorado, Universidade Federal de Mato Grosso, Mato Grosso.

MEURER, E., BATTIROLA, L.D., DELABIE, J.H.C. & MARQUES, M.I. 2015. Influence of the vegetation mosaic on ant (Formicidae: Hymenoptera) distributions in the northern Brazilian Pantanal. Sociobiology 62(3):382-388. 10.13102/sociobiology.v62i3.359

MINELLI, A. & GOLOVATCH, S.I. 2013. Myriapods. In Encyclopedia of Biodiversity (S.A. Levin ed.). Waltham, Academic Press, p. 421-432.

MIRANDA, T.A., SANTANNA, A.D.S., VARGAS, A.B. & ALMEIDA, F.S. 2013. Aspectos estruturais do ambiente e seus efeitos nas assembleias de formigas em ambientes de floresta e bosque. Cadernos UniFOA 21:63-72.

NORONHA, J.C., BATTIROLA, L.D., CHAGAS-JR, A., MIRANDA, R., CARPENEDO, R.S. & RODRIGUES, D.J. 2015. Predation of bat (*Molossus molossus*: Molossidae) by the centipede *Scolopendra viridicornis* (Scolopendridae) in Southern Amazonia. Acta Amaz. 45:333-336. http://dx.doi.org/10.1590/1809-4392201404083

NUNES-DA-CUNHA, C. & JUNK, W.J. 2011. A preliminary classification of habitats of the Pantanal of Mato Grosso and Mato Grosso do Sul, and its relation to national and international wetland classification systems. In The Pantanal, Ecology, biodiversity and sustainable management of a large Neotropical seasonal wetland (W.J. Junk, C.J. Silva, C. Nunes-da-Cunha, & K.M. Wantzen, eds.). Pensoft Publishers, Sofia, p. 127-141.

NUNES-DA-CUNHA, C. & JUNK, W.J. 2015. A classificação dos macrohabitats do Pantanal Matogrossense. In Classificação e delineamento das áreas úmidas brasileiras, e de seus macrohabitats (C. Nunes-da-Cunha, M.T.F. Piedade & W.J. Junk eds.). EdUFMT, Cuiabá, p. 77-122.

NUNES-DA-CUNHA, C., JUNK, W.J. & LEITÃO, H.F. 2007. Woody vegetation in the Pantanal of Mato Grosso, Brazil, a preliminary typology. Amazoniana 19(3):159-184.

OKSANEN, J., BLANCHET, F.G., FRIENDLY, M., KINDT, R., LEGENDRE, P., MCGLINN, D., MINCHIN, P.R., O'HARA, R.B., SIMPSON, G.L., SOLYMOS, P., STEVENS, M.H.H., SZOECS, E. & WAGNER, H. 2017. Vegan: Community Ecology Package. R package version 2.4-0. https://CRAN.R-project.org/package=vegan [Accessed 05/09/2017].

OLIVEIRA-FILHO, A.T.D. 1992. The vegetation of Brazilian 'murundus'-the island-effect on the plant community. J. Trop. Ecol. 8(4):465-486. http://www.jstor.org/stable/2559761

PEREIRA, L.A., ULIANA, M. & MINELLI, A. 2007. Geophilomorph centipedes (Chilopoda) from termite mounds in the northern Pantanal wetland of Mato Grosso, Brazil. Stud. Neotrop. Fauna E. 42:(1)33-48. 10.1080/01650520600915613

PINHEIRO, T.G., MARQUES, M.I. & BATTIROLA, L.D. 2009. Life cycle of *Poratia salvator* Sierwald; Golovatch, 2000 (Diplopoda, Polydesmida, Pyrgodesmidae). Zoologia 26:658-662. 10.1590/S1984-46702009000400010

PINHEIRO, T.G, BATTIROLA, L.D. & MARQUES, M.I. 2011. Fertility tables of two populations of the parthenogenetic species *Poratia salvator* (Diplopoda, Polydesmida, Pyrgodesmidae). Braz. J. Biol. 71:501-510. 10.1590/S1519-69842011000300021

R CORE TEAM 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/ [Accessed 04/09/2017].

RADAMBRASIL 1982. Departamento de Produção Mineral. Projeto Radambrasil. Levantamento de Recursos Naturais. Folha Cuiabá (SD-21). Rio de Janeiro.

REBELLATO, L. & NUNES-DA-CUNHA, C. 2005. Efeito do "fluxo sazonal mínimo da inundação" sobre a composição e estrutura de um campo inundável no Pantanal de Poconé, MT, Brasil. Acta Bot. Bras. 19:789-799. 10.1590/S0102-33062005000400015

SANTOS, G.B., MARQUES, M.I., ADIS, J. & MUSIS, C.R. 2003. Arthropods associated with the canopy of the palm *Attalea phalerata* Mart. (Arecaceae), in the Pantanal of Poconé, Mato Grosso, Brazil. Rev. Bras. Entomol. 47(2): 211-224. 10.1590/S0085-56262003000200010

SANTOS, S.A., POTT, A., RODRIGUES, C.A.C., CARDOSO, E.L., COMASTRI FILHO, J.Á. & CRISPIM, S.M.A. 2012. Pastagem nativa. In Gado de Corte no Pantanal (E.L. Cardoso, ed.) Embrapa, Brasília, p. 93-132.

SANTOS-SILVA, L., PINHEIRO. T.G., MARQUES, M.I. & BATTIROLA, L.D. Phenology of *Promestosoma boggianii* (Diplopoda, Polydesmida, Paradoxosomatidae) in a Neotropical floodplain. Zoologia. 35:e14762. 10.3897/zoologia.35.e14762

SIGNOR, C.A., FERNANDES, I.M. & PENHA, J. 2010. O Pantanal e o sistema de pesquisa. In Biodiversidade no Pantanal de Poconé (I.M. Fernandes, C.A. Signor & J. Penha, eds.). Attema Editora, Manaus, p. 13-23.

SILVA, M.P.D., MAURO, R., MOURÃO G. & COUTINHO, M. 2000. Distribuição e quantificação de classes de vegetação do Pantanal através de levantamento aéreo. Rev. Bras. Bot. 23(2):143-152. 10.1590/S0100-84042000000200004

TEWS, J., BROSE, U., GRIMM, V., TIELBÖRGER, K., WICHMANN, M.C., SCHWAGER, M. & JETSCH, F. 2004. Animal species diversity driven by habitat heterogeneity/diversity: The importance of keystone structures. J. Biogeogr. 31:79-92. 10.1046/j.0305-0270.2003.00994.x

WANTZEN, K.M., MARCHESE, M.R., MARQUES, M.I. & BATTIROLA, L.D. 2016. Invertebrates in Neotropical Floodplains. In Invertebrates in Freshwater Wetlands (D. Batzer & D. Boix, eds.). Springer International Publishing, Switzerland, p. 493-524.

YAMAZAKI, L., MARQUES, M.I., BRESCOVIT, A.D. & BATTIROLA, L.D. 2015. *Tityus paraguayensis* (Scorpiones: Buthidae) em copas de *Callisthene fasciculata* (Vochysiaceae) no Pantanal de Mato Grosso (Brasil). Acta Biol. Par. 44(3-4):153-158. 10.5380/abpr.v44i1-4.44122

*Received: 15/01/2018*
*Revised: 15/03/2018*
*Accepted: 20/03/2018*
*Published online: 23/04/2018*

Biota Neotropica 18(2): e20170444, 2018
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)

**Inventory**

# Biological survey of a cloud forest in southwestern Mexico: plants, amphibians, reptiles, birds, and mammals

*R. Carlos Almazán-Núñez[1]*, Edson A. Alvarez-Alvarez[2], Fernando Ruiz-Gutiérrez[1], Ángel Almazán-Juárez[3], Pablo Sierra-Morales[2] & Sarahi Toribio-Jiménez[1]*

*[1]Universidad Autónoma de Guerrero, Facultad de Ciencias Químico Biológicas, Laboratorio Integral de Fauna Silvestre, Av. Lázaro Cárdenas, 39090, Ciudad Universitaria, Chilpancingo, Guerrero, Mexico*
*[2]Universidad Autónoma de Guerrero, Facultad de Ecología Marina, Maestría en Recursos Naturales y Ecología, 39390, Acapulco, Guerrero, Mexico*
*[3]Universidad Autónoma de Guerrero, Instituto de Investigación Científica Área Ciencias Naturales, 39000, Chilpancingo, Guerrero, Mexico*
**Corresponding author: R. Carlos Almazán-Núñez, e-mail: rcarlos.almazan@gmail.com*

ALMAZÁN-NÚÑEZ, R. C., ALVAREZ-ALVAREZ, E. A., RUIZ-GUTIÉRREZ, F., ALMAZÁN-JUÁREZ, A., SIERRA-MORALES, P., TORIBIO-JIMÉNEZ, S. **Biological survey of a cloud forest in southwestern Mexico: plants, amphibians, reptiles, birds, and mammals**. Biota Neotropica. 18(2): e20170444. http://dx.doi.org/10.1590/1676-0611-BN-2017-0444

***Abstract:*** Cloud forest ecosystems contain unique flora and fauna characterized by high levels of richness and endemism. However, this ecosystem is one of the most threatened because of land-use changes stemming from anthropogenic activities. Therefore, biological inventories are necessary to adequately assess the effects of land-use changes on species now and in the future. In this study, we conducted an inventory of plants and terrestrial vertebrates (amphibians, reptiles, birds, and mammals) in three fragments of cloud forest in southwestern Mexico. Field work was carried out for 15 days per biological group during distinct time periods (2005-2008). Conventional methods of species capture and observation were employed to record species. Recorded species were then categorized based on their endemism and risk category. A total of 67 species of plants, 17 species of amphibians, 25 species of reptiles, 93 species of birds, and 46 species of mammals were recorded. The species accumulation curves for most taxa, except for birds and mammals, showed an asymptotic trend. A total of 56 species endemic to Mexico and four quasi-endemic species were recorded. Plants, amphibians, and reptiles presented the greatest number of species exclusive to Mexico (13 species). Six species of herpetofauna endemic to Guerrero were recorded. According to Mexican laws, 24 of the encountered species are under special protection, while 16 are categorized as threatened and seven as endangered. Reptiles and birds presented the greatest number of at-risk species (14 species). Bird and mammal richness in this study is high in comparison to that recorded in the cloud forests of the entire Mexican state of Guerrero (157 and 75 species, respectively). This data highlights the importance of cloud forests in the study area for local and regional biodiversity. Effective conservation strategies should be prioritized in cloud forests, as this ecosystem is poorly represented in natural protected areas.

***Keywords:*** *cloud forest, conservation, diversity, terrestrial vertebrates, flora, species richness.*

# Estudio biológico del bosque mesófilo de montaña en el suroeste de México: plantas, anfibios, reptiles, aves y mamíferos

***Resumen:*** Los bosques mesófilos de montaña son ecosistemas que contienen flora y fauna única, y son caracterizados por sus altos niveles de riqueza y endemismo. Este ecosistema es uno de los más amenazados debido a los cambios en el uso del suelo por actividades antropogénicas. Por tanto, los inventarios bióticos en este ecosistema son necesarios para evaluar adecuadamente los cambios en el uso del suelo sobre las especies en la actualidad y en el futuro. En este estudio se desarrollaron inventarios de plantas y vertebrados terrestres (anfibios, reptiles, aves y mamíferos) en tres fragmentos de bosque mesófilo de montaña en el suroeste de México. El trabajo de campo se realizó durante 15 días por cada grupo biológico durante distintos períodos de tiempo (2005 al 2008). Los registros de las especies se obtuvieron mediante métodos convencionales de captura y observación. Se categorizaron a las especies por su endemismo y categoría de riesgo. Se registró un total de 67 especies de plantas, 17 especies de anfibios, 25 especies de reptiles, 93 especies de aves y 46 especies de mamíferos. Las curvas de acumulación mostraron un comportamiento asintótico para la mayoría de los taxa, excepto aves y mamíferos. Se obtuvo un total de 56 especies endémicas a México y cuatro cuasiendémicas. Los grupos de plantas, anfibios y reptiles presentaron el mayor número de especies exclusivas al país (13 especies), y se obtuvo un total de seis especies de herpetofauna endémicas a Guerrero. De acuerdo con las leyes mexicanas, se registró un total 24 especies en protección especial, 16 amenazadas y siete en peligro de extinción, de los cuales los grupos de los reptiles y aves presentaron el mayor número de especies en categoría de riesgo (14 especies). La riqueza de especies de aves y mamíferos en este estudio representa un número importante comparado con el total de especies registradas en los bosques mesófilos del estado de Guerrero (157 y 75 especies, respectivamente). Estos datos resaltan la importancia de los bosques mesófilos de montaña del área de estudio para la biodiversidad local y regional, por lo que deben priorizarse estrategias de conservación efectivas para este ecosistema poco representado en áreas naturales protegidas.

***Palabras clave:*** *bosque mesófilo, conservación, diversidad, vertebrados terrestres, flora, riqueza de especies.*

## Introduction

Mexico is a country that contains a large portion of the world's biodiversity and is well represented in worldwide diversity lists, usually occupying one of the first places. Overall, Mexico contains approximately 10% of global biological richness (Mittermeier & Goettsch de Mittermeier 1992, Rammamorthy et al. 1998, Martínez-Meyer et al. 2014). Among higher organisms, Mexico occupies fourth place in plant richness (Villaseñor 2016), fifth in amphibian richness (Parra-Olea et al. 2014), second in reptile richness (Flores-Villela & García-Vázquez 2014), eleventh in bird richness (Navarro-Sigüenza et al. 2014), and third in mammal richness (Ramírez-Pulido et al. 2014). These high levels of biodiversity are partly due to the convergence of the Nearctic and Neotropical biogeographical regions within Mexico's territory, giving rise to species with both temperate and tropical affinities (Plascencia et al. 2011). Despite the vast biological resources of Mexico, the flora and fauna of this country have not been fully documented (Martínez-Meyer et al. 2014), and several regions with potentially high levels of diversity and endemism remain relatively unexplored.

The Sierra Madre del Sur (SMS) in western Mexico is an important region from a biological perspective. This region is characterized by a complex orography and geological history that has promoted the development of a wide range of environments and ecosystems (Ferrusquía 1998, Luna-Vega et al. 2016), including cloud forests (CF). In the SMS, CF covers approximately 1,765 km$^2$ and corresponds to 20% of the territory (INEGI 2010). As previously mentioned, this ecosystem is highly diverse and contains many exclusive flora and fauna species (Challenger 1998, Gual-Díaz & Rendón-Correa 2014). Notably, various fragments of this ecosystem are distributed in the form of an archipelago across the mountainous environments of the SMS, and each fragment has a particular biotic composition (Gual-Díaz & Rendón-Correa 2014). However, limited biological information is available on the CF of this region.

The lack of biological studies on the CF of western Mexico is related to the physical inaccessibility of some sites (e.g., because of difficult terrain or lack of roads) and social problems. As few biotic inventories have been conducted in this region to date, our study serves as an initial approximation for increasing knowledge on the biological diversity of CF in the SMS of the Mexican state of Guerrero. We performed biological inventories of plants and terrestrial vertebrates and provided information on the endemism and risk status of the recorded species. Also, our study represents an important contribution to the national biotic inventory and serves as a baseline of biodiversity with which future scenarios and studies can be compared. Ultimately, this inventory serves as a tool for conservation efforts in the study region, especially considering that CF are highly threatened by human activities.

## Material and Methods

### 1. *Study area*

The study area is located to the west of the biotic province of SMS in the state of Guerrero in southwestern Mexico between 101°6'30.84" to 100°57'57.86" W and 17°46'16.87" to 17°43'24.45" N (Figure 1). The studied CF fragments comprise a total area of 11 km$^2$ and present an altitude between 1700 and 2200 masl (Figure 1). The climate is humid and sub-humid temperate, with a mean annual temperature between 16 and 20 °C and a mean annual precipitation between 1200 and 2000 mm (García 2004). The study area is characterized by rugged orography with slopes of 4° to 60°. Several types of land management are practiced in the CF of the study area, including agriculture (e.g., mainly corn, bean, and squash crops) and forestry, wherein species of economic importance (e.g., *Quercus glaucoides* and *Q. candicans*) are harvested.

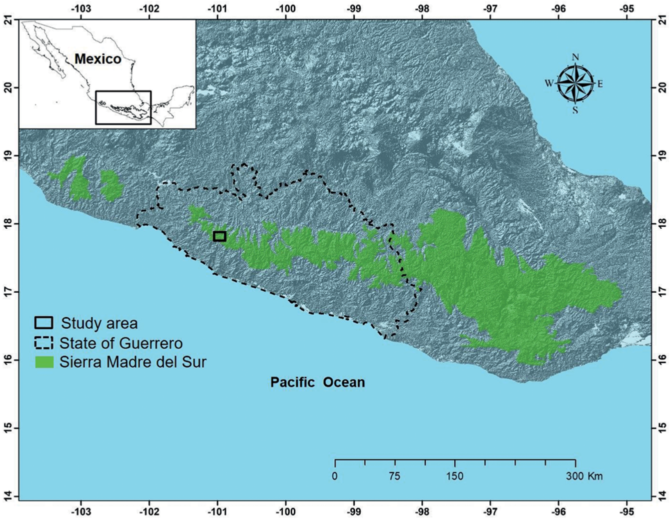

**Figure 1.** Location of the study area in the SMS of the state of Guerrero in southwestern Mexico.

http://dx.doi.org/10.1590/1676-0611-BN-2017-0444

## 2. *Sampling effort, inventory completeness, and identification of species at risk*

Different conventional methods were employed for the inventory of each biological group. A total of 15 days of field work, carried out from 2005–2008, were dedicated to each group. Species accumulation curves were calculated to evaluate the completeness of the inventories of each taxonomic group. Potential species richness was estimated using the incidence-based coverage estimator (ICE) method, wherein the unit effort corresponded with the number of sampling days. This estimator is based on estimated sample coverage (i.e., the proportion of richness represented in a set of replicated incidence samples) and is insensitive to sample size (Gotelli & Colwell 2011). These analyses were performed using the "specaccum" function in the "vegan" package (Oksanen et al. 2017) in R 3.3.3 (R Development Core Team 2017). Following the surveys, a comparative analysis was carried out to evaluate differences in the richness of each biological group in comparison to the richness levels recorded in CF at both the state and national level. For these comparisons, data on plants, amphibians, reptiles, and birds at the state and national level were taken from Villaseñor (2010) and Gual-Díaz & Rendón-Correa (2014). Mammal data at the national level were taken from González-Ruiz et al. (2014). In addition, the studies of León-Paniagua & Romo-Vázquez (1993), Jiménez-Almaraz et al. (1993), Ávila-Nájera (2006), Ruiz-Gutiérrez (2012), and Almazán-Catalán et al. (2013) were used to compare mammals at the state level because no single source has reported the total number of mammal species in the CF of the state of Guerrero.

For each group, the risk status of species was assigned according to the following categories listed in the Mexican Official Standard NOM-059-SEMARNAT-2010 (SEMARNAT 2010): (1) special protection, which includes those species or populations that could be threatened by factors that adversely affect their viability and determine the need to facilitate their recovery (this category may include the lower risk categories of the IUCN classification), (2) threatened, which includes those species or populations that could be in danger of disappearance in the short to medium term if the factors that adversely affect their viability, such as habitat modification or disturbance, directly reduce the size of their populations (this category overlaps with the "vulnerable" category in the IUCN classification), and (3) endangered, which includes those species whose range or population size has dramatically decreased within Mexico as a result of drastic habitat modification or destruction, overharvesting, disease, or predation, among others, thereby threatening the biological viability of these species throughout their natural habitat (this category overlaps with the categories "critically endangered" and "endangered" in the IUCN classification).

## 3. *Plants*

To inventory plant species, we delimited 30 quadrants of 30 x 30 m (0.027 km$^2$) at different sites and counted and identified plant species with flowers and/or fruits. When we were unable to identify plants *in situ*, we collected botanical samples (three specimens per species) for subsequent identification. Collected specimens were pressed and labeled for herborization according to the protocol of Wendt (1986) and identified through comparison with existing specimens in the Herbarium of the Instituto de Investigación Científica Área Ciencias Naturales (IICACN) of the Universidad Autónoma de Guerrero (UAGro) and in the Vascular Plant Laboratory of the Facultad de Ciencias of the Universidad Nacional Autónoma de México (UNAM). Nomenclature was verified in the database of the Missouri Botanical Garden (W3Tropicos 2010). Species endemism was determined based on Villaseñor et al. (2016). The systematic arrangement of species follows Wearn et al. (2013) and the guidelines of the Angiosperm Phylogeny Group (APG IV 2016).

## 4. *Amphibians and reptiles*

To inventory amphibian and reptile species, we conducted walks along linear transects during three daily observation episodes (diurnal, crepuscular, and nocturnal) to cover the peak hours of activity. To cover a high proportion of amphibian and reptile microhabitats, we placed transects along diverse environment, including rivers and streams in CF as well as those associated with coffee plantations. Sampling consisted of direct observation along roads, wetlands, streams, and trunks as well as under rocks and in caves. Specimens were collected employing traditional capture techniques (Casas-Andreu et al. 1996). Individuals were directly collected by hand, and for particularly poisonous species, a herpetological hook was used. For each specimen captured, we recorded meristic data, coloration, and microhabitat. Amphibian and reptile specimens were identified using field guides by Casas & McCoy (1987) and Flores-Villela et al. (1995).

## 5. *Birds*

To inventory bird species, we carried out bird observations during the hours of highest bird activity in the morning (07:00 to 10:30 h) and afternoon (16:00 to 18:30 h). In addition, 10 mist nets 12 m long and 2.5 m wide were placed to complement the species inventory of the study area. A total of 1800 h/net were obtained. Nets were placed in different sites than those used for the bird observations. Captured specimens were identified and subsequently released at the same capture site. Binoculars (8 x 40 and 10 x 50) and field guides (Howell & Webb 1995, National Geographic Society 1999, Sibley 2000) were used to identify species. Each observed bird species was categorized according to its seasonality (Howell & Webb 1995) and endemism (González-García & Gómez de Silva 2003). The scientific nomenclature and systematic arrangement of species followed the guidelines of the American Ornithologists' Union (AOU 1998) and its most recent update (Chesser et al. 2017).

## 6. *Mammals*

To inventory bats, five mist nets 12 m long and 2.5 m wide were used. Nets were placed across rivers and streams and in open areas between wooded areas. All nets were opened daily from 19:00 to 06:00 h; a total of 550 h/net were obtained. To collect rodents, 50 Sherman traps baited with oatmeal and vanilla were placed along two transects. To collect shrews, 1-L pitfall traps were buried at soil level. The traps for rodents and shrews were placed in the afternoon and checked the following morning. Also, the occurrence of medium- and large-sized mammals was confirmed through searching for excreta and footprints, mainly along riversides and walking trails. All excreta and footprints were determined using the guide by Aranda (2000). In addition, data on sightings of medium-sized species in the field were recorded. The taxonomic guides by Hall (1981), Álvarez et al. (1994), and Medellín et al. (1997) were used to identify mammal species. After identification, mammals were released at the same capture site. Endemism was determined following Gutiérrez-Blando et al. (2016). Scientific nomenclature and systematic arrangement followed the guidelines by Ramírez-Pulido et al. (2014).

## Results

### 1. *Plants*

A total of 67 plant species belonging to 30 families were recorded (Figure 2, Appendix 1), 32 of which are herbs (e.g., *Lopezia racemosa*, *Monochaetum calcaratum*, and *Oenothera rosea*), 22 are trees (e.g., *Carpinus caroliniana*, *Pinus ayacahuite*, and *Quercus candicans*), 11 are shrubs (e.g., *Ageratum corymbosum*, *Monnina xalapensis*, and *Rumfordia floribunda*), and two are lianas (i.e., *Canavalia villosa* and *Phaseolus coccineus*; Appendix 1). A total of 13 species were endemic to Mexico (e.g., *Erythrina americana*, *Pinus herrerae*, and *Quercus urbanii*; Figure 2; Appendix 1). Two species are listed in the NOM-SEMARNAT-059-2010 (Figure 2): one under special protection (*Cyathea bicrenata*; Figure 3a,b) and the other as threatened (*Carpinus caroliniana*; Appendix 1). The species accumulation curve showed an asymptotic trend with a slight increase toward the end of the sampling period (Figure 4a). The ICE method estimated 69 species with a confidence interval (CI; α = 0.05) ranging from 48 to 90 species.

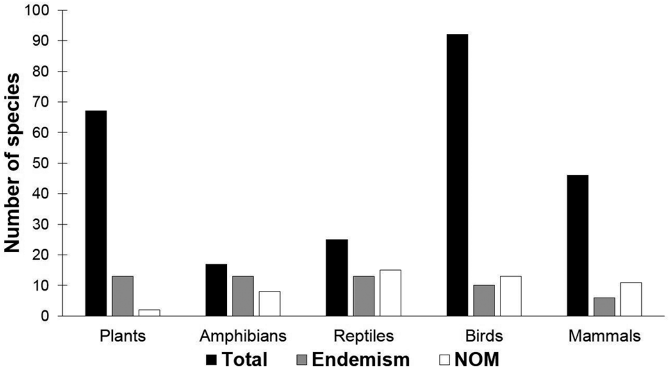

**Figure 2.** Species richness, endemic species, and species at risk per biological group in cloud forest fragments of southwestern Mexico.

### 2. *Amphibians and reptiles*

A total of 17 amphibian species belonging to six families were recorded (Figure 2, Appendix 2). Thirteen species are endemic to Mexico (e.g., *Agalychnis dacnicolor*, *Incilius occidentalis*, and *Tlalocohyla smithii*; Figures 2 and 3c-e), and two are endemic to Guerrero (i.e., *Charadrahyla tecuani* and *Thorius grandis*; Appendix 2). Six species are under special protection (e.g., *Exerodonta melanomma*, *Lithobates forreri*, and *Plectrohyla bistincta*; Figure 2, Appendix 2), and one is threatened (i.e., *Isthmura bellii*). In addition, 25 species of reptiles belonging to nine families were recorded (Figure 2, Appendix 2). Thirteen are endemic to Mexico (e.g., *Anolis nebulosus*, *Plestiodon brevirostris*, and *Thamnophis chrysocephalus*), and four are endemic to Guerrero (e.g., *Abronia martindelcampoi*, *Mixcoatlus barbouri*, and *Sceloporus adleri*; Figure 2, Appendix 2). A total of 14 reptile species are at risk, including 10 species under special protection (e.g., *Crotalus culminatus*, *Mesaspis gadovii*, and *Sceloporus grammicu*; Figure 3f) and four threatened species (e.g., *Boa imperator*, *Thamnophis godmani*, and *Trimorphodon quadruplex*; Figure 2, Appendix 2). The species accumulation curves for both amphibians (Figure 4b) and reptiles (Figure 4c) showed an asymptotic trend, yet the curve for amphibians began to stabilize at the middle of the sampling period. The ICE method estimated 17 amphibian species (CI = 11 to 23 species; α = 0.05) and 26 reptile species for the study area (CI = 8 to 44; α = 0.05).

### 3. *Birds*

A total of 93 bird species belonging to 32 families were recorded (Figure 2, Appendix 3), 68 of which are permanent residents (e.g., *Patagioenas fasciata*, *Piranga bidentata*, and *Rhynchocyclus brevirostris*), 23 are winter visitors (e.g., *Cardellina rubrifrons*, *Regulus calendula*, and *Setophaga townsendi*), and two are transitory (i.e., *Buteo swainsoni* and *Setophaga striata*; Appendix 3). A total of 11 species are endemic to Mexico (e.g., *Cyanolyca mirabilis*, *Cardellina rubra*, and *Piranga erythrocephala*; Figure 3g-h), and four are quasi-endemic (e.g., *Junco phaeonotus*, *Poecile sclateri*, and *Ptiliogonys cinereus*; Figure 2, Appendix 3). Six species are threatened (e.g., *Catharus frantzii*, *Eupherusa poliocerca*, and *Penelope purpurascens*), five species are under special protection (e.g., *Aulacorhynchus prasinus*, *Myadestes occidentalis*, and *Trogon collaris*) and three are endangered (i.e., *Amazona finschi*, *Ara militaris*, and *Cyanolyca mirabilis*; Figure 2, Appendix 3). The number of species continuously increased with sampling, and the accumulation curve was not asymptotic (Figure 4d). The ICE method estimated 101 bird species for the study area (CI = 83 to 119; α = 0.05).

### 4. *Mammals*

A total of 46 species of mammals belonging to 19 families were recorded (Figure 2, Appendix 4). Of these, six species are endemic to Mexico (e.g., *Cryptotis goldmani*, *Dermanura azteca*, and *Sylvilagus cunicularius*; Figures 2 and 3i-j, Appendix 4), and 11 species are found in an at-risk category (Figure 2; Appendix 4). In particular, four species are threatened (e.g., *Choeronycteris mexicana*, *Glaucomys volans*, and *Herpailurus yagouaroundi*). Another four species are endangered (e.g., *Tamandua mexicana*, *Leopardus pardalis*, and *Panthera onca*), and three species are under special protection (i.e., *C. goldmani*, *Megadontomys thomasi*, and *Potos flavus*; Figure 2, Appendix 4). The species accumulation curve showed that mammal richness did not reach the asymptotic threshold (Figure 4e). The ICE method estimated 50 species for the study area (CI = 38 to 56 species; α = 0.05).

### 5. *Comparisons with CF at the state and national level*

The species richness obtained for each taxonomic group in the CF of our study area is not low in comparison to that of CF ecosystems at the state level (Figure 5). For example, 52% of amphibian species, 63% of reptile species, 59% of bird species, and 61% of mammal species recorded in CF of the state of Guerrero were also recorded in the study area. Also, in comparison to the species richness of each group in CF at the national level, the species recorded in our study area represent 1.1% of plant species, 9% of amphibian species, 10% of reptile species, 17% of bird species, and 18% of mammal species (Figure 5).

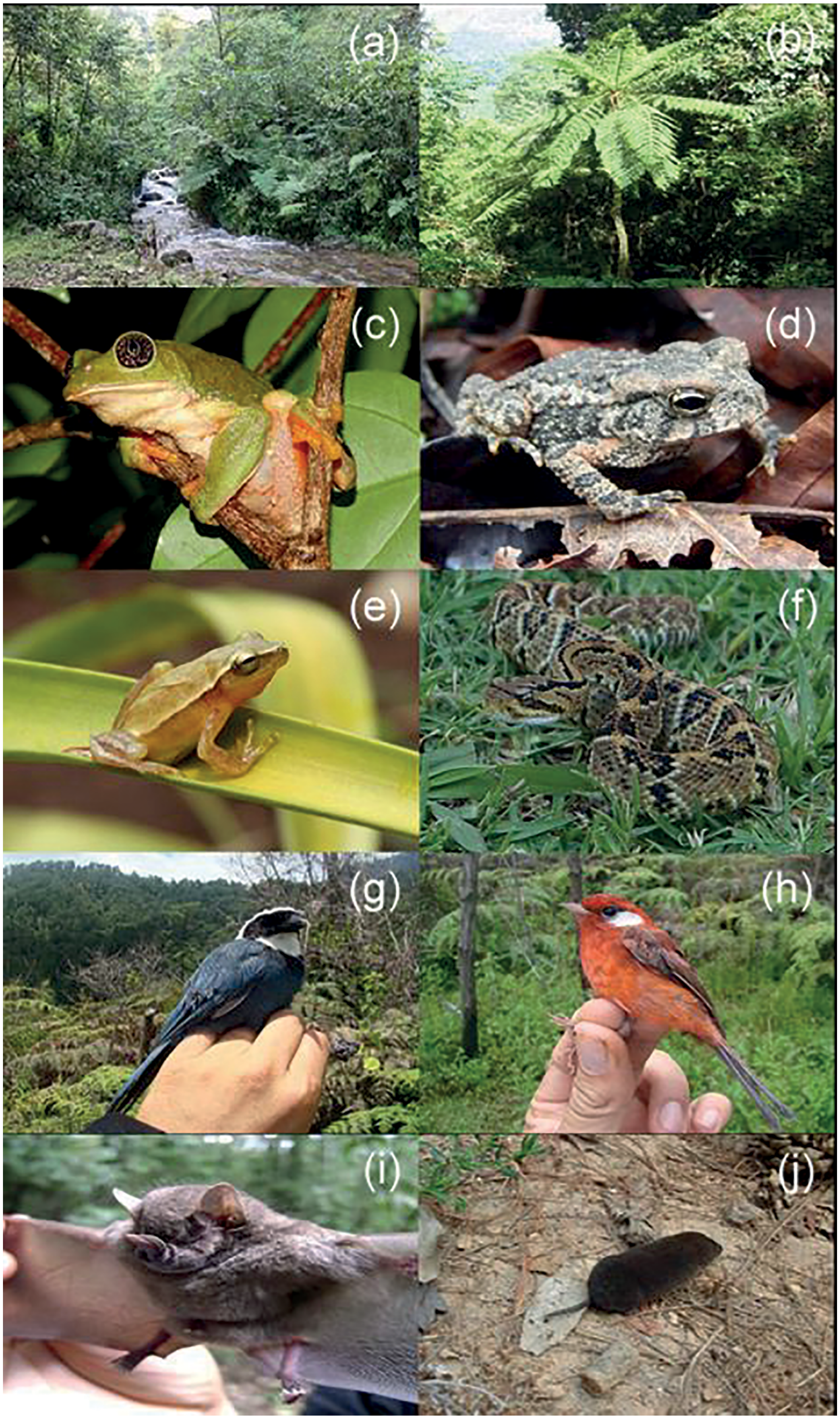

**Figure 3.** Examples of endemic and/or at-risk species recorded in cloud forest fragments in southwestern Mexico. a) sampling site, b) *Cyathea bicrenata*, c) *Agalychnis dacnicolor*, d) *Incilius occidentalis*, e) *Tlalocohyla smithii*, f) *Crotalus culminatus*, g) *Cyanolyca mirabilis*, h) *Cardellina rubra*, i) *Dermanura azteca*, and j) *Cryptotis goldmani*

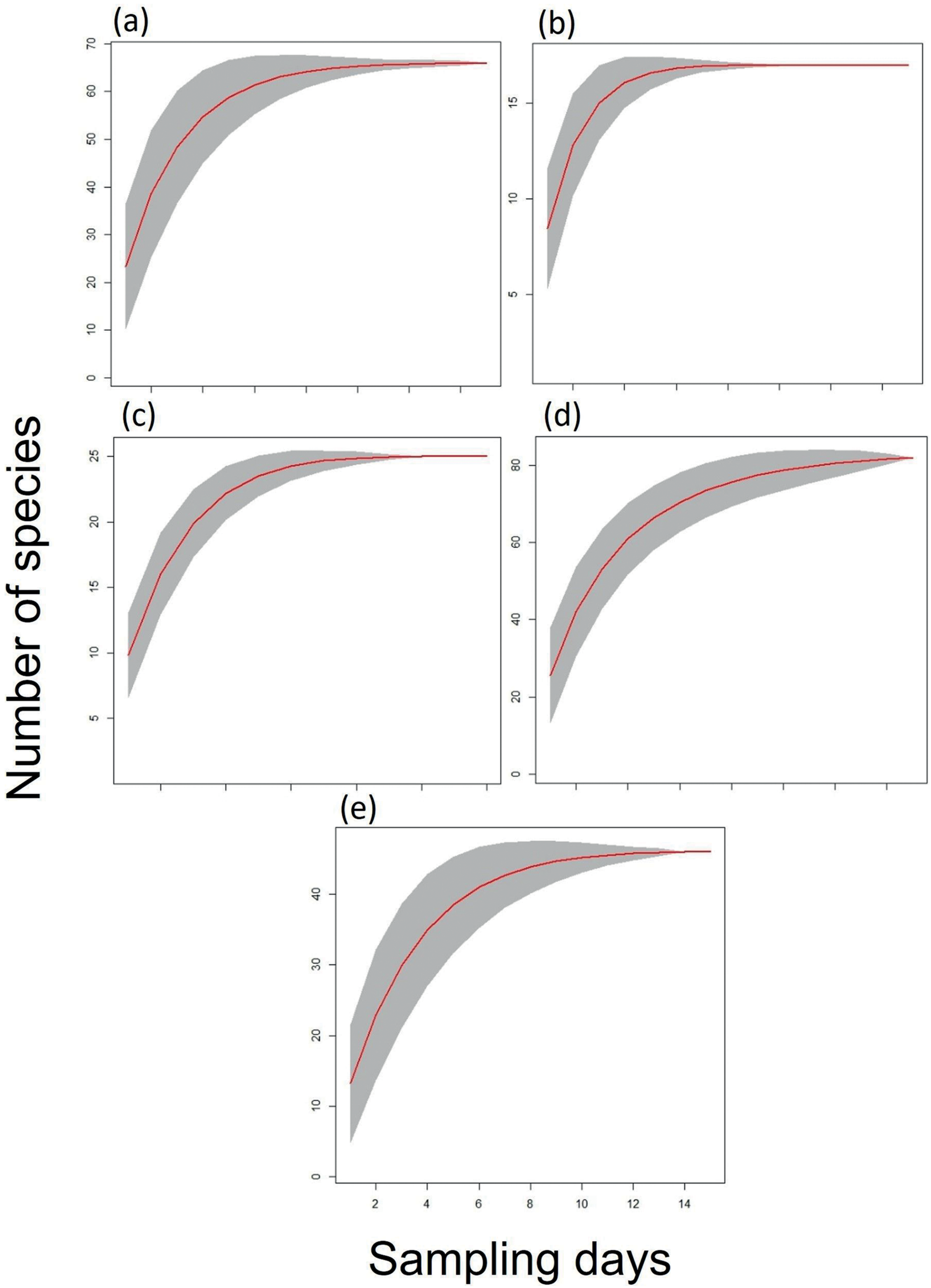

**Figure 4.** Species accumulation curves for a) plants, b) amphibians, c) reptiles, d) birds, and e) mammals in cloud forest fragments in southwestern Mexico. Red lines indicate the cumulative increase of species per biological group, and shaded areas denote the 95% confidence intervals.

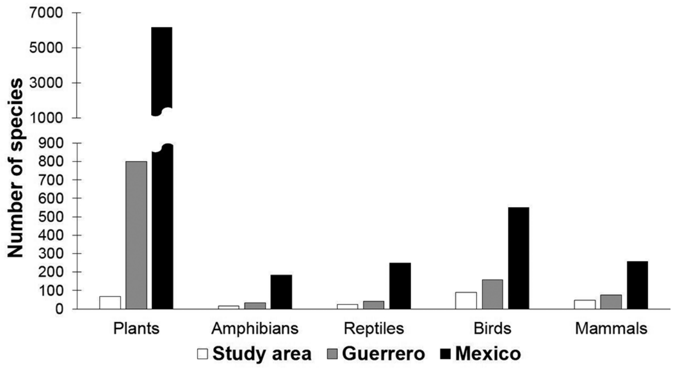

**Figure 5.** Number of species per biological group in the cloud forests of Guerrero and Mexico.

## Discussion

With the exception of plants, the species richness obtained in our study area for the four evaluated animal groups represented more than half of the total species richness of CF in the state of Guerrero. In addition, this species richness represented at least one-quarter of the total species richness of the entire SMS (Espinosa et al. 2016, Flores-Villela & Ochoa-Ochoa 2016, Gutiérrez-Blando et al. 2016, Navarro-Sigüenza et al. 2016). In the case of the plants, the inventory is apparently small, as the sampling was conducted across only 0.027 km$^2$ (0.25% of the entire study area). In comparison with other studies in CF across the SMS, the species richness of our study area is lower than that obtained by Fonseca et al. (2001), Catalán-Heverástico et al. (2003), and Lozada-Perez et al. (2003); however, these studies were carried out in larger areas (35.5 km$^2$, 0.045 km$^2$, and 7 km$^2$, respectively). This suggests the biological importance of the CF in our study area and provides a baseline of species richness in this region. Existing species must be continuously monitored, yet this baseline can be used to develop effective conservation strategies. In addition, these data are of particular importance considering that studies on flora and fauna in the SMS biotic province have been scarce (Luna-Vega et al. 2016), although several descriptive studies of the biological resources of this region have been carried out in the last decade (e.g., Almazán-Núñez et al. 2007, Almazán-Catalán et al. 2009, Almazán-Núñez et al. 2009, Flores-Villela & Ocho-Ochoa 2016, Gutiérrez-Blando et al. 2016, Navarro-Sigüenza et al. 2016).

However, biological studies have not been performed in several areas, particularly CF, that likely have high levels of biodiversity. Cloud forests are one of the ecosystems with the highest levels of biodiversity in Mesoamerica (Gual-Díaz & Rendón-Correa 2014). In Mexico, the best-studied CF in biological terms are located in the central-eastern portion of the country, particularly in the states of Veracruz and Hidalgo (e.g., Martínez-Morales 2007, García-Franco et al. 2008, Álvarez-Zúñiga et al. 2012, Aguilar-López et al. 2013, Rueda-Hernández et al. 2015). Meanwhile, other areas with an extensive presence of this ecosystem, such the southwestern portion of the country (e.g., the state of Guerrero), remain relatively unexplored. In comparative terms, the total species richness of the five taxa in our study area is higher than that reported for Cerro Piedra Larga, Oaxaca, Mexico (Peterson et al. 2004), even though the present study only focused on CF. However, such comparisons should be performed with caution because these geographic areas as well as the corresponding sampling efforts and environmental factors are not similar (Watson & Peterson 1999). The importance of several species recorded in our study area can also be highlighted from a conservation biology perspective. For instance, several species are endemic to western Mexico (e.g., *Eleutherodactylus nitidus, Rhadinaea hesperia, Micrurus distans*, *Piranga erythrocephala,* and *Amazona finschi*). Others are restricted to the state of Guerrero (e.g. *Mixcoatlus barbouri*, *Sceloporus adleri*, and *Thorius grandis*) or to small portions of the SMS (e.g., *Charadrahyla tecuani*, *Eupherusa poliocerca*, *Cyanolyca mirabilis*, and *Cryptotis goldmani*). In fact, our study area is part of the biotic province of the SMS, which is considered a priority terrestrial region because of its high biological diversity and the presence of a significant number of endemic species (Arriaga et al. 2000).

The distribution of species richness in biological groups is not homogeneous across CF at the state and national level, as some areas contain higher concentrations of certain groups of species (Gual-Díaz & Rendón-Correa 2014). The differential presence of distinct biological groups is largely the result of *in situ* speciation processes. The physical characteristics of CF ecosystems, such as climate and historical factors (i.e., rugged orography that acts as a barrier) have favored the presence of many endemic species in CF (Watson & Peterson 1999) and a significant number of species that are restricted to this habitat (e.g., *Cyanolyca mirabilis*, *Megadontomys thomasi*, and *Eleutherodactylus augusti*). Several of these species form genetically differentiated populations that are widely distributed, for example, *Charadrahyla tecuani*, *Thorius grandis*, *Lampornis amethystinus*, *Aulacorynchus prasinus,* and *Chlorospingus flavopectus* (Hanken et al. 1999, Navarro-Sigüenza & Peterson 2004, Campbell et al. 2009). Overall, 75 mammal species have been recorded in other CF of Guerrero by León-Paniagua & Romo-Vázquez (1993), Jiménez-Almaraz et al. (1993), Ávila-Nájera (2006), Ruiz-Gutiérrez (2012), and Almazán-Catalán et al. (2013). In our study area, a relatively large portion of these species were found (46 species). The absence of species characteristic of CF in certain regions may be due to different factors, for example, the variation in dominant floristic species from one region with CF to another. Also, latitude has been suggested to be one of the most important factors that determines differences in species richness and endemism throughout the CF of Mesoamerica (Watson & Peterson 1999). Other possible factor that can explain the absence of some species in the CF of our study area is the uneven sampling effort, as several species unregistered in this study are indeed common and relatively easy to detect in other CF ecosystems (e.g., *Colaptes auricularis*, *Lepidocolaptes affinis*, *Glossophaga soricina*, and *Cryptotis mexicanus*; Hernández-Baños et al. 1995, Peterson et al. 2004, Martínez-Morales 2007, González-Ruiz et al. 2014). Also, some latitudinal migratory species, particularly birds (e.g., *Oreothlypis ruficapilla*, *Polioptila caerulea*, and *Selasphorus rufus*), are likely poorly represented in our study, as the bird sampling period comprised only the months of January, April, and May; this was reflected in the accumulation curve for bird species. However, the lists of each biological group generated in our study may be considered representative based on the expected richness calculated by the ICE estimator.

A high concentration of endemism is present in different biological groups of western Mexico (García-Trejo & Navarro 2004, Ochoa-Ochoa & Flores-Villela 2006, Gutiérrez-Blando et al. 2016, Villaseñor 2016). The flora and fauna endemic to our study area (56 species) was notable compared to the total number of endemic species reported for the entire state of Guerrero (380 species; Navarro 1998, Pérez-Ramos et al. 2000, Villaseñor 2016). This richness of endemic species was found in an area that barely covers 0.02% and 0.019% of the area of Guerrero and the SMS, respectively. In comparison to the CF of Guerrero (Hernández-Baños et al. 1995, Gual-Díaz & Mayer-Goyenechea 2016, Mayer-Goyenechea & Gual-Díaz 2016), our study area contained a large proportion of endemic amphibian species (48%), reptiles (35%), and birds (73%). However, despite the high concentration of endemic plants in CF (Villaseñor 2010), no endemic plants were found in our study.

With respect to the at-risk status of the recorded species, a total of 47 species of flora and fauna were identified to be at risk. In particular, *Carpinus caroliniana, Eupherusa poliocerca, Herpailurus yagouaroundi*, and *Trimorphodon quadruplex* are threatened, and *Aulacorhynchus prasinus, Craugastor uno, Cryptotis goldmani, Cyathea bicrenata*, and *Lithobates sierramadrensis* are under special protection status. Species such as *Cyanolyca mirabilis* and *Tamandua mexicana* are endangered. These results indicate the importance of preserving the CF ecosystems, as it presents high levels of endemism, contains numerous at-risk species, and currently represents one of the most vulnerable and unprotected ecosystems in Mexico.

Despite the high species richness and the high number of at-risk species recorded in the CF of our study area according to NOM-059-SEMARNAT-2010, few studies have focused on the importance of biological richness in CF at the state level. A greater knowledge of wildlife and floristic resources at the local level can complement inventories at the state and national level and can be useful for promoting effective strategies for the conservation and use of biodiversity. For these reasons, it is imperative to continue these types of studies, especially in unexplored environments, in order to obtain greater information on the distribution and diversity of different taxa and to improve conservation efforts for these species.

## Supplementary material

The following online material is available for this article:

**Appendix 1** - List of plant species recorded in a cloud forest of southwestern Mexico.

**Appendix 2** - List of amphibian and reptile species recorded in a cloud forest of southern Mexico.

**Appendix 3** - List of bird species recorded in a cloud forest of southwestern Mexico.

**Appendix 4** - List of mammal species recorded in a cloud forest of southwestern Mexico.

## Acknowledgments

We are grateful for the biology and ecology undergraduate students of the Universidad Autónoma de Guerrero who provided assistance during field work. We also thank the inhabitants of the communities in our study area who provided hospitality and guidance and who offered their vast knowledge of the local biological resources. This study received funding from the Programa de Conservación de la Biodiversidad por Comunidades Indígenas (COINBIO) and the Comisión Nacional Forestal (CONAFOR).

## Author Contributions

All authors contributed to data collection, manuscript preparation, and critical revision.

R. Carlos Almazán-Núñez: contributed in the design of the study and realized statistical analysis.

Edson A. Álvarez-Álvarez: realized some data analysis.

## Conflicts of interest

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

## References

AGUILAR-LÓPEZ, M., ROJAS-MARTÍNEZ, A.E., CORNEJO- LATORRE, C., VITE-SILVA, V.D. & RUANO-ESCALANTE, Y.R. 2013. Lista taxonómica y estructura del ensamblaje de los mamíferos terrestres del municipio de Tlanchinol, Hidalgo, México. Mastozool. Neotrop. 20(2):229–242.

ALMAZÁN-CATALÁN, J.A., TABOADA-SALGADO, A., SÁNCHEZ-HERNÁNDEZ, C., ROMERO-ALMARÁZ, M.L., JIMÉNEZ-SALMERÓN, Y.Q. & GUERRERO-IBARRA, E. 2009. Registros de murciélagos para el estado de Guerrero, México. Acta Zool. Mex. 25(1):177–185.

ALMAZÁN-CATALÁN, J.A., SÁNCHEZ-HERNÁNDEZ, C., RUÍZ-GUTIÉRREZ, F., ROMERO-ALMARAZ, M.L., TABOADA-SALGADO, A., BELTRÁN-SÁNCHEZ, E. & SÁNCHEZ-VÁZQUEZ, L. 2013. Registros adicionales de felinos del estado de Guerrero, México. Rev. Mex. Biodivers. 84(1):347–359.

ALMAZÁN-NÚÑEZ, R.C., NOVA-MUÑOZ, O. & ALMAZÁN-JUÁREZ, Á. 2007. Avifauna de Petatlán en la Sierra Madre del Sur, Guerrero, México. Univ. Ciencia 23(2):141–149.

ALMAZÁN-NÚÑEZ, R.C., PUEBLA-OLIVARES, F. & ALMAZÁN-JUÁREZ, Á. 2009. Diversidad de aves en bosques de pino-encino del centro de Guerrero, México. Acta Zool. Mex. 25(1):123–142.

ÁLVAREZ, T., ÁLVAREZ-CASTAÑEDA, S.T. & LÓPEZ-VIDAL, J.C. 1994. Claves para murciélagos mexicanos. 1 ed. Centro de Investigaciones Biológicas del Noroeste S.C.-Escuela Nacional de Ciencias Biológicas, La Paz, México.

ÁLVAREZ-ZÚÑIGA, E., SÁNCHEZ-GONZÁLEZ, A., LÓPEZ-MATA, L. & TEJERO-DÍEZ, J.D. 2012. Composición y abundancia de las pteridofitas en el bosque mesófilo de montaña del municipio de Tlanchinol, Hidalgo, México. Bot. Sci. 90(2):163–177.

AMERICAN ORNITHOLOGISTS´ UNION (AOU). 1998. Checklist of North and Middle American birds. 7 ed. American Ornithologists´ Union, Lawrence, Kansas, USA.

ANGIOSPERM PHYLOGENY GROUP (APG IV). (2016). An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. Bot. J Linn. Soc. 181(1):1–20.

ARANDA, M. 2000. Huellas y otros rastros de los mamíferos grandes y medianos de México. CONABIO-Instituto de Ecología, A.C., México, D.F.

ARRIAGA, L., ESPINOZA, J.M. AGUILAR, C. MARTÍNEZ, E. GÓMEZ, L. & LOA, E. 2000. Regiones terrestres prioritarias de México. CONABIO, México, D.F.

ÁVILA-NÁJERA, D.M. 2006. Patrones de distribución de la mastofauna del estado de Guerrero, México. Tesis de licenciatura, Facultad de Ciencias, Universidad Nacional Autónoma de México, México.

CAMPBELL, J.A., BLANCAS-HERNÁNDEZ, J.C. & SMITH, E.N. 2009. A New Species of Stream-breeding Treefrog of the Genus *Charadrahyla* (Hylidae) from the Sierra Madre del Sur of Guerrero, Mexico. Copeia 2009(2):287–295.

CASAS-ANDREU, G., MÉNDEZ DE LA CRUZ, F.R. & CAMARILLO, J.L. 1996. Anfibios y reptiles de Oaxaca. Lista, distribución y conservación. Acta Zool. Mex. 69:1–35.

CASAS, G.A. & MCCOY, C.J. 1987. Anfibios y reptiles de México: claves ilustradas para su identificación. Editorial Limusa, México, D.F.

CATALÁN-HEVERÁSTICO, C., LÓPEZ-MATA, L. & TERRAZAS, T. 2003 Estructura, composición florística y diversidad de especies leñosas de un bosque mesófilo de montaña de Guerrero, México. Anales Inst. Biol. Univ. Nac. Autón. México, Ser. Bot. 74(2):209–230.

CHALLENGER, A. 1998. Utilización y conservación de los ecosistemas terrestres de México: pasado, presente y futuro. CONABIO-Instituto de Biología, UNAM-Agrupación Sierra Madre, México, D.F.

CHESSER, R.T., BURNS, K.J., CICERO, C., DUNN, J.L., KRATTER, A.W., LOVETTE, I.J., RASMUSSEN, P.C., REMSEN Jr., J.V. RISING, J.D., STOTZ, D.F. & WINKER, K. 2017. Fifty-eighth supplement to the American Ornithological Society's check-list of North American birds. Auk 134(3):751–773.

ESPINOSA, D., OCEGUEDA-CRUZ, S. & LUNA-VEGA, I. 2016. Introducción al estudio de la biodiversidad de la Sierra Madre del Sur: una visión general. In Biodiversidad de la Sierra Madre del Sur: una síntesis preliminar (I. Luna-Vega, D. Espinosa & R. Contreras-Medina, eds.). UNAM, Ciudad de México, D.F., p. 23–36.

FERRUSQUÍA, I. 1998. Geología de México: una sinopsis. In Diversidad biológica de México: orígenes y distribución (T.P. Ramamoorthy, R. Bye, A. Lot & J. Fa, eds.). Instituto de Biología, UNAM, México, D.F., p. 3–108.

FLORES-VILLELA, O., MENDOZA-QUIJANO, F. & GONZÁLEZ-PORTER, G. 1995. Recopilación de claves para la identificación de anfibios y reptiles de México. Publicaciones Especiales del Museo de Zoología, Facultad de Ciencias, UNAM, México, D.F.

FLORES-VILLELA, O. & GARCÍA-VÁZQUEZ, U.O. 2014. Biodiversidad de reptiles en México. Rev. Mex. Biodivers. 85:467–475.

FLORES-VILLELA, O. & OCHOA-OCHOA, L. 2016. Estado de conocimiento y conservación de la herpetofauna de la Sierra Madre del Sur. In Biodiversidad de la Sierra Madre del Sur: una síntesis preliminar (I. Luna-Vega, D. Espinosa & R. Contreras-Medina, eds.). UNAM, Ciudad de México, D.F., p. 367–380.

FONSECA, R.M., VELÁZQUEZ, E. & DOMÍNGUEZ, E. 2001. Carrizal de Bravos. Bosque mesófilo de montaña. In Estudios florísticos en Guerrero No. 12 (N. Diego-Pérez & R.M. Fonseca, eds.). Facultad de Ciencias, Universidad Nacional Autónoma de México, México, D.F.

GARCÍA, E. 2004. Modificaciones al Sistema de Clasificación Climática de Köpen. 5 ed. Instituto de Geografía, UNAM, México, D.F.

GARCÍA-FRANCO, J.G., CASTILLO-CAMPOS, G., MEHLTRETER, K., MARTÍNEZ, M.L. & VÁZQUEZ, G. 2008. Composición florística de un bosque mesófilo del centro de Veracruz, México. Bol. Soc. Bot. Mex. 83:37-52.

GARCÍA-TREJO. E.A. & NAVARRO, A.G. 2004. Patrones biogeográficos de la riqueza de especies y el endemismo de la avifauna en el oeste de México. Acta Zool. Mex. 20(2):167–185.

GONZÁLEZ-GARCÍA, F. & GÓMEZ DE SILVA, H. 2003. Especies endémicas: riqueza, patrones de distribución y retos para su conservación. In Conservación de aves: experiencias en México (H. Gómez de Silva & O.A. de Ita, eds.). CIPAMEX-CONABIO-NFWF, México, D.F., p. 150–194.

GONZÁLEZ-RUIZ, N., RAMÍREZ-PULIDO, J. & GUAL-DÍAZ, M. 2014. Mamíferos del bosque mesófilo de montaña en México. In Bosques mesófilos de montaña de México: diversidad, ecología y manejo (M. Gual-Díaz & A. Rendón-Correa, eds.). CONABIO, México, D.F., p. 305–326.

GOTELLI, N.J. & COLWELL, R.K. 2011. Estimating species richness. In Biological diversity: frontiers in measurement and assessment (A.E. Magurran & B.J. McGill, eds.). Oxford University Press, New York, USA, p. 39–54.

GUAL-DÍAZ, M. & MAYER-GOYENECHEA, I.G. 2016. Anfibios en el bosque mesófilo de montaña en México. In Bosques mesófilos de montaña de México: diversidad, ecología y manejo (M. Gual-Díaz & A. Rendón-Correa, comps.). CONABIO, México, D.F., p. 249–261.

GUAL-DÍAZ, M. & RENDÓN-CORREA, A. 2014. Bosques mesófilos de montaña de México: diversidad, ecología y manejo. 1 ed. CONABIO, México, D.F.

GUTIÉRREZ-BLANDO, C., OLGUÍN-MONROY, H.C. & LEÓN-PANIAGUA, L. 2016. Patrones biogeográficos de los mamíferos en la Sierra Madre del Sur. In Biodiversidad de la Sierra Madre del Sur: una síntesis preliminar (I. Luna-Vega, D. Espinosa & R. Contreras-Medina, eds.). UNAM, Ciudad de México, D.F., p. 487–506.

HALL, E.R. 1981. The mammals of North America. 2 ed. Wiley, Chichester, New York, USA.

HANKEN, J., WAKE, D.B. & FREEMAN, H.L. 1999. Three new species of Minute Salamanders (*Thorius*: Plethodontidae) from Guerrero, México, including the report of a novel dental polymorphism in urodeles. Copeia 1999(4): 917–931.

HERNÁNDEZ-BAÑOS, B.E., PETERSON, A.T., NAVARRO-SIGÜENZA, A.G. & ESCALANTE-PLIEGO, B.P. 1995. Bird faunas of the humid montane forest of Mesoamerica: biogeographic patterns and priorities for conservation. Bird Conserv. Int. 5:251–277.

HOWELL, S.N.G. & WEBB, S. 1995. A guide to the birds of Mexico and Northern Central America. Oxford University Press Inc., New York, USA.

INEGI (Instituto Nacional de Estadística, Geografía e Informática). 2010. Página electrónica institucional. www.inegi.org.mx (last access at 02/Sep/2017).

JIMÉNEZ-ALMARAZ, T. JUÁREZ-GÓMEZ, J. & LEÓN-PANIAGUA, L. 1993. Mamíferos. In Historia Natural del Parque Ecológico Estatal Omiltemi, Chilpancingo, Guerrero (I.V. Luna & J.B. Llorente, eds.). CONABIO-UNAM, México, D.F., p. 503–549.

LEÓN-PANIAGUA, L. & ROMO-VÁZQUEZ, E. 1993. Mastofauna de la Sierra de Taxco, Guerrero. In Avances en el estudio de los mamíferos de México (R.A. Medellín & G. Ceballos, eds.). Asociación Mexicana de Mastozoología A.C., México, D.F., p. 45–64.

LOZADA-PÉREZ, L., LEÓN, M.E., ROJAS, J. & DE SANTIAGO, R. 2003. Bosque mesófilo de montaña en El Molote. In Estudios florísticos en Guerrero No. 13 (N. Diego-Pérez, & R.M. Fonseca, eds.). Facultad de Ciencias, Universidad Nacional Autónoma de México, México, D.F.

LUNA-VEGA, I., ESPINOSA, D. & CONTRERAS-MEDINA, R. 2016. Biodiversidad de la Sierra Madre del Sur: una síntesis preliminar. 1 ed. UNAM, Ciudad de México.

MARTÍNEZ-MEYER, E., SOSA-ESCALANTE, J.E. & ÁLVAREZ, F. 2014. El estudio de la biodiversidad en México: ¿una ruta con dirección? Rev. Mex. Biodivers. 85:1–9.

MARTÍNEZ-MORALES, M.A. 2007. Avifauna del bosque mesófilo de montaña del noreste de Hidalgo, México. Rev. Mex. Biodivers. 78:149–162.

MAYER-GOYENECHEA, I.G. & GUAL-DÍAZ, M. 2016. Reptiles en el bosque mesófilo de montaña en México. In Bosques mesófilos de montaña de México: diversidad, ecología y manejo (M. Gual-Díaz & A. Rendón-Correa, comps.). CONABIO, México, D.F., p. 263–267.

MEDELLÍN, R.A., ARITA H.T. & SÁNCHEZ, O.H. 1997. Identificación de los murciélagos de México: clave de campo. Asociación Mexicana de Mastozoología A.C., México, D.F.

MITTERMEIER, R.A. & GOETTSCH DE MITTERMEIER, C. 1992. La importancia de la diversidad biológica de México. In México ante los retos de la biodiversidad (J. Sarukhán & R. Dirzo, eds.). CONABIO, México, D.F., p. 63-73.

NATIONAL GEOGRAPHIC SOCIETY. 1999. Field guide to the birds of North America. National Geographic Society, Washington, D.C., USA.

NAVARRO, A.G. 1998. Distribución geográfica y ecológica de la avifauna del estado de Guerrero, México. Tesis de doctorado, Facultad de Ciencias, Universidad Nacional Autónoma de México. México, D.F.

NAVARRO-SIGÜENZA, A.G., REBÓN-GALLARDO, M.F., GORDILLO-MARTÍNEZ, A., PETERSON, A.T., BERLANGA-GARCÍA, H. & SÁNCHEZ-GONZÁLEZ, L.A. 2014. Biodiversidad de aves en México. Rev. Mex. Biodivers. 85:476–495.

NAVARRO-SIGÜENZA, A.G., BLANCAS-CALVA, E., ALMAZÁN-NÚÑEZ, R.C., HERNÁNDEZ-BAÑOS, B.E., GARCÍA-TREJO, E.A. & PETERSON, A.T. 2016. Diversidad y endemismo de las aves de la Sierra Madre del Sur. In Biodiversidad de la Sierra Madre del Sur: una síntesis preliminar (I. Luna-Vega, D. Espinosa & R. Contreras-Medina, eds.). UNAM, Ciudad de México, D.F., p. 381–411.

NAVARRO-SIGÜENZA, A.G. & PETERSON, T. 2004. An alternative species taxonomy of the birds of Mexico. Biota Neotropica. 4(2):1–32. http://dx.doi.org/10.1590/S1676-06032004000200001 (last access on 24/12/2017).

OCHOA-OCHOA, L.M. & FLORES-VILLELA, O.A. 2006. Áreas de diversidad y endemismo de la herpetofauna mexicana. UNAM-CONABIO, México, D.F.

OKSANEN, J., BLANCHET, F.G., FRIENDLY, M., KINDT, R., LEGENDRE, P., MCGLINN, D., MINCHIN, P.R., O'HARA, R.B., SIMPSON, G.L., SOLYMOS, P., STEVENS, M.H.H., SZOECS, E. & WAGNER, H. 2017. Vegan: community ecology package. Version 2.4-3. https://cran.r-project.org/web/packages/vegan/vegan.pdf (last access at 02/September/2017).

PARRA-OLEA, G., FLORES-VILLELA, O. & MENDOZA-ALMERALLA, C. 2014. Biodiversidad de anfibios en México. Rev. Mex. Biodivers. 85: 460–466.

PÉREZ-RAMOS, E. DE LA RIVA, L.S. & URIBE-PEÑA, Z. 2000. A checklist of the reptiles and amphibians of Guerrero, Mexico. An. Inst. Biol., Serie Zoología 71(1):21–40.

PETERSON, A.T., CANSECO, L., CONTRERAS, J.L., ESCALONA-SEGURA, G., FLORES-VILLELA, O., GARCÍA-LÓPEZ J., HERNÁNDEZ-BAÑOS, B., JIMÉNEZ RUIZ, C.A., LEÓN-PANIAGUA, L., MENDOZA-AMARO, S., NAVARRO-SIGÜENZA, A.G., SÁNCHEZ-CORDERO, V. & WILLARD, D.E. 2004. A preliminary biological survey of Cerro Piedra Larga, Oaxaca, Mexico: birds, mammals, reptiles, amphibians, and plants. An. Inst. Biol., Serie Zoologia 75(2):439–466.

PLASCENCIA, R.L., CASTAÑÓN, B.A. & RAZ-GÚZMAN, A. 2011. La biodiversidad en México su conservación y las colecciones biológicas. Ciencias 101:36–43.

RAMÍREZ-PULIDO, J., GONZÁLEZ-RUIZ, N., GARDNER, A.L. & ARROYO-CABRALES, J. 2014. List of recent land mammals of Mexico. Special publications museum of Texas Tech University, Lubbock, Texas, USA.

RAMMAMORTHY, T.R., BYE, R., LOT, A. & FA, J. 1998. Diversidad Biológica de México: orígenes y distribución. Instituto de Biología, UNAM, México.

R DEVELOPMENT CORE TEAM. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. www.r-project.org (last access at 02/Sep/2017).

RUEDA-HERNANDEZ, R., MACGREGOR-FORS, I. & RENTON, K. 2015. Shifts in resident bird communities associated with cloud forest patch size in Central Veracruz, Mexico. Avian Conserv. Ecol. 10(2):2.

RUIZ-GUTIÉRREZ, F. 2012. Situación actual y conservación de los felinos silvestres (Carnivora: Felidae) y sus presas en la sierra del municipio de Petatlán, estado de Guerrero, México. Tesis de maestría, Instituto de Ciencias Básicas e Ingeniería, Universidad Autónoma del Estado de Hidalgo, Hidalgo, México.

SEMARNAT (Secretaría de Medio Ambiente y Recursos Naturales). 2010. Norma Oficial Mexicana NOM-059-SEMARNAT-2010, Protección ambiental-Especies nativas de México de flora y fauna silvestres, Categoría de riesgo y especificaciones para su inclusión, exclusión o cambio-Lista de especies en riesgo. Diario Oficial de la Federación, Diciembre 30, 2010. Ciudad de México, México. http://www.profepa.gob.mx/innovaportal/file/435/1/NOM_059_SEMARNAT_2010.pdf (last access at 01/Sep/2017).

SIBLEY, D.A. 2000. The Sibley guide to birds. 1 ed. Alfred a Knopf Inc, New York, USA.

VILLASEÑOR, J.L. 2010. El bosque húmedo de montaña en México y sus plantas vasculares: catálogo florístico-taxonómico. 1 ed. CONABIO-UNAM, México, D.F.

VILLASEÑOR, J.L. 2016. Checklist of the native vascular plants of Mexico. Rev. Mex. Biodivers. 87(3):559–902.

WATSON, A.T. & PETERSON, D.M. 1999. Determinants of diversity in a naturally fragmented landscape: humid montane forest avifaunas of Mesoamerica. Ecography 22:582–589.

WEARN, J.A., CHASE, M.W., MABBERLEY, D.J. & COUCH, C. 2013. Utilizing a phylogenetic plant classification for systematic arrangements in botanic gardens and herbaria. Bot. J Linn. Soc. 172(2):127–141.

WENDT, T. 1986. Árboles. In Manual de herbario: administración y manejo de colecciones, técnicas de recolección y preparación de ejemplares botánicos (A. Lot & F. Chiang, comps.). Consejo Nacional de la Flora de México A.C., México, D.F., p. 133–142.

W3Tropicos. 2010. Missouri Botanical Garden's VAST nomenclatural database and associated authority files. http://www.tropicos.org/ (last access at 01/Sep/2017).

*Received: 12/09/2017*
*Revised: 12/01/2018*
*Accepted: 25/02/2018*
*Published online: 12/04/2018*

# Erratum: Biological survey of a cloud forest in southwestern Mexico: plants, amphibians, reptiles, birds, and mammals

In the article "*Biological survey of a cloud forest in southwestern Mexico: plants, amphibians, reptiles, birds, and mammals*" with DOI code number http://dx.doi.org/10.1590/1676-0611-bn-2017-0444 published at Biota Neotropica 18(2): e20170444,

| Where you read: | Should be read: |
|---|---|
| (...) and four threatened species (e.g., *Boa imperator*, *Thamnophis godmani*, and *Trimorphodon quadruplex*; Figure 2, Appendix 2). | (...) and four threatened species (e.g., *Boa sigma*, *Thamnophis godmani*, and *Trimorphodon biscutatus*; Figure 2, Appendix 2). |
| In particular, *Carpinus caroliniana*, *Eupherusa poliocerca*, *Herpailurus yagouaroundi*, and *Trimorphodon quadruplex* are threatened (...). | In particular, *Carpinus caroliniana*, *Eupherusa poliocerca*, *Herpailurus yagouaroundi*, and *Trimorphodon biscutatus* are threatened (...). |

And in the "*Appendix 2 - List of amphibian and reptile species recorded in a cloud forest of southern Mexico*",

| Where you read: | Should be read: |
|---|---|
| *Dryophytes eximius* | *Dryophytes arboricola* |
| *Plectrohyla bistincta* | *Sarcohyla bistincta* |
| *Plectrohyla pentheter* | *Sarcohyla pentheter* |
| *Marisora unimarginata* | *Marisora brachypoda* |
| *Boa imperator* | *Boa sigma* |
| *Trimorphodon quadruplex* | *Trimorphodon biscutatus* |
| *Geophis sieboldi* | *Geophis occabus* |

Biota Neotropica 18(2): e20170385, 2018
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
**Article**

# Ichthyofauna of the inner shelf of Paraná, Brazil: checklist, geographic distribution, economic importance and conservation status

*Daphne Spier[1]*, Humberto Luiz Nadolny Gerum[5], Hugo Bornatowski[1], Riguel Contente[2], Natalia A S Mattos[3], Ciro C Vilar[4] & Henry Louis Spach[1]*

*[1]Universidade Federal do Paraná, Centro de Estudos do Mar, Programa de Pós-Graduação em Sistemas Costeiros e Oceânicos, Pontal do Paraná, PR, Brasil*
*[2]Instituto Federal do Pará, Campus Marabá Industrial, Marabá, PA, Brasil*
*[3]Universidade de São Paulo, Escola de Artes, Ciências e Humanidades, São Paulo, SP, Brasil*
*[4]Universidade Federal do Espírito Santo, Departamento de Oceanografia e Ecologia, Vitória, ES, Brasil*
*[5]Associação de Pescadores e Aquicultores de Pontal do Sul, Pontal do Paraná, PR, Brasil*
**Corresponding author: Daphne Spier, e-mail: daphnespier@gmail.com*

SPIER, D., GERUM, H. L. N., BORNATOWSKI, H., CONTENTE, R., MATTOS, N. A. S., VILAR, C. C., SPACH, H. L. **Ichthyofauna of the inner shelf of Paraná, Brazil: checklist, geographic distribution, economic importance and conservation status**. Biota Neotropica. 18(2) e20170385. http://dx.doi.org/10.1590/1676-0611-BN-2017-0385

***Abstract***: Comprehensive species checklists are essential to effectively implementing preservation and recovery measures, and should assess conservation status, vulnerability degree and anthropogenic threats. This checklist was compiled from fish species recorded in surveys conducted over the last 30 years in the shallow inner continental shelf in the State of Paraná, Brazil. Information on biogeography, conservation status, economic importance and degree of species' vulnerability are provided. A total of 272 fish species were recorded, spanning 25 orders and 88 families. The most speciose family was Sciaenidae (25 species), followed by Carangidae (23), Engraulidae (10), Carcharhinidae (9), Epinephelidae (9) and Paralichthyidae (9). Most species occurring in Paraná's shallow inner continental shelf are restricted to the West Atlantic. In terms of economic importance, 93% (253) of the species recorded were of fishery, aquaculture or aquaria interest. A notable fraction (39%) of the recorded species was classified as having moderate to very high vulnerability to extinction. In particular, 28 species (10%) were listed as globally endangered, and 34 species (12%) were listed as endangered in the Brazilian territory.

***Keywords:*** *fish assemblage, species list, Southwest Atlantic, vulnerability*

# Ictiofauna da plataforma interna do Paraná, Brasil: checklist, distribuição geográfica, importância econômica e estado de conservação

***Resumo***: Listas abrangentes de espécies são essenciais para a implementação efetiva de medidas de preservação e devem avaliar o estado de conservação e o grau de vulnerabilidade das comunidades ecológicas. Esta lista foi compilada a partir de espécies de peixes registradas em pesquisas realizadas nos últimos 30 anos na plataforma continental interna rasa do Estado do Paraná. Foram fornecidas informações sobre biogeografia, estado de conservação, importância econômica e grau de vulnerabilidade das espécies. Um total de 272 espécies de peixes foram registradas, abrangendo 25 ordens e 88 famílias. A família com maior número de espécies foi Sciaenidae (25 espécies), seguida de Carangidae (23), Engraulidae (10), Carcharhinidae (9), Epinephelidae (9) e Paralichthyidae (9). A maioria das espécies registrada na plataforma continental interna do Paraná está limitada ao Atlântico Oeste. Em termos de importância econômica, 93% (253) das espécies incluídas nesta lista são comercialmente viáveis, seja na pesca, aquicultura ou aquariofilia. Uma fração notável (39%) das espécies registradas foi classificada como de vulnerabilidade moderada a muito alta. Em particular, 28 espécies (10%) estão listadas como ameaçadas de extinção em escala global, e 34 espécies (12%) estão listadas como ameaçadas de extinção no território brasileiro.

***Palavras-chave:*** *assembleia de peixes, lista de espécies, Atlântico Sudoeste, vulnerabilidade.*

## Introduction

The State of Paraná, in southern Brazil, has a 98 km long coastline, and is cut by two large estuarine complexes, namely, the Paranaguá Bay to the north and the Guaratuba Bay to the south. Its continental shelf extends from 175 to 190 km offshore, and is dominated by sandy bottoms, and a few rocky substrates (Brandini 2014).

Paraná's continental shelf harbors a rich fauna, particularly in its inner region which is nutrient enriched by the continental drainage system. Like the estuaries, the inner shelf functions as habitat for reproduction and development of many fish species; therefore, it performs a vital role in their life cycles (Blaber 2000). In addition, the continental shelf contains several fish species of commercial importance.

There have been several studies on the fish fauna in the Paranaguá Estuarine Complex (Hackradt et al. 2009; Félix-Hackradt et al. 2010; Ignácio & Spach 2010; Contente et al. 2011; Passos et al. 2012; Pichler et al. 2015, 2017; Possatto et al. 2017) and in the Guaratuba Bay (Chaves & Corrêa 1998; Chaves & Vendel 2001). On the other hand, few studies have focused on the continental shelf region, especially those assessing the taxonomic composition of the ichthyofauna (Santos 2006; Carniel 2008; Schwarz-Junior 2010). Of concern is the threat to the region's fish biodiversity, most notably due to overfishing, deposition of dredged sediments, habitat loss, and deployment of new habitats, such as artificial reefs, whose impact on biodiversity is not yet fully understood. In this study, we have compiled a checklist of fish species inhabiting the shallow inner continental shelf of Paraná. Considerations about geographic distribution, conservation status, economic importance, and degree of vulnerability to extinction are provided. This checklist compiles useful information in a single document that should be of great help in devising measures of preservation and species recovery.

## Material and Methods

Data on fish species inhabiting the inner continental shelf of the State of Paraná were compiled from the peer-reviewed literature (Corrêa et al. 1986; Chaves et al. 2003; Godefroid et al. 2004; Costa & Chaves 2006; Gomes & Chaves 2006; Santos et al. 2006; Félix et al. 2007a; Félix et al. 2007b; Bornatowski et al. 2009; Hackradt & Hackradt 2009; Hackradt et al. 2011; Daros et al. 2012; Bornatowski et al. 2014a; Bornatowski et al. 2014b; Rossi-Wongtschowski et al. 2014, Santos et al. 2016) as well as less accessible academic literature (Santos 2006 and Carniel 2008 - master thesis; Schwarz-Junior 2010 and Spier 2016 - PhD thesis) published over the past 30 years. The full extent of Paraná's shallow inner continental shelf was sampled down to the 20 m isobath, including areas near the mouth of the Paranaguá Estuarine Complex and the Guaratuba Bay (Figure 1). Overall, gillnetting, trawling, and underwater visual census were the main sampling methods used in the studies compiled in this work. Further details on sampling methods and sampling areas are provided in Table 1. The taxonomic classification and nomenclature follows Marceniuk (2005), Craig & Hastings (2007), Smith & Craig (2007), Figueiredo & Menezes (2009), Carvalho-Filho et al. (2010), Menezes et al. (2010) and Eschmeyer et al. (2014). Orders and families are listed according to

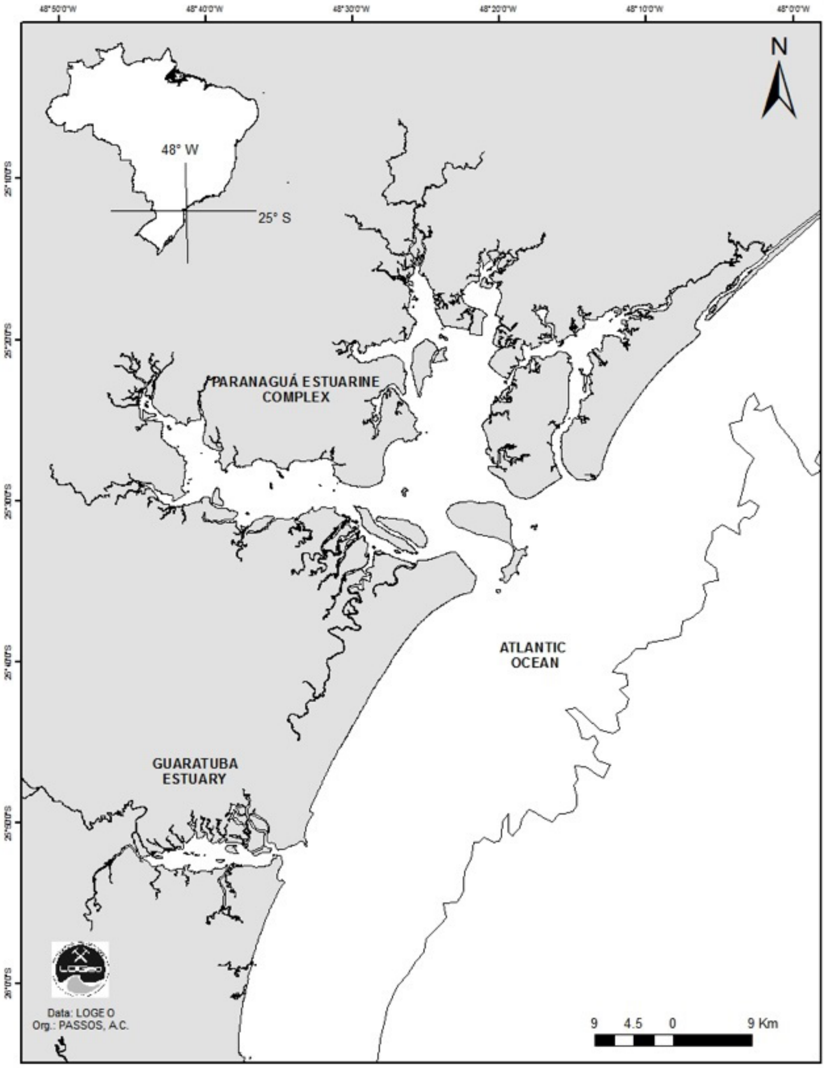

**Figure 1.** Map of the shallow inner continental shelf of Paraná, Brazil, showing the Paranaguá Estuarine Complex and the Guaratuba estuary. The contour represents the 20-meter isobath.

**Table 1.** Details on methods and sampling areas of the different sources consulted. "x"indicates absence of depth data.

| Source | Site | Year | Methods | Isobath |
|---|---|---|---|---|
| Corrêa et al. (1986) | Coasts of Matinhos, Pontal do Sul, Caiobá e Mel island | until 1986 (since 1942) | Museum collections | x |
| Chaves et al. (2003) | Matinhos shelf | March 1999 to January 2000 | Bottom trawl nets (mesh of 2.5 cm) | 10 and 15 m |
| Godefroid et al. (2004) | Shallow infralittoral of Atami Beach (25°30'S; 48°15'W) | July 1998 to June 1999 | Bottom trawl nets (mesh of 1 cm) | 8 and 12 m |
| Costa & Chaves (2006) | Paraná Continental Shelf | July 2001 to March 2003 | Trawling and gillnet | 8 to 20 m |
| Gomes & Chaves (2006) | 2 km from the Guaratuba coast (25°52'S/48°39'W to 25°59'S/48°36'W) | April 2001 to March 2002 | Bottom trawl nets (mesh of 3 cm) | 10 m |
| Santos (2006) | Paraná Continental Shelf (25°26'S to 25°40'S / 48°08'W to 48°26'W) | August 2000 to July 2001 | Bottom trawl nets (mesh of 3 cm) | 6 to 17 m |
| Felix et al. (2007) | Next to the entrance of Paranaguá Bay / Pontal do Sul beach | June 2004 to May 2005 | Beach seine net, 15 m long and 2.6 m height - mesh size of 5 mm. | 2 m |
| Carniel (2008) | Paraná Continental Shelf | 2005 and 2006 | Trawling and gillnet | 8 to 20 m |
| Bornatowski et al. (2009) | PR | until 2009 | Museum/Literature/ field surveys | x |
| Hackradt & Hackradt (2009) | Currais (25°44' S, 48°22' W), Itacolomis (25°50' S, 48°24' W) and Artificial Reefs between these two islands | November 2006 to July 2007 | Underwater visual census (SCUBA) | 6 to 20 m |
| Schwarz-Junior (2009) | Paraná Continental Shelf | August 2004 to July 2005 | Bottom trawl nets (mesh of 2.5 cm) | 6, 9, 12 and 15 m |
| Hackradt et al. (2011) | Currais (25°44' S, 48°22' W), Itacolomis (25°50' S, 48°24' W) and Artificial Reefs between these two islands | January 2006 to March 2006 | Underwater visual census (SCUBA) | 6 to 20 m |
| Daros et al. (2012) | Currais Archipelago (25°44' S, 48°22' W) and Itacolomis Island (25°50' S, 48°24' W) | October 2008 to August 2009 | Underwater visual census (SCUBA) | 3 to 9 m |
| Bornatowski et al. (2014a) | 20 km from the coast | April 2010 to March 2012 | Gillnet of 7, 9, 11, 16, 18 and 45 cm mesh-size | 20 m |
| Bornatowski et al. (2014b) | Itacolomis Island (15 km from the coast) | September 2011 | Gillnet of 9 cm mesh-size | 10 and 12 m |
| Rossi-Wongtschowski et al. (2014) | Paraná Continental Shelf | 1995 to 2010 | Mid-water trawl nets (mesh of 4 cm) | 18 to 145 m |
| Santos et al. (2016) | Paraná Continental Shelf (25°20'S to 25°50'S / 48°08'W to 48°26'W) | August 2000 to July 2001 and August 2004 and July 2005 | Bottom trawl nets (mesh of 3 cm) | 6, 9, 12 and 15 m |
| Spier (2016) | Islands (Currais, Figueira, Galheta) | 2012 to 2016 | Underwater visual census (free dive) | 3 to 16 m |

phylogenetic order (Eschmeyer et al. 2014) and the species inside each family are organized in alphabetical order.

To analyze the zoogeographic affinities of the fauna, the species were classified in geographic distribution categories based on Floeter et al. (2008), Luiz Jr et al. (2008), Eschmeyer et al. (2014) and Froese & Pauly (2017). The categories were: CT = Circumtropical, TA = Trans-Atlantic (Western and Eastern Atlantic Ocean), WA = Western Atlantic (Northern and Southern Atlantic Ocean), SWA = Southwest Atlantic (ranging from Northern Brazil to Argentina), SSWA = Southern Southwest Atlantic (Southeastern and Southern Brazil, Uruguay and Argentina), Ca = Caribbean (ranging from Florida to Venezuela), Br = Brazilian Province [ranging from the Orinoco River Delta in Venezuela to the State of Santa Catarina in Brazil (*sensu* Briggs & Bowen 2012)], and EP = Eastern Pacific.

Regarding species' economic importance in Brazil, we defined four categories, namely, 1) food: referring to human consumption, 2) animal feed, 3) aquarium, and 4) none: referring to species without any identified commercial purpose. Categories 1, 2, and 4 were implemented based on the work of Menezes et al. (2003); Figueiredo & Menezes (2009); Froese & Pauly (2017), as well as on the authors' previous knowledge. Category 3 was implemented based on the technical and scientific bulletin of CEPENE (2005), which lists marine fish species allowed for capture in Brazil. Furthermore, we also indicate which species have economic importance specifically for the State of Paraná, based on the authors' knowledge.

Vulnerability to extinction was categorized as *low, low to moderate, moderate, moderate to high, high, high to very high,* and *very high,* following FishBase (Froese & Pauly 2017). These categories were determined based on the life history and ecological characteristics of each species (Cheung et al. 2005). Species were also classified according to the IUCN categories (IUCN 2017) and the national status of conservation proposed by the Brazilian Ministry of Environment (MMA 2014). Conservation status and vulnerability to extinction provide a rough assessment of species' endangerment.

## Results

A total of 272 fish species (234 Actinopterygii and 38 Elasmobranchii) distributed over 25 orders and 88 families were recorded in the shallow inner continental shelf of Paraná (Table 2). The order richest in species was Perciformes (146), followed by Pleuronectiformes (18), Rajiformes (18), Clupeiformes (16) and Carcharhiniformes (15). Sciaenidae was the richest family with 25 species, followed by Carangidae (23), Engraulidae (10), Paralichthyidae (9), Epinephelidae (9) and Carcharhinidae (9).

**Table 2.** Taxonomic classification of the ichthyofauna recorded in the shallow inner shelf of Paraná, Brazil. Geographic Distribution: CT = Circuntropical, TA = Trans-Atlantic, WA = Western Atlantic, SWA = Southern West Atlantic, SSWA = Southern Southwest Atlantic, Ca = Caribbean, Br = Brazilian Province and EP = Eastern Pacific. Global conservation status according to IUCN (2010) and national conservation status according to MMA (2014): NE= not evaluated, LC= least concern, NT = near threatened, DD = data deficient, VU = vulnerable, EN= endangered, CR = critically endangered. Economic importance in Brazil. Asterisk indicate which species have economic importance specifically for the State of Paraná.

| Orders/Families/Species | Geographic Distribution | Economic Importance | Vulnerability FishBase | Conservation status MMA - 445 | Conservation status IUCN | Source |
|---|---|---|---|---|---|---|
| **Orectolobiformes** | | | | | | |
| **Rhincodontidae** | | | | | | |
| *Rhincodon typus* Smith, 1828 | Ta+EP | No | very high | VU | EN | Bornatowski et al. (2009); Spier (2016) |
| **Carcharhiniformes** | | | | | | |
| **Triakidae** | | | | | | |
| *Mustelus canis* (Mitchill, 1815) | WA | food* | very high | EN | NT | Bornatowski et al. (2009) |
| *Mustelus schmitti* Springer, 1939 | SSWA | food* | high | CR | EN | Corrêa et al. (1986); Bornatowski et al. (2009) |
| **Carcharhinidae** | | | | | | |
| *Carcharhinus brevipinna* (Müller & Henle, 1839) | CT | food* | high | DD | NT | Bornatowski et al. (2009) |
| *Carcharhinus falciformis* (Müller & Henle, 1839) | CT | food* | high | NT | NT | Costa & Chaves (2006); Bornatowski et al. (2009) |
| *Carcharhinus limbatus* (Müller & Henle, 1839) | CT | food* | high | NT | NT | Bornatowski et al. (2009);<br>Bornatowski et al. (2014a) |
| *Carcharhinus plumbeus* (Nardo, 1827) | CT | food* | very high | CR | VU | Bornatowski et al. (2009) |
| *Carcharhinus porosus* (Ranzani, 1839) | WA+EP | food* | very high | CR | DD | Corrêa et al. (1986); Bornatowski et al. (2009) |
| *Carcharhinus obscurus* (Lesueur, 1818) | CT | food* | very high | EN | VU | Bornatowski et al. (2009),<br>Bornatowski et al. (2014a) |
| *Galeocerdo cuvier* (Péron & Lesueur, 1822) | CT | food* | high | NT | NT | Costa & Chaves (2006); Bornatowski et al. (2009); Bornatowski et al. (2014a) |
| *Rhizoprionodon lalandii* (Müller & Henle, 1839) | Ca+SSWA+Br | food* | moderate | NT | DD | Costa & Chaves (2006); Bornatowski et al. (2009); Bornatowski et al. (2014a) |
| *Rhizoprionodon porosus* (Poey, 1861) | Ca+SSWA+Br | food* | moderate to high | DD | LC | Costa & Chaves (2006); Bornatowski et al. (2009) |
| **Scyliorhinidae** | | | | | | |
| *Schroederichthys bivius* (Müller & Henle, 1838) | SSWA+Br+EP | animal feed | moderate to high | - | DD | Bornatowski et al. (2014b) |
| **Sphyrnidae** | | | | | | |
| *Sphyrna lewini* (Griffith & Smith, 1834) | CT | food* | very high | CR | EN | Costa & Chaves (2006); Santos (2006); Bornatowski et al. (2009); Bornatowski et al. (2014a); Santos et al. (2016) |
| *Sphyrna tiburo* (Linnaeus, 1758) | WA+EP | food* | moderate to high | CR | LC | Bornatowski et al. (2009) |
| *Sphyrna zygaena* (Linnaeus, 1758) | CT | food* | very high | CR | VU | Costa & Chaves (2006); Bornatowski et al. (2009); Bornatowski et al. (2014a) |
| **Lamniformes** | | | | | | |
| **Odontaspididae** | | | | | | |
| *Carcharias taurus* Rafinesque, 1810 | CT | food* | high | CR | VU | Bornatowski et al. (2009) |
| **Squaliformes** | | | | | | |
| **Squalidae** | | | | | | |
| *Squalus acanthias* Linnaeus, 1758 | CT | food* | high to very high | CR | VU | Bornatowski et al. (2009) |
| **Squatiniformes** | | | | | | |
| **Squatinidae** | | | | | | |
| *Squatina guggenheim* Marini, 1936 | SWA | food* | high | CR | EN | Costa & Chaves (2006); Bornatowski et al. (2009) |
| *Squatina occulta* Vooren & da Silva, 1992 | SWA | food* | high to very high | CR | EN | Bornatowski et al. (2009) |

**Table 2.** Continued...

| Orders/Families/Species | Geographic Distribution | Economic Importance | Vulnerability FishBase | Conservation status MMA - 445 | Conservation status IUCN | Source |
|---|---|---|---|---|---|---|
| **Rajiformes** | | | | | | |
| **Rhinobatidae** | | | | | | |
| *Pseudobatos horkelii* Müller & Henle, 1841 | SWA | food* | high to very high | CR | CR | Chaves et al. (2003); Bornatowski et al. (2009) |
| *Pseudobatos percellens* (Walbaum, 1792) | TA | food* | high | DD | NT | Chaves et al. (2003); Costa & Chaves (2006); Santos (2006); Carniel (2008); Bornatowski et al. (2009); Hackradt & Hackradt (2009); Schwarz-Junior (2009); Santos et al. (2016); Spier (2016) |
| *Zapteryx brevirostris* (Müller & Henle, 1841) | SWA | food* | moderate | VU | VU | Chaves et al. (2003); Costa & Chaves (2006); Santos (2006); Carniel (2008); Bornatowski et al. (2009); Schwarz-Junior (2009); Santos et al. (2016) |
| **Narcinidae** | | | | | | |
| *Narcine brasiliensis* (Olfers, 1831) | WA | No | low to moderate | DD | DD | Chaves et al. (2003); Godefroid et al. (2004); Costa & Chaves (2006); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Bornatowski et al. (2009); Schwarz-Junior (2009); Santos et al. (2016) |
| **Arhynchobatidae** | | | | | | |
| *Atlantoraja castelnaui* (Miranda Ribeiro, 1907) | SWA | food | very high | EN | EN | Bornatowski et al. (2009) |
| *Atlantoraja cyclophora* (Regan, 1903) | WA | food | high | NT | VU | Bornatowski et al. (2009) |
| *Atlantoraja platana* (Günther, 1880) | SWA | food | high | DD | VU | Bornatowski et al. (2009) |
| *Rioraja agassizii* (Müller & Henle, 1841) | SSWA | food* | high to very high | EN | VU | Costa & Chaves (2006); Bornatowski et al. (2009) |
| **Dasyatidae** | | | | | | |
| *Hypanus americanus* Hildebrand & Schroeder, 1928 | WA | food* | very high | DD | DD | Costa & Chaves (2006); Bornatowski et al. (2009) |
| *Hypanus guttatus* (Bloch & Schneider, 1801) | Ca+Br | food* | very high | - | DD | Costa & Chaves (2006); Bornatowski et al. (2009); Schwarz-Junior (2009); Santos et al. (2016); Spier (2016) |
| *Dasyatis hypostigma* Santos & Carvalho, 2004 | SWA | food* | high to very high | DD | DD | Costa & Chaves (2006); Bornatowski et al. (2009); Spier (2016) |
| **Gymnuridae** | | | | | | |
| *Gymnura altavela* (Linnaeus, 1758) | TA | food* | moderate to high | CR | VU | Costa & Chaves (2006); Santos (2006); Bornatowski et al. (2009); Santos et al. (2016); Spier (2016) |
| **Myliobatidae** | | | | | | |
| *Aetobatus narinari* (Euphrasen, 1790) | CT | food* | high to very high | DD | NT | Bornatowski et al. (2009); Hackradt & Hackradt (2009); Daros et al. (2012); Spier (2016) |
| *Mobula birostris* (Walbaum, 1792) | CT | No | very high | VU | VU | Bornatowski et al. (2009); Hackradt & Hackradt (2009); Spier (2016) |
| *Mobula hypostoma* (Bancroft, 1831) | WA | No | high | VU | DD | Bornatowski et al. (2009) |
| *Myliobatis goodei* Garman, 1885 | CT | food* | moderate to high | CR | DD | Costa & Chaves (2006); Bornatowski et al. (2009) |
| **Rhinopteridae** | | | | | | |
| *Rhinoptera bonasus* (Mitchill, 1815) | TA | food* | high | DD | NT | Corrêa et al. (1986); Bornatowski et al. (2009); Schwarz-Junior (2009); Santos et al. (2016) |
| *Rhinoptera brasiliensis* Müller, 1836 | SWA | food* | moderate to high | CR | EN | Bornatowski et al. (2009); Spier (2016) |
| **Elopiformes** | | | | | | |
| **Elopidae** | | | | | | |
| *Elops saurus* Linnaeus, 1766 | WA | animal feed | moderate | - | LC | Carniel (2008); Spier (2016) |

**Table 2.** Continued...

| Orders/Families/Species | Geographic Distribution | Economic Importance | Vulnerability FishBase | Conservation status MMA - 445 | Conservation status IUCN | Source |
|---|---|---|---|---|---|---|
| **Anguilliformes** | | | | | | |
| **Muraenidae** | | | | | | |
| *Gymnothorax funebris* Ranzani, 1839 | WA | aquarium / food | high to very high | DD | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Gymnothorax miliaris* (Kaup, 1856) | TA | aquarium | moderate | - | LC | Spier (2016) |
| *Gymnothorax moringa* (Cuvier, 1829) | WA | aquarium / food | very high | DD | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Gymnothorax ocellatus* Agassiz, 1831 | SWA+Ca | aquarium | high | DD | LC | Santos (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Gymnothorax vicinus* (Castelnau, 1855) | TA | aquarium / food | high | DD | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| **Ophichthidae** | | | | | | |
| *Myrichthys breviceps* (Richardson, 1848) | WA | aquarium | moderate to high | - | LC | Daros et al. (2012); Spier (2016) |
| *Ophichthus gomesii* (Castelnau, 1855) | WA | No | high | - | LC | Gomes & Chaves (2006); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| **Muraenesocidae** | | | | | | |
| *Cynoponticus savanna* (Bancroft, 1831) | Ca+Br | No | high to very high | - | LC | Godefroid et al. (2004) |
| **Clupeiformes** | | | | | | |
| **Clupeidae** | | | | | | |
| *Harengula clupeola* (Cuvier, 1829) | WA | animal feed* | low | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Santos (2006); Felix et al. (2007); Carniel (2008); Hackradt & Hackradt (2009); Schwarz-Junior (2009); Hackradt et al. (2011); Rossi-Wongtschowski et al. (2014); Santos et al. (2016); Spier (2016) |
| *Opisthonema oglinum* (Lesueur, 1818) | WA | food* | low to moderate | - | LC | Corrêa et al. (1986); Felix et al. (2007); Schwarz Junior (2009); Rossi-Wongtschowski et al. (2014); Santos et al. (2016) |
| *Platanichthys platana* (Regan, 1917) | SSWA | animal feed* | low | - | NE | Felix et al. (2007); Schwarz Junior (2009); Santos et al. (2016) |
| *Sardinella brasiliensis* (Steindachner, 1879) | SSWA | food* | low | DD | NE | Godefroid et al. (2004); Santos (2006); Felix et al. (2007); Carniel (2008); Hackradt & Hackradt (2009); Schwarz-Junior (2009); Hackradt et al. (2011); Rossi-Wongtschowski et al. (2014); Santos et al. (2016); Spier (2016) |
| **Engraulidae** | | | | | | |
| *Anchoa filifera* (Fowler, 1915) | Ca+Br | food | low | - | LC | Corrêa et al. (1986); Gomes & Chaves (2006) |
| *Anchoa lyolepis* (Evermann & Marsh, 1900) | WA | food* | low | - | LC | Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Schwarz-Junior (2009); Santos et al. (2016) |
| *Anchoa parva (Meek & Hildebrand 1923)* | WA | food | low | - | LC | Félix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Anchoa spinifer* (Valenciennes, 1848) | Ca+Br+EP | food | low | - | LC | Santos (2006); Carniel(2008); Schwarz Junior (2009); Santos et al. (2016) |
| *Anchoa tricolor* (Spix & Agassiz, 1829) | SWA | food* | low | - | NE | Corrêa et al. (1986); Godefroid et al. (2004); Santos (2006); Felix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Rossi-Wongtschowski et al. (2014); Santos et al. (2016) |

**Table 2.** Continued...

| Orders/Families/Species | Geographic Distribution | Economic Importance | Vulnerability FishBase | Conservation status MMA - 445 | Conservation status IUCN | Source |
|---|---|---|---|---|---|---|
| *Anchovia clupeoides* (Swainson, 1839) | Ca+Br | food | low | - | LC | Carniel (2008); Schwarz Junior (2009); Santos et al. (2016) |
| *Anchoviella lepidentostole* (Fowler, 1911) | Br | food | low | - | LC | Gomes & Chaves (2006); Santos (2006); Santos et al. (2016); Santos et al. (2016); Spier (2016) |
| *Cetengraulis edentulus* (Cuvier, 1829) | Ca+Br | animal feed* | moderate | - | LC | Corrêa et al. (1986); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Engraulis anchoita* Hubbs & Marini, 1935 | SSWA | food | moderate | - | NE | Santos (2006); Rossi-Wongtschowski et al. (2014); Santos et al. (2016) |
| *Lycengraulis grossidens* (Spix & Agassiz, 1829) | SWA | food* | low to moderate | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Rossi-Wongtschowski et al. (2014); Santos et al. (2016) |
| **Pristigasteridae** | | | | | | |
| *Chirocentrodon bleekerianus* (Poey, 1867) | Ca+Br | animal feed | low | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Rossi-Wongtschowski et al. (2014); Santos et al. (2016) |
| *Pellona harroweri* (Fowler, 1917) | Ca+Br | animal feed | low | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Rossi-Wongtschowski et al. (2014); Santos et al. (2016) |
| **Siluriformes** | | | | | | |
| **Ariidae** | | | | | | |
| *Aspistor luniscutis* (Valenciennes, 1840) | Br | food* | low | - | NE | Gomes & Chaves (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Bagre bagre* (Linnaeus, 1766) | Ca+Br | food* | moderate to high | NT | LC | Corrêa et al. (1986); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Bagre marinus* (Mitchill, 1815) | WA | food* | high | - | LC | Carniel (2008) |
| *Cathorops spixii* (Spix & Agassiz, 1829) | Ca+Br | food* | moderate | - | NE | Chaves et al. (2003); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Genidens barbus* (Lacepède, 1803) | SSWA | food* | high | EN | NE | Chaves et al. (2003); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Spier (2016); Santos et al. (2016) |
| *Genidens genidens* (Cuvier, 1829) | SSWA | food* | moderate | - | LC | Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Schwarz-Junior (2009); Santos et al. (2016) |
| *Notarius grandicassis* (Valenciennes, 1840) | Br | food* | moderate to high | - | LC | Schwarz Junior (2009); Santos et al. (2016) |
| **Stomiiformes** | | | | | | |
| **Sternoptychidae** | | | | | | |
| *Maurolicus stehmanni* Parin & Kobyliansky, 1993 | SWA | animal feed | low | - | NE | Rossi-Wongtschowski et al. (2014) |
| **Aulopiformes** | | | | | | |
| **Synodontidae** | | | | | | |
| *Saurida brasiliensis* Norman, 1935 | Ta | animal feed | low | - | LC | Rossi-Wongtschowski et al. (2014) |

**Table 2.** Continued...

| Orders/Families/Species | Geographic Distribution | Economic Importance | Vulnerability FishBase | Conservation status MMA - 445 | Conservation status IUCN | Source |
|---|---|---|---|---|---|---|
| *Synodus foetens* (Linnaeus, 1766) | WA | aquarium | low to moderate | - | LC | Chaves et al. (2003); Santos (2006); Felix et al. (2007); Hackradt & Hackradt (2009); Hackradt et al. (2011); Rossi-Wongtschowski et al. (2014); Santos et al. (2016) |
| *Synodus synodus* (Linnaeus, 1758) | TA | aquarium | low | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012) |
| **Gadiformes** | | | | | | |
| **Bregmacerotidae** | | | | | | |
| *Bregmaceros atlanticus* Goode & Bean, 1886 | CT | No | low | - | LC | Rossi-Wongtschowski et al. (2014) |
| *Bregmaceros cantori* Milliken & Houde, 1984 | Ca+Br | No | low | - | LC | Rossi-Wongtschowski et al. (2014) |
| **Phycidae** | | | | | | |
| *Urophycis brasiliensis* (Kaup, 1858) | SSWA | food* | moderate | NT | NE | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Urophycis mystacea* Miranda Ribeiro, 1903 | SSWA | animal feed | low | NT | NE | Rossi-Wongtschowski et al. (2014) |
| **Merlucciidae** | | | | | | |
| *Merluccius hubbsi* Marini, 1933 | SSWA | food* | high | NT | NE | Rossi-Wongtschowski et al. (2014) |
| **Batrachoidiformes** | | | | | | |
| **Batrachoididae** | | | | | | |
| *Porichthys porosissimus* (Cuvier, 1829) | SSWA | aquarium | moderate | - | NE | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Rossi-Wongtschowski et al. (2014); Santos et al. (2016) |
| **Lophiiformes** | | | | | | |
| **Ogcocephalidae** | | | | | | |
| *Ogcocephalus vespertilio* (Linnaeus, 1758) | SWA+Ca | aquarium | moderate | - | NE | Corrêa et al. (1986); Santos (2006); Hackradt & Hackradt (2009); Schwarz-Junior (2009); Hackradt et al. (2011); Santos et al. (2016) |
| **Gobiesociformes** | | | | | | |
| **Gobiesocidae** | | | | | | |
| *Gobiesox strumosus* Cope, 1870 | WA+EP | aquarium | low to moderate | - | LC | Corrêa et al. (1986) |
| **Atheriniformes** | | | | | | |
| **Atherinopsidae** | | | | | | |
| *Atherinella brasiliensis* (Quoy & Gaimard, 1825) | WA | animal feed* | low | - | LC | Corrêa et al. (1986); Spier (2016) |
| *Odontesthes bonariensis* (Valenciennes, 1835) | SSWA | food | low to moderate | DD | NE | Félix et al. (2007) |
| **Beloniformes** | | | | | | |
| **Belonidae** | | | | | | |
| *Strongylura timucu* (Walbaum, 1792) | WA | animal feed | moderate | - | LC | Félix et al. (2007); Spier (2016) |
| **Hemiramphidae** | | | | | | |
| *Hemiramphus brasiliensis* (Linnaeus, 1758) | TA | food* | low to moderate | - | LC | Godefroid et al. (2004); Hackradt & Hackradt (2009); Spier (2016) |
| *Hyporhamphus unifasciatus* (Ranzani, 1841) | WA+EP | food* | low | NT | LC | Godefroid et al. (2004); Félix et al. (2007); Hackradt & Hackradt (2009) |
| **Syngnathiformes** | | | | | | |
| **Syngnathidae** | | | | | | |
| *Hippocampus erectus* Perry, 1810 | WA | aquarium | low to moderate | VU | VU | Santos (2006); Santos et al. (2016) |

**Table 2.** Continued...

| Orders/Families/Species | Geographic Distribution | Economic Importance | Vulnerability FishBase | Conservation status MMA - 445 | Conservation status IUCN | Source |
|---|---|---|---|---|---|---|
| *Micrognathus crinitus* (Jenyns, 1842) | WA | No | low | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012) |
| *Syngnathus folletti* Herald, 1942 | SWA | No | low to moderate | - | LC | Félix et al. (2007); Schwarz-Junior (2009); Santos et al. (2016) |
| **Scorpaeniformes** | | | | | | |
| **Scorpaenidae** | | | | | | |
| *Scorpaena brasiliensis* Cuvier, 1829 | WA | aquarium | moderate to high | - | LC | Hackradt et al. (2011); Daros et al. (2012) |
| *Scorpaena isthmensis* Meek & Hildebrand, 1928 | WA | aquarium | low to moderate | - | LC | Santos (2006); Santos et al. (2016) |
| *Scorpaena plumieri* Bloch, 1789 | TA | aquarium | high | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Spier (2016) |
| **Dactylopteridae** | | | | - | | |
| *Dactylopterus volitans* (Linnaeus, 1758) | TA | aquarium | moderate | - | LC | Santos (2006); Félix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Daros et al. (2012); Rossi-Wongtschowski et al. (2014); Santos et al. (2016) |
| **Triglidae** | | | | - | | |
| *Prionotus nudigula* Ginsburg, 1950 | SSWA | aquarium | moderate to high | - | NE | Gomes & Chaves (2006); Santos (2006); Félix et al. (2007); Schwarz-Junior (2009); Santos et al. (2016) |
| *Prionotus punctatus* (Bloch, 1793 | SWA+Ca | food* | moderate to high | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Hackradt & Hackradt (2009); Schwarz-Junior (2009); Rossi-Wongtschowski et al. (2014); Santos et al. (2016) |
| **Perciformes** | | | | | | |
| **Centropomidae** | | | | | | |
| *Centropomus parallelus* Poey, 1860 | WA | food* | high | - | LC | Corrêa et al. (1986); Chaves et al. (2003); Felix et al. (2007); Schwarz-Junior (2009); Santos et al. (2016) |
| *Centropomus undecimalis* (Bloch, 1792) | WA+Ca | food* | moderate to high | - | LC | Hackradt & Hackradt (2009); Spier (2016) |
| **Acropomatidae** | | | | | | |
| *Synagrops spinosus* Schultz, 1940 | WA+EP | No | low | - | LC | Rossi-Wongtschowski et al. (2014) |
| **Serranidae** | | | | | | |
| *Diplectrum formosum* (Linnaeus, 1766) | WA | aquarium | low | - | LC | Chaves et al. (2003); Santos (2006); Santos et al. (2016) |
| *Diplectrum radiale* (Quoy & Gaimard, 1824) | WA | aquarium | low to moderate | - | LC | Chaves et al. (2003); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Hackradt et al. (2011); Daros et al. (2012); Santos et al. (2016); Spier (2016) |
| *Dules auriga Cuvier 1829* | SSWA | aquarium | low | - | NE | Santos (2006); Santos et al. (2016) |
| *Serranus flaviventris* (Cuvier, 1829) | WA | aquarium | low | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| **Epinephelidae** | | | | | | |
| *Epinephelus itajara* (Lichtenstein, 1822) | Ta | food* | high to very high | CR | CR | Hackradt & Hackradt (2009); Hackradt et al. (2011); Spier (2016) |
| *Epinephelus marginatus* (Lowe, 1834) | TA | food* | high to very high | VU | EN | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Epinephelus morio* (Valenciennes, 1828) | WA | food* | high | VU | NT | Carniel (2008); Daros et al. (2012) |

**Table 2.** Continued...

| Orders/Families/Species | Geographic Distribution | Economic Importance | Vulnerability FishBase | Conservation status MMA - 445 | Conservation status IUCN | Source |
|---|---|---|---|---|---|---|
| *Hyporthodus nigritus* (Holbrook, 1855) | WA | food* | high to very high | EN | CR | Santos (2006), Hackradt & Hackradt (2009); Santos et al. (2016); Spier (2016) |
| *Hyporthodus niveatus* (Valenciennes, 1828) | WA | food* | high | VU | VU | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Mycteroperca acutirostris* (Valenciennes, 1828) | Ca+Br | food* | high | DD | LC | Santos (2006); Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Santos et al. (2016); Spier (2016) |
| *Mycteroperca bonaci* (Poey, 1860) | WA | food* | high | VU | NT | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Mycteroperca microlepis* (Goode & Bean, 1879) | WA | food* | high to very high | DD | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Spier (2016) |
| *Rypticus randalli* Courtenay, 1967 | Ca+Br | No | low | - | LC | Chaves et al. (2003); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| **Priacanthidae** | | | | | | |
| *Heteropriacanthus cruentatus* (Lacepède, 1801) | CT | aquarium | low to moderate | - | LC | Rossi-Wongtschowski et al. (2014) |
| *Priacanthus arenatus* Cuvier, 1829 | TA | food* | low to moderate | - | LC | Corrêa et al. (1986); Hackradt & Hackradt (2009); Schwarz-Junior (2009); Daros et al. (2012); Rossi-Wongtschowski et al. (2014); Santos et al. (2016); Spier (2016) |
| **Malacanthidae** | | | | | | |
| *Malacanthus plumieri* (Bloch, 1786) | WA | No | high | - | LC | Spier (2016) |
| **Pomatomidae** | | | | | | |
| *Pomatomus saltatrix* (Linnaeus, 1766) | CT | food* | high | NT | VU | Godefroid et al. (2004); Santos (2006); Felix et al. (2007); Carniel (2008); Hackradt & Hackradt (2009); Schwarz-Junior (2009); Hackradt et al. (2011); Rossi-Wongtschowski et al. (2014); Santos et al. (2016); Spier (2016) |
| **Rachycentridae** | | | | | | |
| *Rachycentron canadum* (Linnaeus, 1766) | CT | food* | moderate | - | LC | Carniel (2008); Hackradt & Hackradt (2009); Spier (2016) |
| **Echeneidae** | | | | | | |
| *Echeneis naucrates* Linnaeus, 1758 | TA | aquarium | moderate to high | - | LC | Hackradt & Hackradt (2009); Spier (2016) |
| *Remora remora* (Linnaeus, 1758) | TA | food | moderate to high | - | LC | Hackradt & Hackradt (2009); Spier (2016) |
| **Carangidae** | | | | | | |
| *Alectis ciliaris* (Bloch, 1787) | Ta+EP | food* | high to very high | - | LC | Spier (2016) |
| *Carangoides bartholomaei* (Cuvier, 1833) | WA | food* | high | - | LC | Godefroid et al. (2004); Carniel (2008); Schwartz-Junior (2009); Santos et al. (2016) |
| *Caranx crysos* (Mitchill, 1815) | TA | food* | low to moderate | - | LC | Santos (2006); Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Santos et al. (2016); Spier (2016) |
| *Caranx hippos* (Linnaeus, 1766) | TA | food* | high | - | LC | Carniel (2008); Spier (2016) |
| *Caranx latus* Agassiz, 1831 | TA | food* | high | - | LC | Corrêa et al. (1986); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Santos et al. (2016); Spier (2016) |
| *Caranx ruber* (Bloch, 1793) | WA | food* | high | - | LC | Godefroid et al. (2004); Spier (2016) |

**Table 2.** Continued...

| Orders/Families/Species | Geographic Distribution | Economic Importance | Vulnerability FishBase | Conservation status MMA - 445 | Conservation status IUCN | Source |
|---|---|---|---|---|---|---|
| *Chloroscombrus chrysurus* (Linnaeus, 1766) | TA | food* | moderate to high | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Hackradt & Hackradt (2009); Schwarz-Junior (2009); Hackradt et al. (2011); Daros et al. (2012); Rossi-Wongtschowski et al. (2014); Santos et al. (2016); Spier (2016) |
| *Hemicaranx amblyrhynchus* (Cuvier, 1833) | WA | food* | low to moderate | - | LC | Chaves et al. (2003); Carniel (2008); Spier (2016) |
| *Oligoplites palometa* (Cuvier, 1832) | Ca+Br | food* | low to moderate | - | LC | Santos (2006); Santos et al. (2016); Spier (2016) |
| *Oligoplites saliens* (Bloch, 1793) | SWA+Ca | aquarium* | moderate | - | LC | Corrêa et al. (1986); Santos (2006); Felix et al. (2007); Carniel (2008); Hackradt & Hackradt (2009); Schwarz-Junior (2009); Hackradt et al. (2011); Rossi-Wongtschowski et al. (2014); Santos et al. (2016) |
| *Oligoplites saurus* (Bloch & Schneider, 1801) | WA | food* | low to moderate | - | LC | Godefroid et al. (2004) |
| *Pseudocaranx dentex* (Bloch & Schneider, 1801) | CT | food* | high to very high | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Selene setapinnis* (Mitchill, 1815) | WA | food* | low to moderate | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Hackradt & Hackradt (2009); Schwarz-Junior (2009); Rossi-Wongtschowski et al. (2014); Santos et al. (2016); Spier (2016) |
| *Selene vomer* (Linnaeus, 1758) | WA | aquarium* | moderate | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Daros et al. (2012); Rossi-Wongtschowski et al. (2014); Santos et al. (2016); Spier (2016) |
| *Seriola dumerili* (Risso, 1810) | CT | food* | moderate to high | - | LC | Santos (2006); Hackradt & Hackradt (2009); Santos et al. (2016) |
| *Seriola lalandi* Valenciennes, 1833 | TA+EP | food* | high to very high | - | LC | Spier (2016) |
| *Seriola rivoliana* Valenciennes, 1833 | WA+EP | food* | high to very high | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Spier (2016) |
| *Trachinotus carolinus* (Linnaeus, 1766) | WA | food* | moderate to high | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Felix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016); Spier (2016) |
| *Trachinotus falcatus* (Linnaeus, 1758) | WA | food* | moderate | - | LC | Corrêa et al. (1986); Felix et al. (2007); Hackradt & Hackradt (2009); Spier (2016) |
| *Trachinotus goodei* Jordan & Evermann, 1896 | WA | food* | low to moderate | - | LC | Félix et al. (2007); Spier (2016) |
| *Trachinotus marginatus* Cuvier, 1832 | SSWA | food* | moderate to high | - | NE | Godefroid et al. (2004); Félix et al. (2007); Spier (2016) |
| *Trachurus lathami* Nichols, 1920 | WA | food | moderate | - | LC | Rossi-Wongtschowski et al. (2014) |
| *Uraspis secunda* (Poey, 1860) | CT | No | low to moderate | - | LC | Godefroid et al. (2004) |
| **Coryphaenidae** | | | | | | |
| *Coryphaena hippurus* Linnaeus, 1758 | CT | food* | moderate | - | LC | Rossi-Wongtschowski et al. (2014); Spier (2016) |
| **Lutjanidae** | | | | | | |

**Table 2.** Continued...

| Orders/Families/Species | Geographic Distribution | Economic Importance | Vulnerability FishBase | Conservation status MMA - 445 | Conservation status IUCN | Source |
|---|---|---|---|---|---|---|
| *Lutjanus analis* (Cuvier, 1828) | WA+Ca | food* | moderate to high | NT | NT | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Lutjanus cyanopterus* (Cuvier, 1828) | WA | food* | high | VU | VU | Hackradt & Hackradt (2009); Spier (2016) |
| *Lutjanus griseus* (Linnaeus, 1758) | WA+Ca | food* | moderate | - | LC | Spier (2016) |
| *Lutjanus jocu* (Bloch & Schneider, 1801) | Ta | food* | high to very high | NT | DD | Spier (2016) |
| *Lutjanus synagris* (Linnaeus, 1758) | WA+Ca | food* | moderate | NT | NT | Hackradt & Hackradt (2009); Hackradt et al. (2011); Spier (2016) |
| *Rhomboplites aurorubens* (Cuvier, 1829) | WA+Ca | food | moderate to high | NT | VU | Hackradt & Hackradt (2009); Hackradt et al. (2011); Rossi-Wongtschowski et al. (2014) |
| **Lobotidae** | | | | | | |
| *Lobotes surinamensis* (Bloch, 1790) | CT | food* | low to moderate | - | LC | Carniel (2008); Spier (2016) |
| **Gerreidae** | | | | | | |
| *Diapterus auratus* Ranzani, 1842 | WA | food* | low to moderate | - | LC | Corrêa et al. (1986); Spier (2016) |
| *Diapterus rhombeus* (Cuvier, 1829) | Ca+Br | food* | moderate | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Hackradt & Hackradt (2009); Schwarz-Junior (2009); Rossi-Wongtschowski et al. (2014); Santos et al. (2016) |
| *Eucinostomus argenteus* Baird & Girard, 1855 | WA+EP | food* | low | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Hackradt & Hackradt (2009); Schwarz-Junior (2009); Hackradt et al. (2011); Rossi-Wongtschowski et al. (2014); Santos et al. (2016) |
| *Eucinostomus gula* (Quoy & Gaimard, 1824) | WA | food* | low to moderate | - | LC | Chaves et al. (2003); Santos (2006); Schwarz-Junior (2009); Santos et al. (2016) |
| *Ulaema lefroyi (Goode, 1874)* | Ca+Br | food* | low | - | LC | Félix et al. (2007) |
| *Eucinostomus melanopterus* (Bleeker, 1863) | TA | food* | low to moderate | - | LC | Gomes & Chaves (2006); Felix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Eugerres brasilianus* (Cuvier, 1830) | WA | food* | moderate | - | LC | Corrêa et al. (1986), Carniel (2008) |
| **Haemulidae** | | | | | | |
| *Anisotremus surinamensis* (Bloch, 1791) | WA | aquarium / food* | high | DD | DD | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Anisotremus virginicus* (Linnaeus, 1758) | WA | aquarium | moderate | - | LC | Carniel (2008); Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Conodon nobilis* (Linnaeus, 1758) | WA | aquarium | low to moderate | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Genyatremus luteus* (Bloch, 1790) | Ca+Br | food* | low to moderate | - | DD | Corrêa et al. (1986), Carniel (2008) |
| *Haemulon aurolineatum* Cuvier, 1830 | WA | food* | moderate | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |

**Table 2.** Continued...

| Orders/Families/Species | Geographic Distribution | Economic Importance | Vulnerability FishBase | Conservation status MMA - 445 | Conservation status IUCN | Source |
|---|---|---|---|---|---|---|
| *Haemulopsis corvinaeformis (Steindachner 1868)* | WA | aquarium | low to moderate | - | LC | Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Haemulon steindachneri* (Jordan & Gilbert, 1882) | SWA+Ca | aquarium | low to moderate | - | LC | Godefroid et al. (2004); Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Orthopristis ruber* (Cuvier, 1830) | SWA+Ca | aquarium | moderate | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Santos (2006); Carniel (2008); Hackradt & Hackradt (2009); Schwarz-Junior (2009); Hackradt et al. (2011); Rossi-Wongtschowski et al. (2014); Santos et al. (2016); Spier (2016) |
| **Sparidae** | | | | | | |
| *Archosargus probatocephalus* (Walbaum, 1792) | WA | food* | moderate | DD | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Archosargus rhomboidalis* (Linnaeus, 1758) | WA | aquarium* | moderate | - | LC | Carniel (2008); Spier (2016) |
| *Diplodus argenteus argenteus* (Valenciennes, 1830) | WA | food* | low to moderate | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| **Sciaenidae** | | | | | | |
| *Bairdiella ronchus* (Cuvier, 1830) | Ca+Br | animal feed | low to moderate | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Ctenosciaena gracilicirrhus* (Metzelaar, 1919) | Ca+Br | animal feed | low | - | LC | Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Cynoscion acoupa* (Lacepède, 1801) | SWA+Ca | food* | high | NT | LC | Gomes & Chaves (2006); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016); Spier (2016) |
| *Cynoscion jamaicensis* (Vaillant & Bocourt, 1883) | SWA+Ca | food* | moderate | - | LC | Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Cynoscion leiarchus* (Cuvier, 1830) | Ca+Br | food* | high | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Cynoscion microlepidotus* (Cuvier, 1830) | Br | food* | high | - | LC | Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Schwarz-Junior (2009); Santos et al. (2016) |
| *Cynoscion striatus* (Cuvier, 1829) | SSWA | food* | moderate to high | - | NE | Carniel (2008) |
| *Cynoscion virescens* (Cuvier, 1830) | Ca+Br | food* | high | - | LC | Gomes & Chaves (2006); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Isopisthus parvipinnis* (Cuvier, 1830) | Ca+Br | food* | low | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Larimus breviceps* Cuvier, 1830 | Ca+Br | food* | low to moderate | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |

**Table 2.** Continued...

| Orders/Families/Species | Geographic Distribution | Economic Importance | Vulnerability FishBase | Conservation status MMA - 445 | Conservation status IUCN | Source |
|---|---|---|---|---|---|---|
| *Macrodon ancylodon (Bloch & Schneider 1801)* | WA | food* | moderate | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Menticirrhus americanus* (Linnaeus, 1758) | WA | aquarium / food* | high | DD | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Rossi-Wongtschowski et al. (2014); Santos et al. (2016) |
| *Menticirrhus littoralis* (Holbrook, 1847) | WA | food* | low to moderate | DD | LC | Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Santos et al. (2016) |
| *Micropogonias furnieri* (Desmarest, 1823) | SWA+Ca | food* | moderate | - | LC | Chaves et al. (2003); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Rossi-Wongtschowski et al. (2014); Santos et al. (2016); Spier (2016) |
| *Nebris microps* Cuvier, 1830 | Br | food* | moderate | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Odontoscion dentex* (Cuvier, 1830) | WA | aquarium* | low | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Ophioscion punctatissimus* Meek & Hildebrand, 1925 | Ca+Br | food* | low to moderate | DD | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Felix et al. (2007); Schwarz-Junior (2009); Santos et al. (2016) |
| *Paralonchurus brasiliensis* (Steindachner, 1875) | SWA+Ca | aquarium | low | - | LC | Corrêa et al. (1986); Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Pareques acuminatus* (Bloch & Schneider, 1801) | WA | aquarium | low | DD | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Pogonias cromis* (Linnaeus, 1766) | WA | food* | high | EN | LC | Godefroid et al. (2004); Santos (2006); Santos et al. (2016) |
| *Stellifer brasiliensis* (Schultz, 1945) | Br | animal feed | low | - | NE | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Stellifer rastrifer* (Jordan, 1889) | SSWA+Br | animal feed | low | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Stellifer stellifer* (Bloch, 1790) | Br | animal feed | low | - | DD | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Umbrina canosai* Berg, 1895 | SSWA | food* | low to moderate | - | NE | Godefroid et al. (2004) |
| *Umbrina coroides* Cuvier, 1830 | WA | food* | low | - | LC | Felix et al. (2007); Schwarz Junior (2009); Santos et al. (2016) |
| **Polynemidae** | | | | | | |
| *Polydactylus oligodon* (Günther, 1860) | WA | food* | low | - | LC | Godefroid et al. (2004); Schwarz Junior (2009); Santos et al. (2016) |

**Table 2.** Continued...

| Orders/Families/Species | Geographic Distribution | Economic Importance | Vulnerability FishBase | Conservation status MMA - 445 | Conservation status IUCN | Source |
|---|---|---|---|---|---|---|
| *Polydactylus virginicus* (Linnaeus, 1758) | WA | food* | low | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Felix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016); Spier (2016) |
| **Mullidae** | | | | | | |
| *Mullus argentinae* Hubbs & Marini, 1933 | SSWA | aquarium | low | - | NE | Santos (2006); Schwarz Junior (2009); Santos et al. (2016) |
| *Pseudupeneus maculatus* (Bloch, 1793) | WA | food* | moderate | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| **Mugilidae** | | | | | | |
| *Mugil curema* Valenciennes, 1836 | TA+EP | food* | high | DD | LC | Corrêa et al. (1986); Carniel (2008); Spier (2016) |
| *Mugil liza* Valenciennes, 1836 | WA | food* | moderate | NT | DD | Carniel (2008); Spier (2016) |
| **Pomacentridae** | | | | | | |
| *Abudefduf saxatilis* (Linnaeus, 1758) | TA | aquarium | low to moderate | - | LC | Corrêa et al. (1986); Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Chromis multilineata* (Guichenot, 1853) | TA | aquarium | low | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Stegastes fuscus* (Cuvier, 1830) | Br | aquarium | low | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Stegastes pictus* (Castelnau, 1855) | Ca+Br | aquarium | low | - | NE | Daros et al. (2012) |
| *Stegastes variabilis* (Castelnau, 1855) | WA | aquarium | low | - | NE | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| **Uranoscopidae** | | | | | | |
| *Astroscopus y-graecum* (Cuvier, 1829) | WA | food* | high | - | LC | Santos (2006); Felix et al. (2007); Schwarz Junior (2009); Santos et al. (2016) |
| **Pinguipedidae** | | | | | | |
| *Pseudopercis semifasciata* (Cuvier, 1829) | SSWA | food | high | DD | NE | Godefroid et al. (2004) |
| **Blenniidae** | | | | | | |
| *Hypleurochilus fissicornis* (Quoy & Gaimard, 1824) | SSWA+Br | No | low | - | LC | Schwarz Junior (2009); Santos et al. (2016); Spier (2016) |
| *Hypsoblennius invemar* Smith-Vaniz & Acero P., 1980 | WA | aquarium | low | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012) |
| *Ophioblennius trinitatis* Miranda Ribeiro, 1919 | Br | aquarium | low | - | LC | Daros et al. (2012) |
| *Parablennius marmoreus* (Poey, 1876) | WA | aquarium | low | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Parablennius pilicornis* (Cuvier, 1829) | TA | aquarium | low | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Scartella cristata* (Linnaeus, 1758) | CT | aquarium | low | - | LC | Hackradt & Hackradt (2009); Daros et al. (2012); Spier (2016) |
| **Gobiidae** | | | | | | |
| *Bathygobius soporator* (Valenciennes, 1837) | TA | aquarium | low to moderate | - | LC | Corrêa et al. (1986); Carniel (2008); Hackradt & Hackradt (2009) |
| *Coryphopterus glaucofraenum* Gill, 1863 | WA | aquarium | low | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Microgobius meeki* Evermann & Marsh, 1899 | Ca+Br | No | low | - | LC | Santos (2006); Santos et al. (2016) |
| **Ephippidae** | | | | | | |

**Table 2.** Continued...

| Orders/Families/Species | Geographic Distribution | Economic Importance | Vulnerability FishBase | Conservation status MMA - 445 | Conservation status IUCN | Source |
|---|---|---|---|---|---|---|
| *Chaetodipterus faber* (Broussonet, 1782) | WA | aquarium / food* | high | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Hackradt & Hackradt (2009); Schwarz-Junior (2009); Hackradt et al. (2011); Daros et al. (2012); Rossi-Wongtschowski et al. (2014); Santos et al. (2016); Spier (2016) |
| **Acanthuridae** | | | | | | |
| *Acanthurus bahianus* Castelnau, 1855 | WA | aquarium | low to moderate | - | LC | Corrêa et al. (1986); Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012) |
| *Acanthurus chirurgus* (Bloch, 1787) | TA | aquarium | low | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Acanthurus coeruleus* Bloch & Schneider, 1801 | WA | aquarium | high | - | LC | Daros et al. (2012); Spier (2016) |
| **Sphyraenidae** | | | | | | |
| *Sphyraena barracuda* (Edwards, 1771) | TA | food* | very high | - | LC | Spier (2016) |
| *Sphyraena guachancho* Cuvier, 1829 | TA | food* | very high | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Hackradt & Hackradt (2009); Schwarz-Junior (2009); Hackradt et al. (2011); Rossi-Wongtschowski et al. (2014); Santos et al. (2016) |
| *Sphyraena picudilla* Poey, 1860 | WA | food* | moderate to high | DD | NE | Chaves et al. (2003) |
| *Sphyraena tome* Fowler, 1903 | SSWA | food* | low to moderate | DD | NE | Santos (2006); Felix et al. (2007); Hackradt & Hackradt (2009); Santos et al. (2016) |
| **Gempylidae** | | | | | | |
| *Thyrsitops lepidopoides* (Cuvier, 1832) | SSWA | food* | moderate | - | NE | Rossi-Wongtschowski et al. (2014) |
| **Trichiuridae** | | | | | | |
| *Trichiurus lepturus* Linnaeus, 1758 | CT | food* | high | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Rossi-Wongtschowski et al. (2014); Santos et al. (2016); Spier (2016) |
| **Scombridae** | | | | | | |
| *Scomber colias* Gmelin, 1789 | Ta | food* | moderate | - | LC | Rossi-Wongtschowski et al. (2014) |
| *Scomberomorus brasiliensis* Collette, Russo & Zavala-Camin, 1978 | WA | food* | high to very high | - | LC | Felix et al. (2007); Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Rossi-Wongtschowski et al. (2014); Spier (2016) |
| *Scomberomorus cavalla* (Cuvier, 1829) | WA | food* | high to very high | - | LC | Carniel (2008); Hackradt & Hackradt (2009); Hackradt et al. (2011); Spier (2016) |
| **Stromateidae** | | | | | | |
| *Peprilus paru* (Linnaeus, 1758) | WA | food* | low to moderate | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Rossi-Wongtschowski et al. (2014); Santos et al. (2016); Spier (2016) |
| **Pempheridae** | | | | | | |

**Table 2.** Continued...

| Orders/Families/Species | Geographic Distribution | Economic Importance | Vulnerability FishBase | Conservation status MMA - 445 | Conservation status IUCN | Source |
|---|---|---|---|---|---|---|
| *Pempheris schomburgkii* Müller & Troschel, 1848 | WA | aquarium | low | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| **Chaetodontidae** | | | | | | |
| *Chaetodon striatus* Linnaeus, 1758 | WA | aquarium | low | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| **Pomacanthidae** | | | | | | |
| *Pomacanthus paru* (Bloch, 1787) | WA | aquarium | moderate | DD | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| **Labridae** | | | | | | |
| *Bodianus rufus* (Linnaeus, 1758) | WA | aquarium | low | - | LC | Daros et al. (2012); Spier (2016) |
| *Halichoeres brasiliensis* (Bloch, 1791) | SWA | aquarium | moderate to high | - | DD | Spier (2016) |
| *Halichoeres poeyi* (Steindachner, 1867) | WA | aquarium | low | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| **Scaridae** | | | | | | |
| *Sparisoma amplum* (Ranzani, 1841) | Br | aquarium | moderate | NT | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012) |
| *Sparisoma axillare* (Steindachner, 1878) | Br | aquarium | moderate | VU | DD | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Sparisoma frondosum* (Agassiz, 1831) | Ca+Br | aquarium | low to moderate | VU | DD | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Sparisoma radians* (Valenciennes, 1840) | WA | aquarium | low | - | LC | Hackradt & Hackradt (2009); Daros et al. (2012) |
| **Labrisomidae** | | | | | | |
| *Labrisomus nuchipinnis* (Quoy & Gaimard, 1824) | TA | aquarium | low | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Malacoctenus delalandii* (Valenciennes, 1836) | WA | No | low | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| *Paraclinus spectator* Guimarães & Bacellar, 2002 | Br | No | low | - | LC | Daros et al. (2012) |
| **Pleuronectiformes** | | | | | | |
| **Paralichthyidae** | | | | | | |
| *Citharichthys arenaceus* Evermann & Marsh, 1900 | WA | animal feed | low | - | LC | Chaves et al. (2003); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Citharichthys macrops* Dresel, 1885 | WA | animal feed | low | - | LC | Santos (2006); Felix et al. (2007); Schwarz-Junior (2009); Santos et al. (2016) |
| *Citharichthys spilopterus* Günther, 1862 | WA | animal feed | low | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Schwarz-Junior (2009); Santos et al. (2016) |
| *Etropus crossotus* Jordan & Gilbert, 1882 | WA+EP | animal feed | low | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Paralichthys brasiliensis* (Ranzani, 1842) | SWA | food | moderate to high | - | NE | Godefroid et al. (2004) |
| *Paralichthys orbignyanus* (Valenciennes, 1839) | SSWA | food | moderate to high | DD | NE | Carniel (2008) |

**Table 2.** Continued...

| Orders/Families/Species | Geographic Distribution | Economic Importance | Vulnerability FishBase | Conservation status MMA - 445 | Conservation status IUCN | Source |
|---|---|---|---|---|---|---|
| *Paralichthys patagonicus* Jordan, 1889 | SSWA+EP | food | low to moderate | NT | NE | Santos (2006); Santos et al. (2016) |
| *Syacium micrurum* Ranzani, 1842 | Ca+Br | food | moderate | - | LC | Schwarz Junior (2009); Santos et al. (2016) |
| *Syacium papillosum* (Linnaeus, 1758) | WA | animal feed | low to moderate | - | LC | Chaves et al. (2003); Santos (2006); Felix et al. (2007); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| **Bothidae** | | | | | | |
| *Bothus robinsi* Topp & Hoff, 1972 | WA | animal feed | low to moderate | - | LC | Chaves et al. (2003) |
| **Pleuronectidae** | | | | | | |
| *Oncopterus darwinii* Steindachner, 1874 | SSWA | animal feed | moderate | - | NE | Godefroid et al. (2004); Santos (2006); Felix et al. (2007); Santos et al. (2016) |
| **Achiridae** | | | | | | |
| *Achirus declivis* Chabanaud, 1940 | WA | animal feed | low | - | LC | Gomes & Chaves (2006); Santos (2006); Schwarz-Junior (2009); Santos et al. (2016) |
| *Achirus lineatus* (Linnaeus, 1758) | WA | aquarium | low to moderate | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Schwarz-Junior (2009); Santos et al. (2016) |
| *Trinectes microphthalmus* (Chabanaud, 1928) | Ca+Br | animal feed | low | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Trinectes paulistanus* (Miranda Ribeiro, 1915) | Ca+Br | animal feed | low | - | LC | Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| **Cynoglossidae** | | | | | | |
| *Symphurus diomedeanus* (Goode & Bean, 1885) | WA | animal feed | low to moderate | - | LC | Corrêa et al. (1986) |
| *Symphurus plagusia* (Bloch & Schneider, 1801) | Ca+Br | animal feed | low to moderate | - | LC | Godefroid et al. (2004) |
| *Symphurus tessellatus* (Quoy & Gaimard, 1824) | Ca+SSWA+Br | animal feed | moderate | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| **Tetraodontiformes** | | | | | | |
| **Balistidae** | | | | | | |
| *Balistes capriscus* Gmelin, 1789 | TA | food* | low to moderate | NT | VU | Chaves et al. (2003); Hackradt & Hackradt (2009); Hackradt et al. (2011); Rossi-Wongtschowski et al. (2014); Spier (2016) |
| **Monacanthidae** | | | | | | |
| *Aluterus monoceros* (Linnaeus, 1758) | CT | food* | high | NT | LC | Hackradt & Hackradt (2009); Spier (2016) |
| *Monacanthus ciliatus* (Mitchill, 1818) | TA | food | low to moderate | - | LC | Godefroid et al. (2004) |
| *Stephanolepis hispidus* (Linnaeus, 1766) | TA | aquarium* | low to moderate | - | LC | Chaves et al. (2003); Santos (2006); Felix et al. (2007); Carniel (2008); Hackradt & Hackradt (2009); Schwarz-Junior (2009); Hackradt et al. (2011); Daros et al. (2012); Rossi-Wongtschowski et al. (2014); Santos et al. (2016); Spier (2016) |

**Table 2.** Continued...

| Orders/Families/Species | Geographic Distribution | Economic Importance | Vulnerability FishBase | Conservation status MMA - 445 | Conservation status IUCN | Source |
|---|---|---|---|---|---|---|
| **Tetraodontidae** | | | | | | |
| *Lagocephalus laevigatus* (Linnaeus, 1766) | TA | aquarium* | high | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Carniel (2008); Schwarz-Junior (2009); Santos et al. (2016) |
| *Sphoeroides greeleyi* Gilbert, 1900 | Ca+Br | aquarium | low | - | LC | Chaves et al. (2003); Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Hackradt & Hackradt (2009); Hackradt et al. (2011); Santos et al. (2016) |
| *Sphoeroides spengleri* (Bloch, 1785) | TA | aquarium | low to moderate | - | LC | Santos (2006); Hackradt & Hackradt (2009); Schwarz-Junior (2009); Hackradt et al. (2011); Daros et al. (2012); Santos et al. (2016); Spier (2016) |
| *Sphoeroides testudineus* (Linnaeus, 1758) | WA | aquarium / food* | low | DD | LC | Godefroid et al. (2004); Gomes & Chaves (2006); Santos (2006); Felix et al. (2007); Carniel (2008); Hackradt & Hackradt (2009); Schwarz-Junior (2009); Santos et al. (2016) |
| **Diodontidae** | | | | | | |
| *Chilomycterus spinosus spinosus* (Linnaeus, 1758) | SWA | aquarium | low to moderate | - | LC | Chaves et al. (2003); Santos (2006); Felix et al. (2007); Carniel (2008); Hackradt & Hackradt (2009); Schwarz-Junior (2009); Hackradt et al. (2011); Rossi-Wongtschowski et al. (2014); Santos et al. (2016) |
| **Molidae** | | | | | | |
| *Ranzania laevis* (Pennant, 1776) | TA+EP | No | moderate to high | - | LC | Spier (2016) |
| **Beryciformes** | | | | | | |
| **Holocentridae** | | | | | | |
| *Holocentrus adscensionis* (Osbeck, 1765) | TA | aquarium | low to moderate | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |
| **Gasterosteiformes** | | | | | | |
| **Fistulariidae** | | | | | | |
| *Fistularia tabacaria* Linnaeus, 1758 | TA | aquarium | high to very high | - | LC | Hackradt & Hackradt (2009); Hackradt et al. (2011); Daros et al. (2012); Spier (2016) |

*Cynoscion* (6) and *Carcharhinus* (6) were the dominant genus in number of species, followed by *Anchoa* (5), *Gymnothorax* (5) and *Lutjanus* (5).

The geographic distribution of species across the different categories defined in the previous section are illustrated in Figure 2. Many of the recorded species are widely distributed over the Western Atlantic, and can be further separated into two groups with distinct distribution: the first, characteristic of the Caribbean fauna, is also found in the Caribbean and Brazilian Province; and the second, with temperate affinities, is characteristic of the Southern Southwest Atlantic, including Argentina and Uruguay.

In terms of Brazilian economic importance, 156 species (57%) are used for human consumption, 74 species (27%) for aquaria and 30 species (11%) for animal feed. Only 19 species (7%) have no commercial importance in Brazil. In the State of Paraná, on the other hand, only 57% of species of economic interest in Brazil are exploited. In particular, 21 species used for human consumption in other parts of Brazil have no economic importance in Paraná. Moreover, the aquaria and animal feed industries are relatively underdeveloped, with only 9 of 74 potentially viable species used in aquaria, and 4 of 30 potentially viable species commercialized for animal feed. In short, of 253 species of economic interest in Brazil, only 144 are exploited in the State of Paraná (Figure 3).

A total of 61% of species were categorized as having low to moderate vulnerability to extinction, and 39% ranged from moderate to very high vulnerability (Table 2). Most Elasmobranchii (29 species) were highly or very highly vulnerable. Among the Perciformes, 50 of the 146 species were classified as having moderate to very high vulnerability. Considering both red lists, 82% of catalogued species in Paraná's inner shelf were assessed for their risk of extinction. Two hundred and forty-two species occurring in the shallow inner continental shelf of Paraná appear in the red list of the International Union for Conservation of Nature (IUCN 2017), where 185 are listed as least concern, 17 as data deficient, 12 as near threatened, 17 as vulnerable, 8 as endangered, and 3 as critically endangered. The Brazilian Ministry of Environment (MMA 2014) classified substantially less species in the area (85 species), however with higher risk of extinction (12 vulnerable, 7 endangered, 15 critically endangered) (Figure 4).

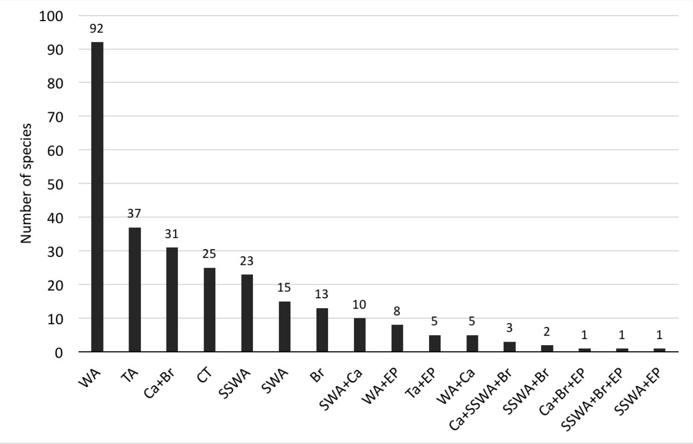

**Figure 2.** Geographic distribution of the species recorded in the shallow inner continental shelf of Paraná. CT = Circumtropical, TA = Trans-Atlantic, WA = Western Atlantic, SWA = Southwest Atlantic, SSWA = Southern Southwest Atlantic, Ca = Caribbean, Br = Brazilian Province, EP = Eastern Pacific.

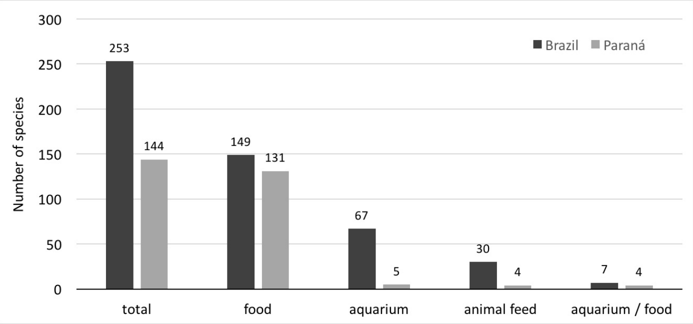

**Figure 3.** Number of catalogued species with economic importance in the State of Paraná only, versus the number with economic importance in Brazil overall.

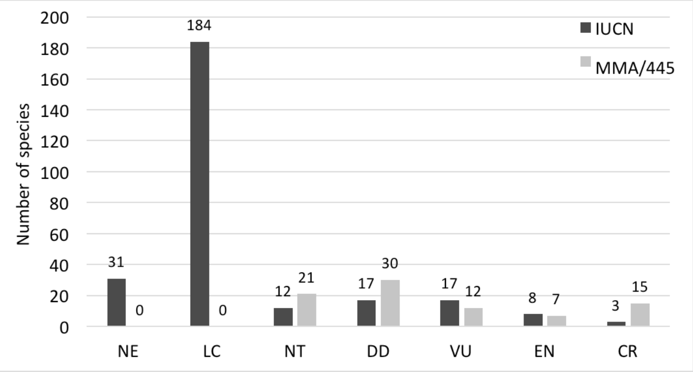

**Figure 4.** Global conservation status according to IUCN (2017) and National conservation status according to MMA (2014): NE= not evaluated, LC= least concern, NT = near threatened, DD = data deficient, VU = vulnerable, EN= endangered, CR = critically endangered.

## Discussion

The vastness of the Brazilian coast and its large ecosystem and biodiversity contributed to a false perception of inexhaustible fishing resources, and the misguided adoption of policies that neglected resource sustainability and focused primarily on species of commercial importance (Nahum et al. 2009). A necessary step towards implementing better informed policies is to obtain an accurate assessment of species occurrence, and their respective economic importance and vulnerability to extinction. Such comprehensive assessment is still lacking for Paraná's shallow inner continental shelf, in Southern Brazil, home to several threatened species. In an attempt to remedy this situation, this study compiled the results of surveys of Paraná's shallow inner continental shelf performed over the past 30 years, providing a comprehensive checklist of fish species, along with information on biogeography, conservation status, economic importance and degree of species' vulnerability.

Extracting correlations between the various factors that could influence species vulnerability to extinction, and hence pinpointing its causes, is beyond the scope if this work. Nonetheless, we believe that our checklist provides valuable information for future studies on the ecology and conservation of the fish fauna of the area.

In our study, we have confirmed a rich fauna of Elasmobranchii in the continental shelf of Paraná, comprising 24% of Brazilian's elasmobranch fauna (Rosa & Gadig 2014). Several elasmobranchs that occur in Paraná seem to use the southern coast of Brazil for reproduction (Bornatowski & Abilhoa 2012). Vooren et al. (2005) recorded 21 species that use areas on the southern continental shelf for reproduction. It is suspected that several species also use Paraná's coast as parturition and nursery grounds, such as *Carcharhinus limbatus, Rhizoprionodon lalandii, Sphyrna lewini, Narcine brasiliensis, Rioraja agassizi, Pseudobatos percellens* and *Zapteryx brevirostris*.

According to Castello (1994), the coastal fish fauna in Southeastern and Southern Brazil is composed of a mixture of species with tropical to subantarctic affinities, explaining the richness of the fish fauna in Paraná's inner shelf. Among the Actinopterygii, Sciaenidae was the most representative family in other continental shelves of Brazil (Rocha & Rossi-Wongtschowski 1998; Muto et al. 2000; Moraes et al. 2009) and its occurrence in Paraná's inner continental shelf is associated with Coastal Water (Muto et al. 2000). Sciaenidae and Carangidae were also the most speciose families in both estuaries of the region: the PEC (Passos et al. 2012) and the Guaratuba Bay (Chaves & Corrêa 1998; Chaves & Vendel 2001). In Brazilian waters, there are 37 species of Sciaenidae and 25 species of *Cynoscion*, with 25 species of Sciaenidae and 9 of *Cynoscion* occurring in Paraná (Nelson et al. 2016). That means that only three species of *Cynoscion* do not occur, or were not registered, in the State of Paraná. *Cynoscion guatucupa,* for instance, is not listed in this checklist, but its range of occurrence goes from southeastern Brazil to Uruguay. The other two *Cynoscion* species (*C. similis* and *C. steindachneri*) only occur in the Northern Brazilian coast (Nelson et al. 2016).

Fishery activities on the coast of Paraná are mostly artisanal or small-scale commercial operations, mainly utilizing two basic types of gear, gillnets and bottom trawl-nets (IPARDES 1981; Andriguetto-Filho 2002; Chaves & Robert 2003; Robert & Chaves 2006; Andriguetto-Filho et al. 2009). They target different resources over the year based on seasonal changes in species abundance and tourism (Robert & Chaves 2006). Trawling targets shrimp, *Xiphopenaus kroyeri* (Heller, 1862), *Litopenaeus schmitti* (Burkenroad 1936) and *Farfantepenaeus* sp. (Branco & Verani 2006; Robert et al. 2007), while gillnetting targets mainly teleosts and elasmobranchs such as Carcharhiniformes and Rhinobatidae (Costa & Chaves 2006; Robert & Chaves 2006; Bornatowski & Abilhoa 2012). A considerable number of species (109) with economic importance in Brazil are not commercialized in Paraná. These species can be considered as bycatch in the region, following Guanais et al. (2015) who define bycatch as the portion of the total catch that is effectively discarded. Sciaenidae, such as *Ctenosciaena gracilicirrhus*, *Isopisthus parvipinnis*, *Larimus breviceps*, *Menticirrhus americanus*, *Paralonchurus brasiliensis*, *Stellifer brasiliensis* and *Stellifer rastrifer*, although reported as shrimp bycatch in other studies (Cattani et al. 2011; Santos et al. 2016), have some economic importance in the region.

The lack of risk assessment for 18% of the species catalogued in this study under global lists can be attributed to the lack of studies on basic biology, habitat requirement, abundance, and distribution (Lamas et al. 2016), as well as lacking fishery statistics (discontinued in 2012) (Dario et al. 2015; Barreto et al. 2017). Therefore, is imperative that fishery monitoring programs be reinstated in Brazil to allow for science-based management (Dario et al. 2015).

We conclude with a few cautionary comments. First of all, the sampling methods and sampling efforts varied across the different studies compiled in this checklist, and therefore comparisons of their results, or statistical inferences based on combined results, are not straightforward to make. Hard conclusions should not be drawn before taking such systematic differences into account. Secondly, the sampling areas also differed across studies, so it was not possible to draw conclusions regarding temporal variations of species' occurrence. Nonetheless, our results, combined with effective monitoring of fishing activities, deposition of dredged sediments, and deployment of artificial habitats, could inform policy making regarding management and administration of the fishery resources of the Brazilian continental shelf.

## Acknowledgements

We are grateful to the Geological Oceanography Laboratory at the Center for Marine Studies, UFPR, for providing its map database. We are also indebted to Pâmela Emanuelly Cattani for her help with maps. The work of Daphne Spier were partially supported by a PhD's grant from the Coordination for Improvement of Higher Education Personnel (CAPES-Brazil).

## Authors' Contributions

Substantial contribution in the concept and design of the study: Daphne Spier, Henry Spach

Contribution to data collection: Daphne Spier, Humberto Gerum, Natalia Mattos, Hugo Bornatowski

Contribution to data analysis and interpretation: Daphne Spier, Humberto Gerum, Riguel Contente, Hugo Bornatowski

Contribution to manuscript preparation: All authors

Contribution to critical revision, adding intelectual content: All authors

## Conflicts of interest

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

## References

ANDRIGUETTO-FILHO, J.M. 2002. Sistemas técnicos de pesca no litoral do Paraná: caracterização e tipificação. In: Desenvolvimento e meio ambiente: em busca da interdisciplinaridade. Pesquisa urbanas e rurais. C. Raynaut, M. Zanoni, P. C. Lana, D. Floriani, A. D. D. Ferreira, J. M. Andriguetto-Filho (Eds). Editora UFPR (Universidade Federal do Paraná), Curitiba, pp. 213–233.

ANDRIGUETTO, J.M., KRUL, R. & FEITOSA, S. 2009. Analysis of natural and social dynamics of fishery production systems in Paraná, Brazil: implications for management and sustainability. J. Appl. Ichthyol. 25(3):277–286.

BARRETO, R.R., BORNATOWSKI, H., MOTTA, F.S., SANTANDER-NETO, J., VIANNA, G.M.S., & LESSA, R. 2017. Rethinking use and trade of pelagic sharks from Brazil. Mar. Policy. 85, 114-122.

BLABER, S.J.M. 2000. Tropical estuarine fishes: ecology, exploitation, and conservation. Fish and Aquatic Resources Series 7. Blackwell Science, CSIRO Marine Research. Cleveland, Queensland, Australia.

BORNATOWSKI, H., ABILHOA, V. & CHARVET-ALMEIDA, P. 2009. Elasmobranchs of the Paraná Coast, southern Brazil, south-western Atlantic. Mar. Biodivers. Rec. 2:e158.

BORNATOWSKI, H. & ABILHOA, V. 2012. Tubarões e raias capturadospela pesca artesanal no Paraná: guia de identificação. Curitiba, Paraná: Hori Consultoria Ambiental. Available from: http://www.hori.bio.br/cadernos/23-HCT4.pdf.

BORNATOWSKI, H., BRAGA, R.R., ABILHOA, V. & CORRÊA, M.F.M. 2014a. Feeding ecology and trophic comparisons of six shark species in a coastal ecosystem off southern Brazil. J. Fish Biol. 85(2):246–263.

BORNATOWSKI, H., SANTOS, L., ROBERT, M.D.C. & WEISER, P.A. 2014b. Occurrence of the narrowmouth catshark *Schroederichthys bivius* (Chondrichthyes: Scyliorhinidae) in southern Brazil. Mar. Biodivers. Rec. 7:e51.

BRANCO, J.O. & VERANI, J.R. 2006. Pesca do camarão sete-barbas e sua fauna acompanhante, na Armação do Itapocoroy, Penha, SC. In: Bases ecológicas para um desenvolvimento sustentável: estudos de caso em Penha, SC. J. O. Branco, A. W. C. Marenzi (Eds). Editora UNIVALI (Universidade do Vale do Itajaí), Itajaí, SC, pp. 153–170.

BRANDINI, F. 2014. Marine biodiversity and sustainability of fishing resources in Brazil: a case study of the coast of Paraná state. Reg. Environ. Chang. 14(6):2127–2137.

BRIGGS, J.C. & BOWEN, B.W. 2012. A realignment of marine biogeographic provinces with particular reference to fish distributions. J Biogeogr 39:12−30.

CARNIEL, V.L. 2008. Interação de aves costeiras com descartes oriundos da pesca artesanal no litoral centro-sul Paranáense. Dissertação de Mestrado, Federal University of Paraná (UFPR), Paraná.

CARVALHO-FILHO, A., SANTOS, S. & SAMPAIO, I. 2010. *Macrodon atricauda* (Günther, 1880) (Perciformes: Sciaenidae), a valid species from the southwestern Atlantic, with comments on its conservation. Zootaxa. 2519:48–58.

CASTELLO, J.P. 1994. Oceanografia Biológica (nécton). In Diagnóstico ambiental oceânico e costeiro das regiões sul e sudeste do Brasil. N. Yamaguti, M. Corrêa, & B. Ledo, Eds. Rio Grande do Sul. 361–379.

CATTANI, A.P., SANTOS, L.O., SPACH, H.L., BUDEL, B.R. & GUANAIS, J.H.D.G. 2011. Avaliação da ictiofauna da fauna acompanhante da pesca do camarão sete-barbas do município de Pontal do Paraná, litoral do Paraná, Brasil. Bol. do Inst. da Pesca. 37(2):247–260.

CEPENE. 2005. Lista de peixes marinhos e estuarinos permitidos à captura. 3(1) (http://ibama.gov.br/biodiversidade-aquatica/aquariofilia/lista-de-peixes-permitidos-para-pesca?id=969)

CHAVES, P.T.C. & CORRÊA, M.F.M. 1998. Composição ictiofaunística da área de manguezal da Baía de Guaratuba, Paraná, Brasil. Rev. Bras. Zool. 15(1):195–202.

CHAVES, P.T.C. & ROBERT, M.C. 2003. Embarcações, artes e procedimentos da pesca artesanal no litoral Sul do Estado do Paraná, Brasil (Boats, gears and procedures of the artisanal fishing at the southern coast of Paraná state, Brazil). Atlântica, 25: 53–59.

CHAVES, P.T.C. & VENDEL, A.L. 2001. Nota complementar sobre a composição ictiofaunística da Baía de Guaratuba, Paraná, Brasil. Rev. Bras. Zool. 18(suppl 1):349–352.

CHAVES, P.T.C., COVA-GRANDO, G. & CALLUF, C. 2003. Demersal ichthyofauna in a continental shelf region on the south coast of Brazil exposed to shrimp trawl fisheries. Acta Biol. Paraná. 32(4):69–82.

CHEUNG, W.W.L., PITCHER, T.J. & PAULY, D. 2005. A fuzzy logic expert system to estimate intrinsic extinction vulnerabilities of marine fishes to fishing. Biol. Conserv. 124(1):97–111.

CONTENTE, R.F., STEFANONI, M.F. & SPACH, H.L. 2011. Fish assemblage structure in an estuary of the Atlantic Forest biodiversity hotspot (southern Brazil). Ichthyol. Res. 58(1):38–50.

CORRÊA, M.F.M., CORDEIRO, A.A.M. & JUSTI, I.M. 1986. Catálogo dos peixes marinhos da coleção da divisão de zoologia e geologia da prefeitura municipal de Curitiba - I. Rev. Nerítica. 1(1): 1-83.

COSTA, L. & CHAVES, P.T.C. 2006. Elasmobrânquios capturados pela pesca artesanal na costa sul do Paraná e norte de Santa Catarina, Brasil. Biota Neotrop. 6(3) : http://www.biotaneotropica.org.br/v6n3/pt/ abstract?article+bn02706032006

CRAIG, M.T. & HASTINGS, P.A. 2007. A molecular phylogeny of the groupers of the subfamily Epinephelinae (Serranidae) with a revised classification of the Epinephelini. Ichthyol. Res. 54(1):1–17.

DARIO, F., ALVES, C.B.M., BOOS, H. et al. 2015. A better way forward for Brazil's fisheries. Science. 347:1079.

DAROS, F.A., BUENO, L.S., VILAR, C.C., PASSOS, A.C. & SPACH, H.L. 2012. Checklist of rocky reef fishes from the Currais Archipelago and Itacolomis Island, Paraná state, Brazil. Check List. 8(3):349–354.

ESCHMEYER, W.N., FRICKE, R. & VAN DER LAAN, R. 2014. Catalog of fishes: genera, species, references. V. 3882. (W.N. Eschmeyer, R. Fricke, & R. van der Laan, Eds.) http://www.calacademy.org/research/ichthyology/catalog/

FÉLIX, F.C., SPACH, H.L., MORO, P.S., HACKRADT, C.W., QUEIROZ, G.M.L.N. & HOSTIM-SILVA, M. 2007a. Ichthyofauna composition across a wave: energy gradient on Southern Brazil beaches. Brazilian J. Oceanogr. 55(4):281–292.

FÉLIX, F.C., SPACH, H.L., MORO, P.S., SCHWARZ, R.J., SANTOS, C., HACKRADT, C.W., HOSTIM-SILVA, M. & FÉLIX, F.C. 2007b. Utilization patterns of surf zone inhabiting fish from beaches in Southern Brazil. Panam. J. Aquat. Sci. 2(1):27–39.

FÉLIX-HACKRADT, F.C., SPACH, H.L., MORO, P.S., PICHLER, H.A., MAGGI, A.S., HOSTIM-SILVA, M., HACKRADT, C.W. & HACKRADT, F.C.F. 2010. Diel and tidal effects on surf zone fish fauna in Southern Brazil. Lat. Am. J. Aquat. Res. 38(3):447–460.

FIGUEIREDO, J.L. & MENEZES, N.A. 2009. Manual de peixes marinhos do sudeste do Brasil. Volumes I, II, III, V. Museu de Zoologia da Universidade de São Paulo, São Paulo.

FLOETER, S.R., ROCHA, L.A., ROBERTSON, D.R., JOYEUX, J.C., SMITH-VANIZ, W.F., WIRTZ, P., EDWARDS, A.J., BARREIROS, J.P., et al. 2008. Atlantic reef fish biogeography and evolution. J. Biogeogr. 35:22–47.

FROESE, R. & PAULY, D. 2017. World Wide Web electronic publication. Available: http://www.fishbase.org/search.php [2017, May 15].

GODEFROID, R.S., SPACH, H.L., SANTOS, C., MACLAREN, G. & SCHWARZ jr., R. 2004. Mudanças temporais na abundância e diversidade da fauna de peixes do infralitoral raso de uma praia, sul do Brasil. Iheringia. Série Zool. 94(1):95–104.

GOMES I.D. & CHAVES P.T. 2006. Ictiofauna integrante da pesca de arrasto camaroeiro no litoral sul do estado do Paraná, Brasil. Fish faunal composition in the shrimp fisheries at the southern coast of Paraná, Brazil. Bioikos 20(1): 9–13.

GUANAIS, J.H.D.G., MEDEIROS, R.P., MCCONNEY, P.A. 2015. Designing a framework for addressing bycatch problems in Brazilian small-scale trawl fisheries. Marine Policy 51, 111–118.

HACKRADT, C.W., PICHLER, H.A., FÉLIX, F.C., SCHWARZ jr., R., SILVA, L.O. & SPACH, H.L. 2009. A estrutura da comunidade de peixes em praias de baixa energia do complexo estuarino da Baía de Paranaguá, Brasil. Rev. Bras. Zoociências. 11(3):231–242.

IPARDES (Parana Institute of Economic and Social Development), 1981. Comercialização do pescado no litoral paranaense. Secretaria do Estado de Planejamento, Curitiba, pp. 179.

IGNÁCIO, J.M. & SPACH, H.L. 2010. Variação entre o dia e a noite nas características da ictiofauna do infralitoral raso do Maciel, Baía de Paranaguá, Paraná. 32(2):163–176.

IUCN. 2017. The IUCN red list of threatened species. International ed. IUCN Global Species Programme Red List Unit. Available: http://www.iucnredlist.org/.

LAMAS, R.A., LÚCIA, C., BIANCO, D. & CONTENTE, R.F. 2016. Checklist of the fish fauna of the Araçá Bay, São Sebastião. Check List 12(6): 2004.

LUIZ JR, O.J., CARVALHO-FILHO, A., FERREIRA, C.E.L., FLOETER, S.R., LUIZ GASPARINI, J. & SAZIMA, I. 2008. The reef fish assemblage of the Laje de Santos Marine State Park, Southwestern Atlantic: annotated checklist with comments on abundance, distribution, trophic structure, symbiotic associations, and conservation. Zootaxa. 1807:1–25.

MARCENIUK, A.P. 2005. Chave para identificacao das espécies de bagres marinos (Siluriformes, Ariidae) da costa brasilera. Bol. do Inst. da Pesca. 31(2):89–101.

MENEZES, N.A., BUCKUP, P.A., FIGUEIREDO, J.L. & MOURA, R.L. 2003. Catálogo das Espécies de Peixes Marinhos do Brasil. Museu de Zoologia da USP. São Paulo.

MENEZES, N.A., OLIVEIRA, C. & NIRCHIO, M. 2010. An old taxonomic dilemma: the identity of the western south Atlantic lebranche mullet (Teleostei: Perciformes: Mugilidae). Zootaxa. 2519:59–68.

MENNI, R.C., JAUREGUIZAR, A.J., STEHMANN, M.F.W. & LUCIFORA, L.O. 2010. Marine biodiversity at the community level: zoogeography of sharks, skates, rays and chimaeras in the southwestern Atlantic. Biodivers. Conserv. 19(3):775–796.

MMA 2014. Portaria Nº445 de 7 de setembro de 2014. [ (accessed in 9 May 2017)

MORAES, L.E., ROMERO, R., ROCHA, G.R.A. & MOURA, R.L. 2009. Ictiofauna demersal da plataforma continental interna ao largo de Ilhéus, Bahia, Brasil. Biota Neotrop. 9(4): http://www.biotaneotropica.org.br/v9n4/en/abstract?inventory+bn01409042009

MUSICK, J.A., HARBIN, M.M. & COMPAGNO, J.V. 2004. Historical Zoogeography of the Selachii. In Biology of Sharks and Their Relatives. V. 20043354. (J. Musick, J. Carrier, & M. Heithaus, Eds.) (Marine Biology). CRC Press.

MUTO, E.Y., SOARES, L.S.H. & ROSSI-WONGTSCHOWSKI, C.L.D.B. 2000. Demersal fish assemblages off São Sebastião, southeastern Brazil: structure and environmental conditioning factors (summer 1994). Rev. Bras. Oceanogr. 48(1):09–27.

NELSON, J.S., GRANDE, T.C., WILSON, M.V.H. 2016. Fishes of the world. Fifth Edition, John Wiley & Sons, New York, 752p.

NAHUM, V.J.I., CASTELLO, J.P. & ROSENTHAL, H. 2009. Special issue: modern fisheries research approaches in Brazil. J. Appl. Ichthyol. 25(3):243–243.

PASSOS, A.C., CONTENTE, R.F., ARAUJO, C.C.V., DAROS, F.A.L.M., SPACH, H.L., ABILHÔA, V. & FÁVARO, L.F. 2012. Fishes of Paranaguá Estuarine Complex, South West Atlantic. Biota Neotrop. 12(3): http://www.biotaneotropica.org.br/v12n3/en/abstract?inventory+bn01312032012

PICHLER, H.A., SPACH, H.L., GRAY, C.A., BROADHURST, M.K., SCHWARZ, R. & OLIVEIRA NETO, J.F. 2015. Environmental influences on resident and transient fishes across shallow estuarine beaches and tidal flats in a Brazilian World Heritage area. Estuar. Coast. Shelf Sci. 164:482–492.

PICHLER, H.A., GRAY, C.A., BROADHURST, M.K., SPACH, H.L. & NAGELKERKEN, I. 2017. Seasonal and environmental influences on recruitment patterns and habitat usage among resident and transient fishes in a World Heritage Site subtropical estuary. J. Fish Biol. 90(1):396–416.

POSSATTO, F.E., BROADHURST, M.K., GRAY, C.A., SPACH, H.L. & LAMOUR, M.R. 2017. Spatiotemporal variation among demersal ichthyofauna in a subtropical estuary bordering World Heritage-listed and marine protected areas: implications for resource management. Mar. Freshw. Res. 68(4):703–717.

ROBERT, M.C.; CHAVES, P.T.C. 2006. Dinâmica da atividade pesqueira artesanal em duas comunidades da regia˜o litora^nea limı’trofe Santa Catarina-Paraná, Brasil (Dynamics of the artisanal fishing activity in two communities on the south coast of Brazil). Bol. Inst. Pesca 32: 15–23.

ROBERT, R.; BORZONE, C.A.; NATIVIDADE, C.D. 2007. Os camarões da fauna acompanhante na pesca dirigida ao camarão-sete-barbas (*Xiphopenaeus kroyeri*) no litoral do Paraná (Shrimp composition of the sea bob (*Xiphopenaeus kroyeri*) fishery by-catch at the coast of Paraná). Bol. Inst. Pesca. 33: 237–246

ROCHA, G.R.A. & ROSSI-WONGTSCHOWSKI, C.L.D.B. 1998. Demersal fish community on the inner shelf of Ubatuba, southeastern Brazil. Rev. Bras. Oceanogr. 46(2):93–109.

ROSA, R.S. & GADIG, O.B.F. 2014. Conhecimento da diversidade dos Chondrichthyes marinhos no Brasil: a contribuição de José Lima de Figueiredo. Arquivos de Zoologia. São Paulo. Vol. 45(esp.):89–104

ROSSI-WONGTSCHOWSKI, C.L.D.B., VAZ-DOS-SANTOS, A.M. & SILIPRANDI, C.C. 2014. Checklist of the marine fishes collected during hydroacoustic surveys in the southeastern brazilian bight from 1995 to 2010. Arq. Zool. 45(esp):73–88.

SANTOS, C. 2006. Comunidade de peixes demersais e ciclo reprodutivo de quatro espécies da família Sciaenidae na plataforma interna entre Superagüi e Praia de Leste, PR. Curitiba. PhD Thesis, Federal University of Paraná, Paraná.

SANTOS, C., CORTELLET, G.M., ARAUJO, K.C. & SPACH, H.L. 2006. Estrutura populacional da raia-viola *Zapteryx brevirostris* (Chondrichthyes, Rhinobatidae) na plataforma adjacente à Baía de Paranaguá, PR. Acta Biol. Leopondensia. 28(1):32–37.

SANTOS, L. O., CATTANI, A.P. & SPACH, H.L. 2016. Ictiofauna acompanhante da pesca de arrasto para embarcações acima de 45 hp no litoral do Paraná, Brasil. Bol. do Inst. Pesca. 42(4):816–830.

SCHWARZ-JUNIOR, R. 2009. Composição, estrutura e abundância da ictiofauna capturada com redes de arrasto de portas na plataforma continental interna rasa do litoral do Paraná. PhD Thesis, Federal University of Paraná, Paraná.

SMITH, W.L. & CRAIG, M.T. 2007. Casting the Percomorph Net Widely: The Importance of Broad Taxonomic Sampling in the Search for the Placement of Serranid and Percid Fishes. Copeia. (1):35–55.

SPIER, D. 2016. Integrating ecological niche modelling and beta diversity analysis in marine systems management. PhD Thesis, Federal University of Paraná, Paraná.

VOOREN C.M., KLIPPEL S. and GALINA A.B. 2005. Elasmobrânquios das águas costeiras da Plataforma Sul. In Vooren C.M. and Klippel S. (eds) Ações para conservação de tubarões e raias no sul do Brasil, Capítulo 7. Porto Alegre: Igará, pp. 114–120.

*Received: 19/05/2017*
*Revised: 12/01/2018*
*Accepted: 24/01/2018*

Biota Neotropica 18(2): e20170453, 2018
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
**Inventory**

# Living and lost mammals of Rio de Janeiro's largest biological reserve: an updated species list of Tinguá

***Leandro Travassos[1]*, Israel Dias Carvalho[2], Alexandra S. Pires[2], Sérgio Nunes Gonçalves[1], Paulo Malvino Oliveira[3], Alexandre Saraiva[4] & Fernando A. S. Fernandez[5]***

*[1]Universidade Federal do Rio de Janeiro, Programa de Pós-Graduação em Ecologia, Associação Ecocidade, Rua Comendador Silva Cardoso nº5 quadra 03, Pilar, Duque de Caxias, RJ, Brasil*
*[2]Universidade Federal Rural do Rio de Janeiro, Instituto de Florestas, Departamento de Ciências Ambientais, Rio de Janeiro, Rodovia BR 465 - Km 7, Seropédica, RJ, Brasil*
*[3]Reserva Biológica do Tinguá - ICMBio, Estrada do Comércio 3400, Tinguá, Nova Iguaçu, Rio de Janeiro, Brasil*
*[4]Superintendência da Polícia Federal - Regional Maranhão, São Luís, MA, Brasil*
*[5]Universidade Federal do Rio de Janeiro, Departamento de Ecologia, Rio de Janeiro, RJ, Brasil*
**Corresponding author: Leandro Travassos, e-mail: travassosleandro@gmail.com*

TRAVASSOS, L., CARVALHO, I. D., PIRES, A. S., GONÇALVES, S.N., OLIVEIRA, P. M., SARAIVA, A., FERNANDEZ, F. A. S. **Living and lost mammals of Rio de Janeiro's largest biological reserve: an updated species list of Tinguá**. Biota Neotropica 18(2): e20170453, 2018. http://dx.doi.org/10.1590/1676-0611-BN-2017-0453

***Abstract:*** The Tinguá Biological Reserve (TBR) is the largest protected area of this category in Rio de Janeiro state. Here, for the first time, we present the historical composition of terrestrial mammals' assemblage of TBR region. An inventory was conducted using transect surveys, nonstandard transects, survey of museum specimens and informal reports. Considering all the data, eighty-five species were recorded, placing TBR as the second one in the number of mammals recorded in "Serra do Mar" ecoregion of Atlantic Forest and in the Rio de Janeiro state. Among the species with historical records are the jaguar (*Panthera onca*) and the golden-lion-tamarin (*Leontopithecus rosalia*) while the current presence of the maned wolf (*Chrysocyon brachyurus*) was recorded for the first time. Priority studies should focus on Chiroptera, Rodentia and Didelphimorphia orders, especially in the most remote areas of the reserve, and long-term surveys of endangered species. Besides hunting, fragmentation of its interior by roads, pipelines and transmission lines and exotic species, TBR is also threatened by the urban growth around it and the pressure to reduce its area and its protection category, demanding greater attention by the high levels of governance of protected areas in Brazil.
***Keywords:*** *Mammal community, Atlantic Forest, Tinguá Biological Reserve, endangered species, museum data.*

# Mamíferos atuais e extintos na maior Reserva Biológica do Rio de Janeiro: uma lista atualizada de espécies do Tinguá

***Resumo:*** A Reserva Biológica Tinguá (RBT) é a maior área protegida desta categoria no estado do Rio de Janeiro. Aqui, pela primeira vez, apresentamos a composição histórica da assembleia de mamíferos terrestres da região da RBT. Um inventário foi realizado utilizando amostragem por transectos, transectos não padronizados, busca por espécimes em museu e relatos. Considerando todos os dados, foram registradas oitenta e cinco espécies, colocando a RBT como a segunda no número de mamíferos registrados na ecorregião "Serra do Mar" da Mata Atlântica e no estado do Rio de Janeiro. Entre as espécies com registros históricos estão a onça-pintada (*Panthera onca*) e o mico-leão-dourado (*Leontopithecus rosalia*), enquanto a presença atual do lobo-guará (*Chrysocyon brachyurus*) foi registrada pela primeira vez. Estudos prioritários devem se concentrar nas ordens de Chiroptera, Rodentia e Didelphimorphia, especialmente nas áreas mais remotas da reserva, e pesquisas de longo prazo sobre espécies ameaçadas de extinção. Além da caça, a fragmentação em seu interior por estradas, gasodutos e linhas de transmissão e a presença de espécies exóticas, a TBR é ameaçada também pelo crescimento urbano no entorno e pela pressão para reduzir sua área e categoria de proteção, exigindo maior atenção dos altos níveis de gestão de áreas protegidas no Brasil.
***Palavras-chave:*** *comunidade de mamíferos, Mata Atlântica, Reserva Biológica de Tinguá, espécies ameaçadas de extinção, dados de museu.*

## Introduction

In the last decades tropical forests have lost several vertebrate species due to anthropogenic impacts, especially habitat loss and fragmentation (Laurance et al. 2002, Ferraz et al., 2003), hunting (Parry & Peres 2015), biological contamination (Lessa et al. 2016 ) or by the synergy between these processes (Peres 2001, Chiarello 1999, 2000, Cullen Jr. et al. 2000, 2000, 2004). This resulted in defaunated areas (Peres & Laake, 2003, Travassos 2011, Dirzo et al., 2014, Ripple et al. 2015), that can cover large extensions (Canale et al. 2012, Galetti et al. 2016), where several ecological processes mediated by locally extinct animals are missing (Galetti et al. 2006, Kuprewicz 2013). Large mammals are among the animals most affected by defaunation. Ecological interactions between mammal and plant populations shape the vegetation dynamics through herbivory and physical damage (Keuroghlian & Eaton 2009, Beck et al. 2013), and also through their role as seed dispersers and predators (Galetti et al. 2006, Andreazzi et al. 2009, Kuprewicz 2013).

In Rio de Janeiro state, several mammal surveys found a high richness of small and medium species and the local extinction of large herbivores as *Tapirus terrestris* (Linnaeus, 1758), feeding guild specialists as *Priodontes maximus* (Kerr, 1792), *Myrmecophaga tridactyla* (Linnaeus, 1758) and top predators as *Panthera onca* (Linnaeus, 1758) (Araújo et al. 2008, Modesto et al. 2008a, 2008b, Pessôa et al. 2009, Delciellos et al. 2012, Carvalho et al. 2014, Aximoff et al. 2015). As a result of these impacts many populations show low densities and changes in behavior and activity patterns (Di Bitetti et al. 2008, Galetti et al. 2016). In most cases the Atlantic Forest mammal surveys are conducted with combined use of more than one sampling technique, such as camera traps surveys, interviews, linear transects and search by tracks and signs (Modesto et al. 2008a, 2008b, Silva & Passamani 2009, Espartosa et al. 2011, Delciellos et al. 2012, Carvalho et al. 2014). Most Atlantic Forest remnants are concentrated in the southeast region of Brazil, mainly in mountain hilltops of Serra do Mar. This mountain range cross the metropolitan zone of Rio de Janeiro in the "*Baixada Fluminense*" region (Custódio 2007), and this is the major refuge for wildlife in the surroundings of Rio de Janeiro city (MMA/IBAMA 2006). The Tinguá Biological Reserve is located in a megadiverse region of the Atlantic Forest. It has high plant diversity and richness (IPJB/UFRRJ 2002) and is equally important for the conservation of threatened and endemic species of birds, reptiles and amphibians (MMA/IBAMA 2006). For example, the Tinguá Biological Reserve is the only government-owned protected area in whole state of Rio de Janeiro where the Ornate Hawk-Eagle *Spizaetus ornatus* (Daudin, 1800) still occurs (Mendonça-Lima & Pacheco 2003). Although mammalian surveys performed at Tinguá neighboring protected areas showed high richness and the presence of endemic and endangered species (Cunha 2007, Olifiers et al. 2007, Carvalho et al. 2014), the composition of mammal species of Tinguá Biological Reserve remains poorly known.

The goal of this paper was to show what is known about the current and historical richness and composition of Tinguá's assemblage of terrestrial mammals. For this objective we performed an intensive field survey by linear transects. In a complementary way, we performed nonstandard sampling following trails, literature search, surveys in museum collection and gathered informal reports. These reports, about rare and shy species, were obtained with former poachers, local residents, rangers and other employees. Based on this information we recorded the degree of threat and discussed the importance of TBR to Atlantic Forest Mammals conservation and the necessity of long-term mammal surveys.

## Materials and Methods

### 1. *Study area*

The Tinguá Biological Reserve (22º28'S and 22º40'S, 43º36'W and 43º13'W) (thereafter TBR) is the oldest protected area in Brazil; in 1833 emperor D. Pedro II created a Protection Forest to preserve the quality of the headwaters of three rivers, thus setting aside the area that later became TBR. Currently, TBR is administrated by "Chico Mendes Institute of Biodiversity Conservation" (ICMBio) - a government institute subordinate to the Ministry of the Environment. It is also the largest Biological Reserve in Rio de Janeiro state, with 248 km² spread over valleys and hills of Serra do Mar up to the altitude of 1600 m. The predominant vegetation is Dense Evergreen Atlantic Forest with a mix of mature and medium successional stages, and a canopy that reaches up to 25 meters. It has a high floristic diversity and the structure of the vegetation is considered one of the most well preserved in the whole Atlantic Forest biome (Iguatemy et al. 2017). The high terrain slope has prevented intensive logging. The east portion of TBR receives the rains that come from Atlantic Ocean. The mean annual temperature ranges between 20 and 26ºC and the annual precipitation is about 2000 mm (1970-1990); there is no dry season (MMA/IBAMA 2006). The TBR is the core zone of a Biosphere Reserve of UNESCO, and close to other protected areas, like Araras Biological Reserve (38 km²), the Serra dos Órgãos National Park (200 km²) and Três Picos State Park (587 km²). This mosaic cover a total range of about 1.065 km² (MMA/IBAMA 2006).

Despite its high biological value - preliminary surveys has revealed that TBR harbors 350 species of birds and 52 species of amphibians (IBAMA 1996, MMA/IBAMA 2000) - TBR is subject to several anthropic impacts. Poaching and harvest of palm heart are frequent in the Reserve, due to its large perimeter and poor fiscalization (MMA/IBAMA 2006). Livestook and horses from vicinity also invade the area occasionally and the reserve is crossed by electrical transmission lines and an oil pipeline (MMA /IBAMA 2006). During the last twelve years, the TBR buffer zone was subject of some deforestation due to logistic projects and other enterprises (Fundação S.O.S Mata Atlântica & INPA 2009, 2010, 2017).

### 2. *Data collection*

Between June 2005 and November 2006 a field survey was conducted using 10 linear transects spread throughout TBR forest. The length of transects ranged from 0.55 km to 2 km (average = 1.16 km; sd= 0.46 km) and the predominant vegetation was forests in late secondary successional stage. We started transect surveys from 30 minutes to one hour before sunrise and finished 3 or 4 hour after sunset. Transects were surveyed by one observer, rarely two, walking at 1 km/h, with brief stops each 50 or 100 meters. Besides that, opportunistic sightings and footprints were recorded from 2005 to 2009, either during the fieldwork carried out for this study or other field activities that together summed 1060 h. In the same period, we also recorded informal reports about the presence of medium or large mammals, cryptic or rare species with seventeen people that have a wide knowledge about the region, including former poachers, local residents that are in the region for over 20 years, TBR staff and researchers. During the study period, authorizations for research activities, which did not require catches for collections, were granted directly by the unit manager.

The mammal collection of the Museu Nacional at Rio de Janeiro was consulted in 2009 to record the species collected in the municipalities that harbor TBR (Nova Iguaçu, Duque de Caxias, Petrópolis and Miguel Pereira). A list of the specimens, summarizing all their information, was provided by the curators Dr. João A. Oliveira and Mr. Sérgio Maia Vaz. Only the specimens that were accurately identified in the list and do not have doubts about their identification were considered.

A literature search was conducted in specialized websites (e.g. Google Acadêmico, Scielo, Web of Science) aiming to compile faunistic surveys published up to 2016. To carry out the research we used key words "tinguá biological reserve", "mammals + reserva biológica do tinguá" or "reserva biológica do tinguá".

For each species we recorded the degree of threat using Bergallo et al. (2000) for the state of Rio de Janeiro, Chiarello et al. (2008) for the Brazil and the International Union for Conservation of Nature (IUCN 2015) for globally threatened species.

## Results

A total of 433 kilometers walked on linear transects, 327 km diurnal and 106 km nocturnal, resulted in the visual records of 24 species of non-volant mammals. Occasional sightings and footprints recorded 22 species, adding ten species for those recorded through linear transects (Table 1). Three species were registered exclusively through reports, the neotropical otter *Lontra longicaudis* (Olfers, 1818), observed recently and the southern muriqui *Brachyteles arachnoides* (É. Geoffroy, 1806) and the jaguar *Panthera onca* (Linnaeus, 1758), recorded for the last time in the 1990s.

Thirty-seven species were recorded through surveys of specimens deposited in the Museu Nacional do Rio de Janeiro, mostly small mammals (Table 1). Twelve species recorded exclusively in the museum collection were *Gracilinanus microtarsus* (Wagner, 1842), *Marmosops incanus* (Lund, 1840) *Marmosa paraguayanus* (Tate, 1931) *Leontopithecus rosalia* (Linnaeus, 1766), *Akodon serrensis* Thomas, 1902, *Calomys* sp. Waterhouse, 1837, *Euryoryzomys* sp. Weksler, Percequillo & Voss, 2006, *Necromys lasiurus* (Lund, 1841), *Oligoryzomys* sp. Bangs, 1900, *Euryzygomatomys spinosus* (G. Fisher, 1814) and the exotic species *Rattus rattus* (Linnaeus, 1758) and *Rattus norvegicus* (Berkenhout, 1769).

The literature review recorded 63 species (Vaz 1984, Tribe, 1987, Plano de Manejo 2006, Dias & Peracchi 2007, Dias et al. 2008, Dias & Peracchi 2008, Moratelli et al. 2011, Lourenço et al. 2014), 35 of non-volant mammals and 28 of bats (Table 1).

Summing up all kind of records 85 mammal species were registered, distributed in nine orders and 27 families. The orders that most contributed to species richness were Chiroptera with 28 species (33%), Rodentia with 19 species (22%) and Carnivora with 15 species (16.6%). Didelphimorphia contributed with 9 species (10%), Primates with five species (6%), Artiodactyla and Cingulata with three each (3.5%), Pilosa with two species (2.3%) and Lagomorpha with one species (1.2%). Five species were exotic: *Felis catus*, *Canis lupus familiaris*, *Rattus rattus*, *Rattus norvergicus* and *Callithrix jacchus*.

The total of mammals recorded in TBR corresponds to approximately 50% of the native terrestrial mammal species of the Rio de Janeiro state (Rocha et al. 2004), 27% of Atlantic Forest mammals and 13% of the endemic ones (Paglia et al. 2012). Twelve species (15%) recorded in TBR are in some threat categories at state level (Bergallo et al. 2000), seven species (9%) at national level (MMA 2014) and two species (2.6%) are in some threat categories of IUCN (IUCN 2017) (Table 1).

## Discussion

This study reports the first comprehensive list of the mammals of the region of Tinguá Biological Reserve, providing the most complete "picture" of what we know about TBR's mammals. Despite the widespread defaunation scenery of Atlantic forest (Canale et al. 2012, Galetti et al. 2016), the TBR still harbor populations of large frugivores and apex predators like brocket deer, white lipped peccary and cougar, besides several mesopredators. TBR is one of the last shelters for large mammals in Rio de Janeiro and the last one in the northern portion of the Serra do Mar ecoregion. For example, TBR is the only refuge for white-lipped peccaries from the central region of the state up to the extreme north. No protected area north of TBR has currents sightings of the species in recent years (Araújo et al. 2008, Modesto et al. 2008a, 2008b, Pessôa et al. 2009, Carvalho et al. 2014). The red-brocket deer, by its turn, was recorded by one opportunistic sighting and three reports, one with a photo of an individual slaughtered inside the TBR (Figure 1). According to Duarte et al. (2016) Rio de Janeiro state is out of the geographic distribution of the species but our results together with the records in the Parque Nacional da Serra da Bocaina (Delciellos et al., 2012), Parque Nacional do Itatiaia (Aximoff et al. 2015) and Reserva Biológica Poço das Antas (Araújo et al., 2008) suggest that this interpretation should be revised.

The TBR is the second one in number of mammals already recorded in "Serra do Mar" ecoregion of Atlantic Forest and in Rio de Janeiro state, with 80 native species, exceeded only by Itatiaia National Park, and followed by Serra dos Órgãos National Park, with 106 and 75 species respectively (Table 2). However, these two protected areas are among the best sampled in Rio de Janeiro (e.g. Schirch 1932, Ávila-Pires & Gouveia 1977, Tribe 1987, Geise et al. 2004, Loretto & Rajão 2005, Cunha 2007, Macedo et al. 2007, Olifiers et al. 2007), so an increase in the sampling effort could reveal an even more important role for TBR. Small mammals, for example, are clearly underrepresented, as there is only one previous surveys carried out by Vaz (1984). The number of rodent species can be considered low when compared with other Serra do Mar study areas (Geise et al. 2004, Olifiers et al. 2007). Studies focused on these groups and the use of other methodologies not used in this study and able to detect inconspicuous species, like pit-falls and camera-traps (e.g. Srbek-Araujo & Chiarello 2005, Pardini & Umetsu 2006), could increase the number of species and are strongly recommended.

For bats, the studies carried out by Dias & Peracchi (2008) and Lourenço et al. (2014) resulted in a number of species similar to other localities (Table 2). However, the absence of records of species present in other areas of Rio de Janeiro's Atlantic Forest (eg. *Chrotopterus auritus*, *Trachops cirrohsus* and *Noctilio leporinus*) also suggests that TBR is undersampled and that other species can be recorded with

**Table 1.** Mammals recorded to the Tinguá Biological Reserve or around them, Rio de Janeiro state. The types of records were sighting in transection (T), opportunistic sighting (O), footprints (F), recorded in literature (L), museum collection (M) and report (R). For species registered only by reports the year in which the species was observed is provided in parentheses. Classification in categories of threatened species are according to Bergallo et al.(2000) at state level, Environment Ministry list (2014) at national level and IUCN (2015) at world level. Codes of threat degree are DD (deficient data), LC (least concern), PT (presumably threatened), NT (near threatened), VU (vulnerable), EN (endangered), CR (critically endangered), PEX (probably extinct) and EX (extinct). Species assigned with an asterisk are endemic of the Atlantic Forest. For species at the museum collection, the number of the considered exemplars are provided at the end of the table.

| Species | Common name | Type of record | Risk category | | |
|---|---|---|---|---|---|
| | | | RJ | BR | IUCN |
| **Didelphimorphia** | | | | | |
| **Didelphidae** | | | | | |
| *Caluromys philander* (Linnaeus, 1758) | Bare-tailed woolly opossum | L | | | LC |
| *Chironectes minimus* (Zimmermann, 1780) | Water opossum | L | | | LC |
| *Didelphis aurita* (Wied-Neuwied, 1826) * | Big-eared opossum | T, O, L, M | | | LC |
| *Gracilinanus microtarsus* (Wagner, 1842) * | Brazilian gracile opossum | M | | | LC |
| *Marmosops incanus* (Lund, 1840) | Gray slender opossum | M | | | LC |
| *Metachirus nudicaudatus* (É. Geoffroy, 1803) | Guianan brown four-eyed opossum | L, M | | | LC |
| *Marmosa paraguayanus* (Tate, 1931) | Tate's woolly mouse opossum | M | | | LC |
| *Monodelphis americana* (Müller, 1776) | Northern three-striped opossum | L, M | | | LC |
| *Philander frenatus* (Olfers, 1818) * | Southeastern four-eyed opossum | T, L, M | | | LC |
| **Cingulata** | | | | | |
| **Dasypodidae** | | | | | |
| *Cabassous tatouay* (Desmarest, 1804) | Greater naked-tailed armadillo | T, L, M | | | LC |
| *Dasypus novemcinctus* Linnaeus, 1758 | Nine-banded armadillo | T, L, M | | | LC |
| *Euphractus sexcinctus* (Linnaeus, 1758) | Six-banded armadillo | O | | | LC |
| **Pilosa** | | | | | |
| **Bradypodidae** | | | | | |
| *Bradypus variegatus* Schinz, 1825 | Brown-throated sloth | O, L | | | LC |
| **Myrmecophagidae** | | | | | |
| *Tamandua tetradactyla* (Linnaeus, 1758) | Southern tamandua | T, L | | | LC |
| **Primates** | | | | | |
| **Atelidae** | | | | | |
| *Alouatta guariba* (Humboldt 1812)* | Brown howler monkey | T, L, M | | VU | LC |
| *Brachyteles arachnoides* (É. Geoffroy, 1806) | Southern muriqui | R (1990) | CR | EN | EN |
| **Callitrichidae** | | | | | |
| *Callithrix jacchus* (Linnaeus, 1758) | Common marmoset | T, O, L, M, R | | | LC |
| *Leontopithecus rosalia* (Linnaeus, 1766)* | Golden lion tamarin | M | EN | EN | EN |
| **Cebidae** | | | | | |
| *Sapajus nigritus* (Goldfuss, 1809)* | Black capuchin | T, L, M | | | NT |
| **Carnivora** | | | | | |
| **Canidae** | | | | | |
| *Canis lupus familiaris* Linnaeus, 1758 | Domestic dog | T, O | | | - |
| *Cerdocyon thous* (Linnaeus, 1766) | Crab-eating fox | T, O, L, M | | | LC |
| *Chrysocyon brachyurus* (Illiger, 1815) | Maned Wolf | F | | VU | NT |
| **Procyonidae** | | | | | |
| *Nasua nasua* (Linnaeus, 1766) | South american coati | T, O, L, M | | | LC |
| *Potus flavus* (Schreber, 1774) | Kinkajou | O, L, R | | | LC |
| *Procyon cancrivorus* (G. [Baron] Cuvier, 1798) | Crab-eating raccoon | T, L | | | LC |
| **Mustelidae** | | | | | |
| *Eira barbara* (Linnaeus, 1758) | Tayra | T, L, M | | | LC |
| *Lontra longicaudis* (Olfers, 1818) | Neotropical otter | R (2009) | | | NT |

**Continued Table 1.**

| Species | Common name | Type of record | Risk category | | |
|---|---|---|---|---|---|
| | | | **RJ** | **BR** | **IUCN** |
| *Galictis cuja* (Molina, 1782) | Lesser grison | T, L, M | | | LC |
| **Felidae** | | | | | |
| *Felis catus* Linnaeus, 1758 | Domestic cat | O | | | - |
| *Leopardus* sp. Gray, 1842 (*L. guttulus* or *L. wiedii*) | Southern tiger cat or Margay | T, L | -/VU | VU/VU | VU/NT |
| *Leopardus pardalis* (Linnaeus, 1758) | Ocelot | T, L | VU | - | LC |
| *Panthera onca* (Linnaeus, 1758) | Jaguar | R (1990) | VU | VU | NT |
| *Puma concolor* (Linnaeus, 1771) | Cougar | F, L, R | | VU | LC |
| *Puma yagouaroundi* (É. Geoffroy Saint-Hilare, 1803) | Jaguarondi | O | | VU | LC |
| **Artiodactyla** | | | | | |
| **Tayassuidae** | | | | | |
| *Pecari tajacu* (Linnaeus, 1758) | Collared peccary | T, O, L, M, R | VU | | LC |
| *Tayassu pecari* (Link, 1795) | White-lipped peccary | T, O, L, R | EN | VU | VU |
| **Cervidae** | | | | | |
| *Mazama* cf. *americana* (Erxleben, 1777) | Red-brocket deer | O, R | EN | - | DD |
| **Rodentia** | | | | | |
| **Sciuridae** | | | | | |
| *Guerlinguetus ingrami* (Thomas, 1901) * | Southeastern squirrel | T, O, L, M | | | LC |
| **Muridae** | | | | | |
| *Rattus rattus* (Linnaeus, 1758) | Black rat | M | | | LC |
| *Rattus norvegicus* (Berkenhout, 1769) | Brown rat | M | | | LC |
| **Cricetidae** | | | | | |
| *Akodon cursor* (Winge, 1887) | Grass mouse | L, M | | | LC |
| *Akodon serrensis* Thomas, 1902 * | Grass Mouse | M | | | LC |
| *Calomys* sp. Waterhouse, 1837 | Laucha | M | | | - |
| *Euryoryzomys* sp. Weksler, Percequillo & Voss, 2006 | Rice Rat | M | | | - |
| *Necromys lasiurus* (Lund, 1841) | Hairy-tailed bolo mouse | M | | | LC |
| *Nectomys squamipes* (Brants, 1827) | South american water rat | L, M | | | LC |
| *Oligoryzomys* sp. Bangs, 1900 | Rice rat | M | | | - |
| *Oxymycterus* sp. Waterhouse, 1837 | Hocicudo | L, M | | | - |
| **Caviidae** | | | | | |
| *Cavia* sp. Pallas, 1766 | Guinea pig | O, M | | | - |
| **Hydrochoeridae** | | | | | |
| *Hydrochoerus hydrochaeris* (Linnaeus, 1766) | Capybara | F, L | | | LC |
| **Agoutidae** | | | | | |
| *Cuniculus paca* (Linnaeus, 1758) | Spotted paca | T, O, F, L, M | VU | - | LC |
| **Dasyproctidae** | | | | | |
| *Dasyprocta aguti* (Linnaeus, 1766) | Red-rumped agouti | T, O, F, L | | | - |
| **Erethizontidae** | | | | | |
| *Coendou spinosus* (F. Cuvier, 1823) | Paraguay hairy dwarf porcupine | T, O, L | | | LC |
| **Echimyidae** | | | | | |
| *Euryzygomatomys spinosus* (G. Fisher, 1814) | Guiara | M | | | LC |
| *Kannabateomys amblyonyx* (Wagner, 1845) * | Atlantic Bamboo Rat | T, L, M | VU | | LC |
| *Trinomys dimidiatus* (Günther, 1877) * | Soft-spined Atlantic Spiny-rat | L, M | | | LC |

**Continued Table 1.**

| **Species** | **Common name** | **Type of record** | **Risk category** | | |
|---|---|---|---|---|---|
| | | | **RJ** | **BR** | **IUCN** |
| **Lagomorpha** | | | | | |
| **Leporidae** | | | | | |
| *Sylvilagus brasiliensis* (Linnaeus, 1758) | Tapeti | T, O, L, M | | | LC |
| **Chiroptera** | | | | | |
| **Emballonuridae** | | | | | |
| *Peropteryx macrotis* (Wagner, 1843) | Lesser dog-like bat | L | | | LC |
| *Saccopteryx leptura* (Schreber, 1774) | Lesser sac-winged bat | L | | | LC |
| **Phyllostomidae** | | | | | |
| *Anoura caudifer* (E. Geoffroy, 1818) | Tailed tailless bat | L, M | | | LC |
| *Anoura geoffroyi* Gray, 1838 | Geoffroy's tailless bat | L | | | LC |
| *Dermanura cinereus* (Gervais, 1856) | Gervais' fruit-eating bat | L | VU | - | LC |
| *Artibeus fimbriatus* Gray, 1838 | Fringed fruit-eating bat | L | | | LC |
| *Artibeus lituratus* (Olfers, 1818) | Great fruit-eating bat | L | | | LC |
| *Artibeus obscurus* (Schinz, 1821) | Dark fruit-eating bat | L | | | LC |
| *Carollia perspicillata* (Linnaeus, 1758) | Seba's short-tailed bat | L | | | LC |
| *Desmodus rotundus* (E. Geoffroy, 1810) | Common vampire bat | L | | | LC |
| *Diphylla ecaudata* Spix, 1823 | Hairy-legged vampire bat | L | | | LC |
| *Glossophaga soricina* (Pallas, 1766) | Pallas's long-tongued bat | L | | | LC |
| *Lonchophylla peracchii* Dias, Esbérard & Moratelli, 2013* | Peracchi's nectar bat | L | VU | - | - |
| *Micronycteris microtis* Miller, 1898 | Common big-eared bat | L | | | LC |
| *Mimon bennettii* (Gray, 1838) | Southern golden bat | L | VU | - | LC |
| *Platyrrhinus lineatus* (Thomas, 1901) | White-lined broad-nosed bat | L | | | LC |
| *Platyrrhinus recifinus* (E. Geoffroy, 1810) | Recife broad-nosed bat | L | VU | - | LC |
| *Pygoderma bilabiatum* (Wagner, 1843) | Ipanema broad-nosed bat | L | | | LC |
| *Sturnira lilium* (E. Geoffroy, 1810) | Little yellow-shouldered bat | L | | | LC |
| *Tonatia bidens* (Spix, 1823) | Greater round-eared bat | L | | | DD |
| *Vampyressa pusilla* (Wagner, 1843) | Southern little yellow-eared bat | L | | | DD |
| **Molossidae** | | | | | |
| *Molossus molossus* (Pallas, 1766) | Pallas's mastiff bat | L, M | | | LC |
| *Molossus rufus* E. Geoffroy, 1805 | Black mastiff bat | L | | | LC |
| **Vespertilionidae** | | | | | |
| *Eptesicus brasiliensis* (Desmarest, 1819) | Brazilian brown bat | L | | | LC |
| *Myotis nigricans* (Schinz, 1821) | Black myotis | L | | | LC |
| *Myotis riparius* Handley, 1960 | Riparian myotis | L | | | LC |
| *Myotis ruber* (E. Geoffroy, 1806) | Red myotis | L | VU | - | NT |
| *Myotis izecksohni* Moratelli, Peracchi, Dias & Oliveira, 2011* | Izecksohn's myotis | L | | | - |

**Da*: MN 5857, 5794, 5797, 5795, 5792, 5861, 5862, 5856, 5860, 5859, 5858, 5855, 5863, 5864, 5812, 5796, 5793, 5808, 5813, 5811, 42826, 50638, 51877, 51873, 51877, 51878, 28895, 28825, 28835, 28841, 5799, 5798, 5801, 5800, 28913, 50672; *Gm*: MN 53886; *Mi*: MN 27826; *Mn*: MN 5805, 5806; *Mp*: MN 28594, 42823, 50639, 51876; *Ma*: MN 10209; *Pf*: MN 50653, 5807, 5804, 5802, 25610, 25308, 25018, 27100, 25017, 26628, 8235, 1203; *Ct*: MN 1854; *Dn*: MN 1853, 2432, 2433, 10044, 10070, 10073,10079; *Ag*: MN: 30474; *Cj*: MN 30492; *Lr*: MN 1834; *Sn*; 31859; *Ct*: MN 25596; *Nn*: MN 3059, 3060, 5835, 8482; *Eb*: MN 7309; *Gc*: MN 5809, 29985; *Pt*: MN -; *Gi*: MN 30491; *Rr*: MN 30512, 52419, 52420, 52421, 53309, 53310, 53311, 53312, 53313, 53314; *Rn*: MN 42827, 59421; *Ac*: MN 2225, 5827, 5822, 5823, 26792, 25741, 26810, 28928, 30726, 30730; *As*: MN 51664; *Calomys* sp.: MN 60536; *E* sp.: MN 5824; *Nl*: MN 25029; *Ns*: MN 5826, 6468, 28542, 28840, 28844, 28955, 28991, 30129, 30142, 42827, 42828, 42829, 61792, 61793, 61794, 61795, 61991; *Oligoryzomys* sp.: MN 50723, 53887; *Oxymycterus* sp.: MN 2226, 5814, 5825, 26854, 28553, 28829, 30135, 30138, 42824; *Cavia* sp.: MN 43273; *Cp*: MN 50400; *Es*: MN 50721, 53885; *Ka*: MN 61811; *Td*: MN 4941, 4942, 4943, 4944, 4945, 4946, 4947, 4948, 4949, 4950, 4951, 4953, 4954, 8302, 21098, 34488; *Sb*: MN 2436, 24068, 50704; *Ac*: MN 43084, 43269, 43305; *Mm*: MN 47138, 50084, 50085.

**Figure 1.** Some of medium and large-sized mammals of Tinguá Biological Reserve, Rio de Janeiro, Brazil. a) Nine-banded armadillo (*Dasypus novemcinctus*); b) Brown-throated sloth (*Bradypus variegatus*); c) Southern tamandua (*Tamandua tetradactyla*); d) South american coati (*Nasua nasua*); e) paca (*Cuniculus paca*); f) Paraguay hairy dwarf porcupine (*Coendou spinosus*); g) white-lipped-peccari (*Tayassu pecari*) shot by poachers and seized by federal police; h) Red-brocket deer (*Mazama* cf. *americana*) hunted in Tinguá Biological Reserve; i) Footprint of maned wolf (*Chrysocyon brachyurus*); j) Footprint of cougar (*Puma concolor*).

adequate sampling effort. In recent years, two new species of bats were assigned in TRB (Moratelli et al. 2011, Dias et al. 2013). *Lonchophylla peracchii* was described from specimens that had been first identified as *L. bokermanni* (Dias et al. 2013). *Myotis izecksohni,* previously identified as *M. levis,* had their types collected in TRB (Moratelli et al. 2011). This fact suggests that other new species can be hidden under cryptic taxa, reinforcing the importance of taxonomic studies.

Two species recorded by reports were no longer seen at TBR. The southern muriqui *Brachyteles arachnoides* (É. Geoffroy, 1806) was recorded in 1979 by an amateur ornithologist, Romildo de Mello, by a former poacher in the 1980s and by one of the authors in the 1990s, but its currently presence in TBR requires confirmation. The literature confirms the occurrence of the jaguar *Panthera onca* in Tinguá region in late 1960 decade (Silveira 1968) and we obtained two reports by former

**Table 2.** Inventories of mammals in Ombrofilous Dense Atlantic Rainforest and Semideciduous and their respective areas of study. Medium mammals included *Cavia*, *Guerlinguetus* and *Didelphis*.

| Local Protected area/State | Area (ha) | Bats | Small mammals | Medium and large mammals | Total | Reference |
|---|---|---|---|---|---|---|
| Reserva Biológica Augusto Ruschi/Espírito Santo | 4000 | - | - | 29 | 29 | Gatti et al. 2014 |
| Estação Biológica de Santa Lúcia/Espírito Santo | 440* | - | 18 | 30 | 48 | Passamani et al. 2000 |
| Duas Bocas Biological Reserve/Espírito Santo | 2910 | - | 22 | 17 | 39 | Tonini et al. 2010 |
| Desengano State park/Rio de Janeiro | 22400 | 15 | 18 | 23 | 56 | Modesto et al. 2008a |
| Reserva Ecológica de Guapiaçú/Rio de Janeiro | 7300 | 33 | 9 | 22 | 64 | Pessoa 2009, Santos 2013, Carvalho et al. 2014 |
| Poço das Antas Biological Reserve/Rio de Janeiro | 5052 | 25 | 24 | 28 | 77 | Brito et al. 2004 |
| Serra dos Órgãos National Park/Rio de Janeiro | 20024 | 16 | 25 | 41 | 82 | Cunha 2007, Moratelli & Peracchi 2007, Olifiers et al. 2007, Aximoff et. al. 2015 |
| **Tinguá Biological Reserve/Rio de Janeiro** | **24812** | **28** | **21** | **36** | **85** | **This study** |
| Itatiaia National Park/Rio de Janeiro-Minas Gerais | 28084 | 29 | 33 | 44 | 106 | Ávila-Pires & Gouveia 1977, Geise et al. 2004, Aximoff et. al. 2015, Martins et al. 2015 |
| Rio das Pedras Reserve/Rio de Janeiro | 1360 | - | 12 | 11 | 23 | Pessôa et al. 2009 |
| Bocaina National Park/Rio de Janeiro - São Paulo | 104000 | 10 | 17 | 21 | 48 | Delciellos et al. 2012 |
| Pedra Branca – Paraty -edge of Bocaina National Park | - | - | 16 | 17 | 33 | Vaz 2005 |
| Núcleo Picinguaba - Serra do Mar State Park/São Paulo | 47500 | - | 19 | 8 | 27 | Pinheiro & Geise 2008 |
| Núcleo Santa Viginia - Serra do Mar State Park/São Paulo | 17000 | - | 23 | 35 | 58 | Rocha et al. 2015 |
| Núcleo Caraguatatuba - Serra do Mar State Park/São Paulo | 49953 | - | - | 18 | 18 | Norris et al. 2012 |
| Morro Grande Forest Reserve/São Paulo | 10870 | - | 22 | 18 | 40 | Negrão & Valadares-Pádua 2006, Pardini & Umetsu 2006 |
| Carlos Botelho State Park/São Paulo | 37644 | - | 18 | 35 | 53 | Brocardo et al. 2012 |
| Alto Ribeira Touristic State Park/São Paulo | 35772 | - | - | 24 | 24 | Meirelles 2009 |

poachers that described the killing of two individuals, an young male (whose carcass weighed approximately 30 kg) in the early 1980s and one adult in the early 1990s. The loss and fragmentation of the habitat and hunting pressure (and competition with human hunters by the same prey species) can have extinguished the jaguars in TBR.

Another species previously recorded in the museum collection and not found nowadays was the golden-lion-tamarin *Leontopithecus rosalia* Linnaeus, 1766. The species was collected in Duque de Caxias municipality, locality of "Serra do Barro Branco" in 1939, near the area that would later become TBR. This record suggests that the lower slopes of TBR once housed a *L. rosalia* population, confirming the distribution of this species in the "Baixada Fluminense" (Coimbra-Filho 1969). This locality is in the same mountain range where a group of the species was recorded recently (Burity et al. 2007).

Some species which potential distribution includes the TBR and were never recorded in the area were the bush dog *Speothos venaticus* (Lund, 1842), a specialist carnivore, and large Insectivores and frugivores like *Myrmecophaga tridactyla* (Linnaeus, 1758) and *Tapirus terrestris* (Linnaeus, 1758) respectively. Although there are scarce records of lowland tapirs in Rio de Janeiro state (Schirch 1932, Ávila-Pires & Gouveia 1977, Spix & Martius 1981), the habitat of TBR is very similar of contiguous Serra dos Órgãos where the species was seen by early naturalists (Schirch 1932, Spix & Martius 1981). Therefore, it seems that these species are also locally extinct at TBR.

We also did not record medium and small species that have potential distribution for this portion of Serra do Mar including the nine-banded armadillo *Dasypus septemcinctus*, the marmoset *Callithrix aurita*, the titi monkey *Callicebus nigrifrons*, small rodents (*Phylomys*, *Dellomys*, *Juliomys*, *Thaptomys*) and some bats (*Chrotopterus auritus*, *Trachops cirrohsus* and *Noctilio leporinus*) among others species. These absences can be a methodological artifact, because few studies were long-term and some TRB areas, especially the most inaccessible stretches, were never sampled. However, the arrival of exotic invasive species can be an alternative explanation for the absence of some of them. *Rattus rattus* and *Rattus norvergicus*, for example, were reported in TRB for the first time in the 1940s. These rodents are effective competitors with small native rodents and can even prey upon some of them (e.g. Banks & Hughes 2012). *Calithrix jacchus*, by its turn, can also have negative impacts in other primate populations (e.g. Ruiz-Miranda et al. 2006). Besides these species, this study report for the first time the presence of *Felis catus* and *Canis lupus familiaris* within TBR. These animals, by their turn, have negative impacts on mammal population within protected areas (Galetti & Sazima 2006, Lessa et al. 2016).

Inversely, the unexpected presence of the maned-wolf *Chrysocyon brachyurus* Illiger, 1815 was first documented in TBR. This species is typical from the cerrado but has been recorded in areas previously occupied by humid forests in the southeast coastal region (Queirolo et al. 2011). The process of savanization of the Atlantic Forest can be an important factor for the range expansion of this species (Sampaio et al. 2017).

The field sampling carried out in this study was useful to update the first TBR mammal list and show that species recorded by Vaz (1984) are still there. In comparison with other surveys in Atlantic Forest reserves (Cunha 2007, Norris et al. 2012, Rocha-Mendes et al. 2015), linear transects in TBR recorded more species of meso-predators. Besides the conservation status of the area, the record of many species of medium carnivores could be due to the use of local field workers, who are highly familiar with the forest and its local fauna, perceiving the signs of them easily, including the most inconspicuous ones.

In summary, our results show that TBR still maintains a high richness of mammals, and it is an important remnant to conserve medium and large-sized Atlantic Forest mammals. This patch was able to conserve populations of large game species like white lipped peccaries and can be a source of individuals to recolonize other areas, naturally or through reintroduction initiatives. It can also receive reintroduction initiatives provided that hunting pressure is controlled. Mammalogists and mammal ecologists have much work ahead, with low logistical investment due to its proximity to the large urban centers. Considering that hunting is still a significant presence in TBR interior, we recommend that population estimates of large mammals be produced and poaching effects investigated. The sampling of less studied groups such as Rodentia, Chiroptera, and Didelphimorphia would also be desirable. Most studies have been performed around a dirt road that cuts the TBR, while more remote areas remain without any sampling. The sampling of these areas and the use of the pitfalls, camera-traps and live-traps along all the altitudinal gradient, with appropriate sampling effort, could increase the number of species for the Reserve. All these efforts to know TBR species, however, will not be worth if the area continues to be neglected by the high levels of administration of protected areas in Brazil. Besides hunting, internal fragmentation and exotic species, TBR is threatened by the urban growth around it and the pressure to reduce its area and its protection level. If nothing is done to contain these threats, one of the best representatives of what was the mastofauna of the Atlantic Forest in the state of Rio de Janeiro may become just another example of an empty forest.

## Acknowledgments

We are very grateful to Eduardo Bernhardt, Gustavo Borges, Adilson Salino, Nery Pinto and "Seu" Walter, by help us in hard field work. Special thanks to Dr. João A. Oliveira, Mr. Sérgio Maia Vaz and Ms. Stella Maris Franco, by assistance to access the mammalian collection of Museu Nacional do Rio de Janeiro/UFRJ. We are very grateful to Instituto Chico Mendes de Conservação da Biodiversidade by logistic support by Mr. Márcio de Castro das Mercês (Agent of TBR) and, Mr. Luis Henrique dos Santos Teixeira (Director of TBR). We thank Conservation International - CEPF (*Critical Ecosystem Partnership Fund*) by financial support and Jason Cole and Ivana Lamas. We also thank *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* (CAPES), Dr. Beatriz Beisiegel and Bsc. Rogério Cunha de Paula for identifying a maned wolf footprint, Dr. José Maurício Barbanti Duarte for photographic identification of a *Mazama*. To Carlos Eduardo de Viveiros Grelle, Adrian Monjeau and an anonymous reviewer for the useful comments in earlier versions of this manuscript.

## Authors' Contributions

Leandro Travassos: Contribution to data collection; contribution to data analysis and interpretation; contribution to manuscript preparation.

Israel Dias Carvalho: Contribution to data collection.

Alexandra S. Pires: Contribution to data analysis and interpretation; contribution to critical revision, adding intellectual content.

Sérgio Nunes Gonçalves: Contribution to data collection.

Paulo Malvino Oliveira: Contribution to data collection.

Alexandre Saraiva: Contribution to data collection.

Fernando A. S. Fernandez: Contribution to critical revision, adding intellectual content.

## Conflicts of interest

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

## References

ANDREAZZI, C.S., PIRES, A.S. & FERNANDEZ, F.A.S. 2009. Mamíferos e palmeiras neotropicais: interações em paisagens fragmentadas. Oecol. Bras. 13(4): 554-574.

ARAÚJO, R.M., SOUZA, M.B. & RUIZ-MIRANDA, C.R. 2008. Densidade e tamanho populacional de mamíferos cinegéticos em duas Unidades de Conservação do Estado do Rio de Janeiro, Brasil. Iheringia, Sér. Zool. 98(3): 391-396.

ÁVILA-PIRES, F.D. & GOUVÊA, E. 1977. Mamíferos do Parque Nacional do Itatiaia. Bol. Mus. Nac. 291: 1-29.

AXIMOFF, I., CRONEMBERGER, C. & PEREIRA, F.A. 2015. Amostragem de longa duração por armadilhas fotográficas dos mamíferos terrestres em dois parques nacionais no estado do Rio de Janeiro. Oecol. Aust. 19(1): 215-231.

BANKS, P.B. & HUGHES, N. K. 2012. A review of the evidence for potential impacts of black rats (*Rattus rattus*) on wildlife and humans in Australia. Wild. Res. 39: 78-88.

BECK, H., SNODGRASS, J.W. & THEBPANYA, P. 2013. Long-term exclosure of large terrestrial vertebrates: implications of defaunation for seedling demographics in the Amazon rainforest. Biol. Conserv. 163: 115–121.

BERGALLO, H.G., FIDALGO, E.C.C., ROCHA, C.F.D., UZÊDA, M.C., COSTA, M.B. ALVES, M.A.S., VAN SLUYS, M., SANTOS, M.A., COSTA, T.C.C. & COZZOLINO, A.C.R. (Orgs.). Estratégias e Ações para a Conservação da Biodiversidade no Estado do Rio de Janeiro. Instituto Biomas. Rio de Janeiro.

BERGALLO, H.G., GEISE, L., BONVICINO, C.R., CERQUEIRA, R., D'ANDREA, P.S. ESBÉRARD, C.E., FERNANDEZ, F.A.S., GRELLE, C.E., PERACCHI, A. L., SICILIANO, S. & VAZ, S.M. 2000. Mamíferos; pp. 125-135, in: BERGALLO, H.G., ROCHA, C.F.D., ALVES, M.A.S. & VAN SLUYS, M. (eds.). A fauna ameaçada de extinção do estado do Rio de Janeiro. Editora da Universidade do Estado do Rio de Janeiro. Rio de Janeiro.

BONVICINO, C.R, OLIVEIRA, J. A. & D'ANDREA, P.S. 2008. Guia dos Roedores do Brasil., com chaves para gêneros baseadas em caracteres externos. Série de Manuais Técnicos 11. Centro Pan-Americano de Febre Aftosa - OPAS/OMS.

BROCADO, C.R., RODARTE, R., BUENO, R.S., CULOT, L. & GALETTI, M. Non-volant mammals of Carlos Botelho State Park, Paranapiacaba Forest Continuum. 2012. Biota Neotrop. 12(4): 1-11 http://www.biotaneotropica.org.br /v12n4/pt/abstract?inventory+bn02512042012 (last access at 18/september/2017)

BRITO, D., OLIVEIRA, L.C., & MELLO, M.A.R. 2004. An overview of mammalian conservation at Poço das Antas Biological Reserve, southeastern Brazil. J. Nat. Conserv. 12 (2004) 219—228.

BURITY, C.H.F., CRUZ, L.D., ROCHA, V.L., CONCEIÇÃO, N.B., LUZ, D.E., SANTOS, D.S., CAMPOS, D.C., & PISSINATI, A. 2007. Golden Lion Tamarins, *Leontopithecus rosalia* (Linnaeus, 1766) in the Taquara Municipal Natural Park (Duque de Caxias, RJ): A Southern Extension of the known Range. Neotrop. Primates 14(1): 30-31.

CANALE, G.R, PERES, C.A, GUIDORIZZI, C.E., GATTO, C.A.F., & KIERULFF, M.C.M. 2012. Pervasive Defaunation of Forest Remnants in a Tropical Biodiversity Hotspot. PLoSONE 7(8): e41671.

CARVALHO, I.D., OLIVEIRA, R., & PIRES, A.S. 2014. Medium and large-sized mammals of the Reserva Ecológica de Guapiaçú, Cachoeiras de Macacu, RJ. Biota Neotrop. 14(3): 1–9. http://dx.doi.org/10.1590/1676-06032014007414 (last access at 18/september/2017)

CHIARELLO, A.G. 1999. Effects of fragmentation of the Atlantic forest on mammal communities in south-eastern Brazil. Biol. Conserv. 89:71-82.

CHIARELLO, A.G. 2000. Influência da caça ilegal sobre mamíferos e aves das matas de tabuleiro do norte do estado Espírito Santo. Bol. Mus. Biol. Mello Leitão. 11/12: 379-396.

CHIARELLO, A.G., AGUIAR, L.M.S., CERQUEIRA, R., MELO, F.R., RODRIGUES, F.H.G. & SILVA, V.M.F. 2008. Mamíferos ameaçados de extinção no Brasil; pp. 681-702. In: MACHADO, A.B.M., DRUMMOND, G.M. & PAGLIA, A.P. (eds.) Livro vermelho da fauna brasileira ameaçada de extincão. MMA/Fundacão Biodiversitas. 1420p.

COIMBRA-FILHO, A.F. 2006. Apresentação. Rodriguésia 57(3).

COSTA, L.P., LEITE, Y.L.R. & PATTON, J.L. 2003. Phylogeography and systematic notes on two species of gracile mouse opossums, genus *Gracilinanus* (Marsupialia: Didelphidae) from Brazil. Proc. Biol. Soc. Wash. 116(2):275-292.

CULLEN Jr., L.; BODMER, R.E. & VALLADARES-PÁDUA, C. 2000. Effects of hunting in habitat fragments of the Atlantic Forests, Brazil. Biol. Conserv. 95:49-56.http://www.sciencedirect.com/science/article/pii/S0006320700000112

CULLEN Jr., L.; BODMER, R.E. & VALLADARES-PÁDUA, C. 2001. Ecological consequences of hunting in Atlantic forests patches, São Paulo, Brazil. Oryx, 35: 137-144.

CULLEN Jr., L.; BODMER, R.E.; VALLADARES-PÁDUA, C. & BALLOU, J.D. 2004. Mammalian densities and species extinctions in atlantic forest fragments: The need for population management. Pp 211-226. In: Silvius, K.M., Bodmer, R.E. & Fragoso, J.M.V. (eds.). People in Nature: Wildlife Conservation in South and Central America. Columbia University Press. New York.

CUNHA, A.A. 2007. Alterações na composição da comunidade e o status de conservação dos mamíferos de médio e grande porte da Serra dos Órgãos. In Ciência e conservação na Serra dos Órgãos (C. Cronemberger & E.B. Viveiros de Castro, orgs) IBAMA, Brasília, p. 211–224.

CUSTÓDIO, I. A. 2007. História da Paisagem da Região de Tinguá e Arredores da Baía de Guanabara, Rio de Janeiro, RJ. Dissertação de mestrado. Instituto de Pesquisas Jardim Botânico/Escola Nacional de Botânica Tropical. Rio de Janeiro.

DEAN, W. 1996. A ferro e fogo: a história e a devastação da Mata Atlântica brasileira. Companhia das Letras. São Paulo.

DELCIELLOS, A.C., NOVAES, R.L.M., LOGUERCIO, M.F.C., GEISE, L., SANTORI, R.T., SOUZA, R.F., PAPI, B.S., RAICES, D., VIEIRA, N.R., FELIX, S., DETOGNE, N., SILVA, C.C.S., BERGALLO, H.G. & ROCHA-BARBOSA, O. 2012. Mammals of Serra da Bocaina National Park, state of Rio de Janeiro, southeastern Brazil. Check List, 8(4): 675–692.

DIAS, D., ESBÉRARD, C.E.L. & PERACCHI, A.L. 2008. Riqueza, diversidade de espécies e variação altitudinal de morcegos na Reserva Biológica do Tinguá, estado do Rio de Janeiro, Brasil (Mammalia, Chiroptera); pp. 125-142, in: REIS, N.R.; PERACCHI, A.L.; & SANTOS, G.A.S.D. (Orgs.). Ecologia de morcegos. Technical Books. Londrina.

DIAS, D. & PERACCHI, A.L. 2007. Primeiro registro de *Myotis riparius* Handley (Mammalia, Chiroptera, Vespertilionidae) no estado do Rio de Janeiro, sudeste do Brasil. Rev. Bras. Zool. 24 (2): 508-511.

DIAS, D., & PERACCHI, A.L. 2008. Quirópteros da Reserva Biológica do Tinguá, estado do Rio de Janeiro, sudeste do Brasil (Mammalia: Chiroptera). Rev. Bras. Zool. 25(2): 333-369.

DIAS, D., ESBÉRARD, C.E.L. & MORATELLI, R. 2013. A new species of *Lonchophylla* (Chiroptera, Phyllostomidae) from the Atlantic Forest of southeastern Brazil, with comments on *L. bokermanni.* Zootaxa 3722 (3): 347–360.

DI BITETTI, M.S., PAVIOLO, A., FERRARI, C.A., DE ANGELO, C., & DI BLANCO, Y. 2008. Differential Responses to Hunting in Two Sympatric Species of Brocket Deer (*Mazama americana* and *M. nana*). Biotropica 40(5): 636–645.

DIRZO, R., YOUNG, H.S., GALETTI, M. CEBALLOS, G., ISAAC, N.J.B & COLLEN, B. 2014. Defaunation in the Anthropocene. Science 345, 401 (2014); DOI: 10.1126/science.1251817

DUARTE, J.M.B & VOGLIOTTI, A. 2016. *Mazama americana*. The IUCN Red List of ThreatenedSpecies2016:e.T29619A22154827. http://dx.doi.org/10.2305/IUCN.UK.20161.RLTS.T29619A22154827.en. (last access at 10/july/2017).

ESPARTOSA, K.D., PINOTTI, B.T. & PARDINI, R. 2011.Performance of camera trapping and track counts for surveying large mammals in rainforest remnants. Biodivers. Conserv. 20: 2815–2829.

FERRAZ, G., RUSSEL, G.J., STOUFFER, P.C., BIERREGAARD, R.O., PIMM, S.L. & LOVEJOY, T.E., 2003. Rates of species loss from Amazonian forest fragments. Proc. Natl. Acad. Sci. U.S.A. 100, 14069–14073.

FUNDAÇÃO S.O.S MATA ATLÂNTICA & INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS. 2009. Atlas dos remanescentes florestais da Mata Atlântica. Período 2005-2008. Relatório parcial. São Paulo.

FUNDAÇÃO S.O.S MATA ATLÂNTICA & INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS. 2010. Atlas dos remanescentes florestais da Mata Atlântica. Período 2008-2010. Dados parciais dos estados avaliados até maio de 2010. São Paulo.

FUNDAÇÃO S.O.S MATA ATLÂNTICA & INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS. 2017. Atlas dos remanescentes florestais da Mata Atlântica. Período 2016-2017. Relatório técnico. São Paulo.

GALETTI, M., DONATTI, C.I., PIRES, A.S., GUIMARÃES JR, P.R & JORDANO, P. 2006. Seed survival and dispersal of endemic Atlantic Forest palm: the combined effects of defaunation and forest fragmentation. Bot. J. Linn. Soc. 151: 141–149.

GALETTI, M., BROCARDO C.R., BEGOTTI, R.A., HORTENCI, L., ROCHA-MENDES, F., BERNARDO, C.S.S., BUENO, R.S., NOBRE, R., BOVENDORP, R.S., MARQUES, R. M., MEIRELLES, F., GOBBO, S. K., BECA, G., SCHMAEDECKE, G. & SIQUEIRA, T. 2016. Defaunation and biomass collapse of mammals in the largest Atlantic forest remnant. Anim. Conserv. 1-12.

GATTI, A., SEGATTO, B., CARNELLI, C.C. & MOREIRA, D.O. 2014. Mamíferos de médio e grande porte da Reserva Biológica Augusto Ruschi, Espírito Santo. Nat. on line. 12 (2): 61-68.

GEISE, L., PEREIRA, L.G., BOSSI, D.E.P. & BERGALLO, H.G. 2004. Pattern of Elevational Distribution and Richness of Non Volant Mammals in Itatiaia National Park and its Surroundings in Southeastern Brazil. Braz. J. Biol. 64(3B): 599-612.

IGUATEMY, M.A.; SILVA NETO, S.J., LOBÃO, A., BOVINI, M.G., BRAGA, J.M.A., NEGREIROS, F.F., LIMA, H.C., RODRIGUES, P.J.F.P., SIMÕES-JESUS, MARIELA F., HOTTZ, D., LIMA, M.S.C.; RAMOS, E., QUINET, A., SOUZA, M., PESSOA, S.V.A., KURTZ, B.C., BARROS, C.F. 2017. AN ANNOTATED CHECKLIST OF ATLANTIC RAINFOREST TREES IN SOUTHEASTERN BRAZIL, TINGUÁ BIOLOGICAL RESERVE, RIO DE JANEIRO. J. Bot. Res. Inst. Texas 11(2): 479 – 497.

INSTITUTO BRASILEIRO DO MEIO AMBIENTE E RECURSOS NATURAIS RENOVÁVEIS (IBAMA). 1996. Plano de Ação Emergencial - Reserva Biológica do Tinguá. Diretoria de Ecossistemas. Dpto de Unidades de Conservação. Brasília.

INTERNATIONAL UNION FOR CONCERVATION OF NATURE (IUCN). 2017. IUCN Red List of Threatened Species. Version 2017-1. http://www.iucnredlist.org. (last access at 16/june2017).

JORGE, M.L.S., GALETTI, M., RIBEIRO, M.C. & FERRAZ, K.M.P. 2013. Mammal defaunation as surrogate of trophic cascades in a biodiversity hotspot. Biol. Conserv. 163, 49–57.

KEUROGHLIAN, A. & EATON, D.P. 2009. Removal of palm fruits and ecosystem engineering in palm stands by white-lipped peccaries (*Tayassu pecari*) and other frugivores in an isolated Atlantic Forest fragment. Biodivers. Conserv. 18:1733–1750.

KUPREWICZ, E.K. 2013. Mammal abundances and seed traits control the seed dispersal and predation roles of terrestrial mammals in a Costa Rican Forest. Biotropica, 45(3): 333–342.

LAURANCE, W.F., LOVEJOY, T.E., VASCONCELOS, H.L., BRUNA, E.M., DIDHAM, R.K., STOUFFER, P.C., GASCON, C., BIERREGAARD, R.O., LAURANCE, S.G. & SAMPAIO, E., 2002. Ecosystem decay of Amazonian forest fragments: a 22-year investigation. Conserv. Biol. 16, 605–618.

LESSA, I., GUIMARÃES, T.C.S., BERGALLO, H.G., A. CUNHA & VIEIRA, E.M. 2016. Domestic dogs in protected areas: a threat to Brazilian mammals? Natureza & Conservacão 14(2): 46–56.

LORETTO, D. & RAJÃO, H. 2005. Novos registros de primatas no Parque Nacional do Itatiaia, com ênfase em *Brachyteles arachnoides* (Primates, Atelidae). Neotrop. Primates 13(2): 28-30.

LOURENÇO, E.C.; GOMES, L.A.C.; PINHEIRO, M.C.; PATRÍCIO, P.M.P.; FAMADAS, K.M. 2014. Composition of bat assemblages (Mammalia: Chiroptera) in tropical riparian forests. Zoologia, 31(4):361-369.

MACEDO, J., LORETTO, D., MELLO, M.C.S., FREITAS, S.R., VIEIRA, M.V. & CERQUEIRA, R. 2007. História natural dos mamíferos de uma área perturbada do Parque Nacional da Serra dos Órgãos; pp. 165-181. In Ciência e conservação na Serra dos Órgãos (C. Cronemberger & E.B. Viveiros de Castro, orgs) IBAMA, Brasília, p. 165–181.

MARTINS, M. A., CARVALHO, W. D. D., DIAS, D., FRANÇA, D. D. S., OLIVEIRA, M. B. D., & PERACCHI, A. L. (2015). Bat species richness (Mammalia, Chiroptera) along an elevational gradient in the Atlantic Forest of Southeastern Brazil. Acta Chiropterol. 17(2), 401-409.

MEIRELLES F.A. 2009. Levantamento e censo de aves e mamíferos cinegéticos no Parque Estadual Turístico do Alto Ribeira (PETAR), SP. Trabalho de Conclusão de Curso, Universidade Estadual Paulista, Rio Claro.

MENDONÇA-LIMA, A. & J. F. PACHECO. 2003. Registros recentes de falconiformes na Reserva Biológica do Tinguá, RJ. Boletim ABFPAR 6 (1):7-9.

MINISTÉRIO DO MEIO AMBIENTE. 2000. Avaliação e ações prioritárias para a conservação da biodiversidade da Mata Atlântica e Campos Sulinos. Por: Conservation International do Brasil, Fundação SOS Mata Atlântica, Fundação Biodiversitas, Instituto de Pesquisas Ecológicas, Secretaria do Meio Ambiente do Estado de São Paulo, SEMAD/Instituto Estadual de Florestas-MG. Brasília: MMA/SBF. 40 pp.

MINISTERIO DO MEIO AMBIENTE. 2014. Portaria nº444 de 17 de dezembro de 2014. http://www.in.gov.br/autenticidade.html, 00012014121800121

MINISTÉRIO DO MEIO AMBIENTE/INSTITUTO BRASILEIRO DO MEIO AMBIENTE E DOS RECURSOS NATURAIS RENOVÁVEIS. 2006. Plano de Manejo da Reserva Biológica do Tinguá, Brasília. 102 pp.

MODESTO, T.C., PESSÔA, F.S., ENRICI, M.C., ATTIAS, N., JORDÃO-NOGUEIRA, T., COSTA, L.M., ALMEIDA, J., ALBUQUERQUE, H.G., & BERGALLO, H.G. 2008a. Mamíferos do Parque Estadual do Desengano, Rio de Janeiro, Brasil. Biota Neotrop. 8(4): 153–159, http://dx.doi.org/10.1590/S1676-06032008000400015 (last access at 18/september/2017)

MODESTO, T.C., PESSÔA, F.S., JORDÃO-NOGUEIRA, T., ENRICI, M.C., COSTA, L.M., ATTIAS, N., ALMEIDA, J., RAICES,D.S.L., ALBUQUERQUE, H.G., PEREIRA, B.C., ESBÉRARD, C.E.L. & BERGALLO, H.G. 2008b. Mammals, Serra da Concórdia, state of Rio de Janeiro, Brazil. Check List, 4(3): 341–348.

MORATELLI, R. & PERACCHI, A. L. 2007. Morcegos (Mammalia, Chiroptera) do Parque Nacional da Serra dos Órgãos. In Ciência e conservação na Serra dos Órgãos (C. Cronemberger & E.B. Viveiros de Castro, orgs) IBAMA, Brasília, p. 193–210.

MORATELLI, R., PERACCHI, A.L., DIAS, D. & OLIVEIRA, J.A. 2011. Geographic variation in South American populations of *Myotis nigricans* (Schinz, 1821) (Chiroptera, Verpertilionidae), with the description of two new species. Mamm. Biol. 76: 592-607.

NEGRÃO, M.F.F. & VALLADARES-PÁDUA, C. 2006. Registro de mamíferos de maior porte na Reserva Florestal de Morro Grande, São Paulo. Biota Neotrop. 6(2): 1–13 http://www.biotaneotropica.org.br/v6n2/pt/abstract?article+bn 00506022006 (last access at 18/september/2017).

NORRIS, D., RAMIREZ, J.M., ZACCHI, C. & GALETTI, M. 2012. A survey of mid and large bodied mammals in Núcleo Caraguatatuba, Serra do Mar State Park, Brazil. Biota Netrop. 12(2): 127-133 http://www.biotaneotropica.org.br/v12n2/en/abstract? inventory+bn00312022012 (last access at 18/september/2017).

OLIIFIERS, N., CUNHA, A.A., GRELLE, C.E.V., BONVICINO, C.R., GEISE, L., PEREIRA, L.G. VIEIRA, M.V., D'ANDREA, P.S. & CERQUEIRA, R. 2007. Lista de pequenos mamíferos não-voadores do Parque Nacional da Serra dos Órgãos. In Ciência e conservação na Serra dos Órgãos (C. Cronemberger & E.B. Viveiros de Castro, orgs) IBAMA, Brasília, p. 183–192.

PARDINI, R. & UMETSU, F. 2006. Pequenos mamíferos não-voadores da Reserva Florestal do Morro Grande – distribuição das espécies e da diversidade em uma área de Mata Atlântica. Biota Neotrop. (6)2: 1-22. doi: http://dx.doi.org/10.1590/S1676-06032006000200007 (last access at 18/september/2017).

PAGLIA, A.P., FONSECA, G.A.B, RYLANDS, A.B., HERRMANN, G., AGUIAR, L.M.S., CHIARELLO, A.G., LEITE, Y.L.R., COSTA, L.P., SICILIANO, S., KIERULFF, M.C.M., MENDES, S.L., TAVARES, V.C., MITTERMEIER, R.A. & PATTON, J.L. 2012. Lista anotada dos mamíferos do Brasil. 2a edição. Occasional Papers in Conservation Biology. No.6. Conservation International. 76p.

PARRY, L., & C. A. PERES. 2015. Evaluating the use of local ecological knowledge to monitor hunted tropical-forest wildlife over large spatial scales. Ecol. Soc. 20(3): 15.

PESSÔA, F.S., MODESTO, T.C., ALBUQUERQUE, H.G., ATTIAS, N. & BERGALLO, H.G. 2009. Non-volant mammals, Reserva Particular do Patrimônio Natural (RPPN) Rio das Pedras, municipality of Mangaratiba, state of Rio de Janeiro, Brazil. Check List **5**(3): 577–586.

PINHEIRO, P.S. & GEISE, L. 2008. Non-volant mammals of Picinguaba, Ubatuba, state of São Paulo, southeastern Brazil. Bol. Mus. Biol. Mello Leitão. 23:51–59.

PERES, C.A. 2001. Synergistic effects of subsistence hunting and habitat fragmentation on Amazonian forest vertebrates. Conserv. Biol. 15: 1490–1505.

PERES C.A. & LAKE, I.R. 2003. Extent of nontimber resource extraction in tropical forests: accessibility to game vertebrates by hunters in the Amazon basin. Conserv. Biol. 17: 521–535.

PESSÔA, F.S. 2009. Comunidades de pequenos mamíferos no estado do Rio de Janeiro. Dissertação de mestrado. Universidade do Estado do Rio de Janeiro. Rio de Janeiro.

QUEIROLO, D., MOREIRA, J. R., SOLER, L., EMMONS, L. H., RODRIGUES, F. H. G.,PAUTASSO, A. A., CARTES, J. L. & SALVATORI, V. 2011. Historical and Present Geographic Distribution of *Chrysocyon brachyurus* (Carnivora: Canidae). Oryx, 45: 296-303.

RIPPLE, W. J., NEWSOME, T. M., WOLF, C., DIRZO, R., EVERATT, K. T., GALETTI, M., HAYWARD, M. W., KERLEY, G. I. H., LEVI, T., LINDSEY, P. A., MACDONALD, D. W., MALHI, Y., PAINTER, L. E., SANDOM, C. J., TERBORGH, J., VAN VALKENBURGH, B. 2015. Collapse of the world's largest herbivores. Sci. Adv. 1(4): e1400103.

ROCHA, C.F.D., BERGALLO, H.G., POMBAL-JR, J.P., GEISE, L., VAN-SLUYS, M., FERNANDES, R. & CARAMASCHI, U. 2004. Fauna de anfíbios, répteis e mamíferos do estado do Rio de Janeiro, Sudeste de Brasil. Publi. Avulsas Mus. Nac. 104: 1–24.

ROCHA-MENDES, F., NEVES, C.L., NOBRE, R.A., MARQUES, R.M., BIANCONI, G.V., GALETTI, M. Non-volant mammals from Núcleo Santa Virgínia, Serra do Mar State Park, São Paulo, Brazil. Biota Neotrop. 15(1): 1–9. http://dx.doi.org/10.1590/1676-06032014000814 (last access at 18/september/2017).

RUIZ-MIRANDA, C.R., AFFONSO, A., MORAIS, M.M., VERONA, C.E.S., MARTINS, A. & BECK, B. B. 2006. Behavioral and ecological interactions between reintroduced golden lion tamarins (*Leontopithecus rosalia* Linnaeus, 1766) and introduced marmosets (*Callithrix* spp, Linnaeus, 1758) in Brazil's Atlantic Coast Forest fragments. Braz. Arch. Biol. Technol. 49(1): 99-109.

SANTOS, C.S. 2013. Quiropterofauna da Reserva Ecológica de Guapiaçu, Cachoeiras de Macacu, RJ: considerações sobre a composição e a diversidade e comparações com comunidades de morcegos de outras áreas de Mata Atlântica no sudeste do Brasil. Dissertação de mestrado. Universidade Federal do Estado do Rio de Janeiro. Rio de Janeiro.

SCHIRCH, P.F. 1932. Contribuição ao conhecimento da fauna de Therezópolis, 960 m. Bol. Mus. Nac. 8, 77-86.

SRBEK-ARAÚJO, A.C. & CHIARELLO, A.G. 2005. Is camera-trapping an efficient method for surveying mammals in Neotropical forests? A case study in south-eastern Brazil. J. Trop. Ecol. 21: 121-125.

SRBEK-ARAÚJO, A.C. & CHIARELLO, A.G. 2007. Armadilhas fotográficas na amostragem de mamíferos: considerações metodológicas e comparação de equipamentos. Rev. Bras. Zool. 24(3): 647–656.

SILVA, L.D. & M. PASSAMANI. 2009. Mamíferos de médio e grande porte em fragmentos florestais no município de Lavras, MG. Ver. Bras. Zoociências, 11(2): 137–144.

SILVEIRA, E.K.P. 1968. Notas sobre a fauna original de vertebrados florestais nos maciços montanhosos da Guanabara. Boletim Geográfico, 203: 67-83.

SPIX, J.B.V. & MARTIUS, C.F.P. 1981. Viagem pelo Brasil: 1817-1820, 4ª edição. 46, volume I. São Paulo: Livraria Itatiaia Editora/Editora da Universidade de São Paulo. 264 pp.

TONINI, J.F.R., CARÃO, L.M., PINTO, I.S., GASPARINI, J.L., LEITE, Y.L.R. & COSTA, L.P. 2010. Non-volant tetrapods from Reserva Biológica de Duas Bocas, State of Espírito Santo, Southeastern Brazil. Biota Neotrop. 10(3): 339-351. http://www.biotaneotropica.org.br/v10n3/en/abstract?inventory+bn02710032010 (last access at 18/september/2017).

TRAVASSOS, L. 2011. Impacto da sobrecaça em populações de mamíferos e suas interações ecológicas nas florestas neotropicais. Oecol. Aust. 15(2): 380–411.

TRIBE, C.J., 1987, A mastofauna do Estado do Rio de Janeiro, com especial referência à ordem Polyprotodontia (Marsupiais). Universidade Federal do Rio de Janeiro/Museu Nacional. Rio de Janeiro.

VAZ, S.M. 1984. Lista Preliminar sobre os Mamíferos Existentes na Serra do Tinguá. Bol. FBCN 19: 749-154.

XAVIER, M.S., LEMOS, H.M., CACCAVO, A., BEZERRA, A., SECCO, H. & GONÇALVES, P.R. 2017. Noteworthy coastal records of the maned wolf, *Chrysocyon brachyurus* (Illiger, 1815), in Southeastern Brazil. BOL. SOC. BRAS. MASTOZOOLOGIA, v. 78, p. 9-13.

*Received: 29/09/2017*
*Revised: 29/01/2018*
*Accepted: 05/03/2018*
*Published online: 16/04/2018*

Biota Neotropica 18(2): e20170506, 2018
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
**Inventory**

# Phanerogamic flora and phytogeography of the Cloud Dwarf Forests of Ibitipoca State Park, Minas Gerais, Brazil

***Breno Moreira[1]*, Fabrício Alvim Carvalho[2], Luiz Menini Neto[2] & Fátima Regina Gonçalves Salimena[2]***

*[1]Universidade Federal de Juiz de Fora, Programa de Pós Graduação em Ecologia, Campus Universitário, Rua José Lourenço Kelmer, s/n, Martelos, 36036-330, Juiz de Fora, MG, Brasil*
*[2]Universidade Federal de Juiz de Fora, Departamento de Botânica, Campus Universitário, Rua José Lourenço Kelmer, s/n, Martelos, 36036-330, Juiz de Fora, MG, Brasil*
**Corresponding author: Breno Moreira, e-mail: biomota2009@hotmail.com*

MOREIRA, B.; CARVALHO, F. A.; MENINI NETO, L.; SALIMENA, F. R. G. **Phanerogamic flora and phytogeography of the Cloud Dwarf Forests of Ibitipoca State Park, Minas Gerais, Brazil**. Biota Neotropica. 18(2): e20170506. http://dx.doi.org/10.1590/1676-0611-BN-2017-0506

***Abstract:*** This study was developed in Ibitipoca State Park (ISP), a mountainous massif that stands out in the Serra da Mantiqueira, in the Southeastern Region of Brazil. The vegetation is represented by a phytophysiognomic mosaic where areas of *campos rupestres* interspersed with cloud dwarf forests predominate, at altitudes of 1100 to 1700 m.s.m. The cloud dwarf forests exist in narrow altitude belts on the mountain peaks, immersed in a layer of clouds. They form a peculiar landscape high in the mountains by the short stature of the arboreal elements and richness of lichens and bryophytes, which develop under constant condensation of humidity, low temperatures, and frequent winds. The objective of the present work was to determine the floristic composition and phytogeography of the cloud dwarf forests of ISP. Twelve monthly campaigns were conducted to collect botanical material during the years 2014 and 2015. The collected material was deposited in the collection of the CESJ Herbarium. A total of 372 species, 209 genera, and 73 families of phanerogams were found. The richest families were Orchidaceae (84 spp.), Asteraceae (39 spp.), and Melastomataceae (21 spp). The genera with the greatest wealth were *Leandra* (09 spp.), *Epidendrum* (09 spp.), *Pleurothallis* (09 spp.), *Mikania* (07 spp.), and *Miconia* (07 spp). The arboreal habit was predominant with 103 species (27.7%), followed by 83 shrubs (22.3%), 82 epiphytic herbs (22%), 80 terrestrial herbs (21.5%), and 23 lianas (6.5%). The floristic composition presents elements typical of altitude vegetation, including species of *campos rupestres* and high epiphytes richness, especially of the families Orchidaceae and Bromeliaceae. The genera with tropical distribution represent 86.5%, whereas the temperate elements represent 13.5% of the total. The cloud dwarf forests presented similarity, at the family and gender levels, with the upper montane forests of the Andes, besides phytogeographic characteristics that allow to associate them to a transition environment between the *campos rupestres* and the upper montane forests of the Southeast Region of Brazil.
***Keywords:*** *Atlantic Forest, cloud forest, conservation, dense ombrophylous forest, Serra da Mantiqueira.*

# Flora fanerogâmica e fitogeografia das Nanoflorestas Nebulares do Parque Estadual do Ibitipoca, Minas Gerais, Brasil

***Resumo:*** Este estudo foi desenvolvido no Parque Estadual do Ibitipoca (PEIB), um maciço montanhoso que se destaca na Serra da Mantiqueira, na Região Sudeste do Brasil. A vegetação é representada por um mosaico fitofisionômico onde predominam áreas de campos rupestres entremeadas às Nanoflorestas Nebulares, em altitudes de 1100 a 1700 m.s.m. As Nanoflorestas Nebulares ocorrem em cinturões de altitude estreitos, nos picos de montanhas, imersas na camada de nuvens. Formam uma paisagem peculiar no alto das montanhas, pela baixa estatura dos elementos arbóreos e riqueza de líquens e briófitas, que se desenvolvem sob constante condensação de umidade, baixas temperaturas e ventos freqüentes. O presente trabalho teve como objetivo conhecer a composição florística e fitogeografia das Nanoflorestas Nebulares do PEIB. Foram realizadas 12 campanhas mensais para coleta de material botânico, durante os anos de 2014 e 2015. O material coletado foi depositado na coleção do Herbário CESJ. Foram encontradas 372 espécies, 209 gêneros e 73 famílias de fanerógamas. As famílias de maior riqueza foram Orchidaceae (84 spp.), Asteraceae (39 spp.) e Melastomataceae (21 spp). Os gêneros com maior riqueza foram *Leandra* (09 spp.), *Epidendrum* (09 spp.), *Pleurothallis* (09 spp.) *Mikania* (07 spp.) e *Miconia* (07 spp). O hábito arbóreo foi predominante, com 103 espécies (27,7%), seguido por 83 arbustivas (22,3%), 82 ervas epífitas (22%), 80 ervas terrestres (21,5%) e 23 lianas (6,5%). A composição florística apresenta elementos típicos de vegetação de altitude, incluindo espécies de campos rupestres. Destaque para a alta riqueza de epífitas, especialmente das famílias Orchidaceae e Bromeliaceae. Os gêneros com distribuição tropical representam 86,5%, enquanto os elementos temperados representam 13,5% do total. As Nanoflorestas Nebulares apresentaram similaridade, em nível de família e gênero, com as florestas montana e altmontana dos Andes, além de características fitogeográficas que permitem associá-las a um ambiente de transição entre os campos rupestres e as florestas altomontanas da Região Sudeste do Brasil.

***Palavras-chave:*** *Conservação, Floresta Atlântica, Floresta Nebular, Floresta Ombrófila Densa, Serra da Mantiqueira.*

## Introduction

The regions of tropical mountains are considered of great importance for the conservation of natural resources, presenting high biological diversity and a high index of endemism, propitiated by the variety of environments associated with biotic and abiotic factors that provide places favorable to speciation (Martinelli 2007). These regions represent refuges and corridors for regional and continental migrations, and often have richer plant diversity than the adjacent lowlands (Martinelli 2007). Nevertheless, little is known about the ecology, biogeography, and natural history of these formations, which have unique physiognomic characteristics (Körner 1999).

The upper montane vegetation in the Southeastern Region of Brazil is constituted by a vegetative mosaic composed by forest and field formations, which vary according to the geographic region and the altitude gradients (Oliveira-Filho 2009). Changes in floristic composition related to altitudinal gradients are strongly influenced by local environmental variables, since different altimetric heights have different temperature conditions, air humidity, water availability, exposure to winds, and classes of depth and soil drainage (Rahbek 2005, Grytnes & McCain 2007, Slik et al. 2010). The increase in altitude and topographic irregularity in mountainous environments can decisively influence the heterogeneity of landscapes, interfering in the circulation of masses of air and exposure to the sun rays (Webster 1995). The influence of altitude on species diversification is complex. It is believed that the decrease in atmospheric pressure and temperature, as well as the increase in wind speed and solar radiation, may be related to high plant diversity (Körner 1999, Rahbek 2005).

The Serra da Mantiqueira is one of the largest and most important mountain chains in the Southeastern Region of Brazil (Almeida & Carneiro 1998). It houses more than half of the endangered species of the fauna of Minas Gerais, with an expressive endemism of plant species (Costa & Herrmann 2006). It extends from the Caldas Plateau and the Campos do Jordão Plateau in the south of Minas Gerais, a border with São Paulo, to the Plateau of Caparaó, on the border between Minas Gerais and Espírito Santo, with an approximate area of 13,176 km² (Moreira & Camelier 1977, Almeida & Carneiro 1998). These mountain ranges have rocks dating from the Pre-Cambrian period and later shaped by large archways in the Late Cretaceous (Teixeira & Cordani 2007). The Serra da Mantiqueira was part of a large crystalline plateau, and in the Triassic period this plateau underwent a process of bending and fracturing. After extensive erosive work and geological processes during the quaternary period, this plateau became massive, with isolated points and deep valleys (Meireles et al. 2014).

In regions of occurrence of nebular forests, there are areas with climatic and topographic conditions favorable to the regular formation of fogs. These areas present well-developed natural forests that, because they remain frequently enveloped in fog and clouds, are generally called cloud forests (Bruijnzeel et al. 2010). These forests account for only 2.5% of the total area of tropical forests in the world, with an overall surface area of approximately 380,000 km² (Bubb et al. 2004). In Brazil, they are represented mainly by the montane and upper montane rainforests along the Serra do Mar in the states of Santa Catarina, Paraná, São Paulo, and Rio de Janeiro, in small stretches of the Serra da Mantiqueira de Minas Gerais, and still high in the plateaus and mountains of the Amazon, such as Pico da Neblina and Monte Roraima (Oliveira-Filho 2009; Bertoncello et al. 2009). These forests are responsible for hidden precipitation, that is, additional water entry into the ecosystem through the fog, by interception of water through the treetops and subsequent drainage to the forest floor (Arcova 2013). Thus, for these localities, the abstraction of water from the atmosphere constitutes an important process of the hydrological cycle of the hydrographic basins (Bruijnzeel et al. 2010, Arcova 2013).

The forests of Serra da Mantiqueira are still little known, and their floristic composition and richness have been described in some places by Oliveira-Filho & Fontes (2000), França & Stehmann (2004), Meireles et al. (2008), Valente et al. (2011), Salimena et al. (2013), Meireles et al. (2014), Santiago et. al. (2018), Oliveira-Filho et al. (2013), and Pompeu et al. (2014), among others. Nevertheless, the great environmental heterogeneity presented by this mountain chain has not been sufficiently detailed (Martinelli 2007). Among the least known forest formations are the cloud dwarf forests (sensu Oliveira-Filho et al. 2013).

The aspects that involve the cloud dwarf forests are related to the fact of their immersion in the cloud layer and to the local hydrological cycle (Oliveira-Filho & Fontes 2000). They occur in narrow altitude belts, in ridges of mountainous relief, or in mountain peaks, with a distribution of species similar to archipelagos (Vazquez-Garcia 1995). The abundance, diversity, and distribution of cloud dwarf forest species are determined by global and regional climatic processes that operate on the phylogenetic lines observed over time on a geographic scale (Brown et al. 1996). The geographic distribution of the taxa is unique, being determined by their autoecological characteristics, geoclimatic barriers, climatic changes, and historical ecological processes (Brown et al. 1996). The discontinuous distribution of the altitude massifs of the Serra da Mantiqueira promotes the isolation of the cloud dwarf forests and the species that compose them, being able to restrict gene flow and to prevent the connectivity between the different populations. This process favors the occurrence of species and local endemism (Safford 1999). The species that occur in cloud dwarf forests tolerate adverse conditions such as freezing night temperatures, high temperatures during the day, frost, climatic seasonality, and physical changes such as high light intensity and low atmospheric pressure (Oliveira-Filho & Fontes 2000), with the presence of haze (Bruijnzeel et al. 2010). In addition, it is important to note that the dwarf forests are more likely to be found in high-altitude areas.

Seeking to broaden the knowledge about the altitude formations of the Serra da Mantiqueira, this study was developed with the objective of determining the floristic composition of the cloud dwarf forests of Ibitipoca State Park (ISP) and the contribution of the tropical and temperate distribution elements in this phytophysiognomy.

## Material and Methods

### 1. *Study area*

ISP is located in Minas Gerais, between the municipalities of Lima Duarte, Bias Fortes, and Santa Rita do Ibitipoca, at coordinates 21º40'-21º44 'S and 43º52'-43º55' W and covers an area of 1,488 ha. The region's climate is classified as Cwb, according to Köppen (1948), with dry winters and rainy and mild summers. The Serra do Ibitipoca has relief formed by high escarpments or hills, with variable altitudes between 1100 m and 1784 m (Rodela & Tarifa 2002) (Figure 1).

ISP is one of the many areas of rocky outcropping in Southeastern Brazil, where there are Proterozoic metastatic rocks of the Andrelândia Group, mainly quartzites and schists, which are on a basement formed of orthogneisses and migmatites belonging to the Mantiqueira Group (Nummer 1991, Corrêa Neto & Baptista Filho 1997). Soils are acidic, alkaline, dystrophic, kaolinitic, and shallow, with little water retention capacity, and support a mosaic of complex vegetation (Dias et al. 2002).

The predominant landscape in ISP is represented by savannas and prairies, described in the literature as *campos rupestres*, and most of the forest cover is cloud dwarf forests that cover about 226 ha or 15.6% of the surface of the park (Oliveira- Filho et al. 2013). The distribution of most cloud dwarf forests in ISP appears to be closely related to the local drainage network, housed in depressions in the ground and in the bottom of valleys, where there is high deposition of sediment and water (Oliveira-Filho et al. 2013). The identification and recognition of the vegetative types of ISP in this work follow the proposal of Oliveira-Filho et al. (2013) (Figure 2).

### 2. *Floristic composition*

In order to evaluate the floristic composition of the cloud dwarf forests of ISP, 12 field campaigns were carried out to collect botanical material, from September 2014 to September 2015, lasting three days each, in different areas of cloud dwarf forests distributed in varying altimetric heights, between 1100 and 1700 m.s.m. The collection was performed by traversing trails inside the dwarf forests, seeking to cover as much of the area as possible, following the method of walking (Filgueiras et al. 1994). The classification of the species habit followed Gonçalves & Lorenzi (2007).

The collected material was herborized according to the techniques of Mori et al. (1989) and deposited in the collection of the CESJ Herbarium of the Federal University of Juiz de Fora (acronym according to Thiers 2016), where it was identified with the help of specialized literature and comparison with the collection of ISP already deposited in the collection, in addition to consulting specialists. The names of the angiosperm families followed the system proposed by APG IV (2016). The synonymy, the spelling and the authorship of the names of the species were conferred through Flora do Brasil 2020 (under construction). Materials deposited in the collections of the herbariums CESJ, BHCB, ESAL, and RB (acronyms according to Thiers 2016) from botanical works in ISP for more than 40 years were included in the floristic listing.

### 3. *Phytogeography*

For the phytogeography analyses, the genera were classified into seven phytogeographic groups delimited based on their current centers of diversity cited by Safford (2007). The groups are: Austral-Antarctic - from temperate regions of the Southern hemisphere; Holistic - center of diversity in temperate Northern hemisphere; Generalized Tempering; Cosmopolitan - worldwide distribution; Tropical Species - at least 5% of species on a second continent; Neotropical; and Endemic to Brazil. The geographic distribution of the species was based on the literature and on specialized sites, such as speciesLink (CRIA 2001), w3Tropicos (MBG 2014), and BFG (2015).

## Results

### 1. *Floristic composition*

A total of 372 species were recorded, distributed in 209 genera and 73 families of phanerogams, with only one species, *Podocarpus sellowii* Klotzsch (Podocarpaceae), representative of the group of gymnosperms. Of the total specimens, 337 were identified at a specific level, the remaining 28 at the gender level, and seven at the family level (Table 1).

The richest families are Orchidaceae (84 spp.), Asteraceae (39 spp.), Melastomataceae (21 spp.), Bromeliaceae (20 spp.), Myrtaceae (18 spp.), and Rubiaceae (17spp) (Figure 3).

The genera with the greatest richness were *Epidendrum* (nine spp.), *Leandra* (nine spp.), *Pleurothallis* (nine spp.), *Mikania* (seven spp.), *Miconia* (seven spp.), *Tillandsia* (six spp.), *Solanum* (six spp.), and *Myrcia* (six spp.) (Figure 4).

Among the 372 species found, 103 are arboreal (27.7%), 83 shrub (22.3%), 82 epiphytic herbs (22%), 80 terrestrial herbs (21.5%), and 23 lianas (6.5%). Among the tree species, the families Myrtaceae with 17 species and Melastomataceae with 14, with greater richness, stand out. Among the shrubs, the greatest wealth is of the family Asteraceae with 21 spp., followed by Rubiaceae (eight) and Melastomataceae (seven). The terrestrial herbaceous habit was highlighted among the Orchidaceae families with 23 species, Asteraceae with nine, and Bromeliaceae with eight. Epiphytic species predominated in the Orchidaceae family, with 61 species. Among the lianas, the most representative family was Asteraceae with six species, followed by Apocynaceae and Smilacaceae with four each.

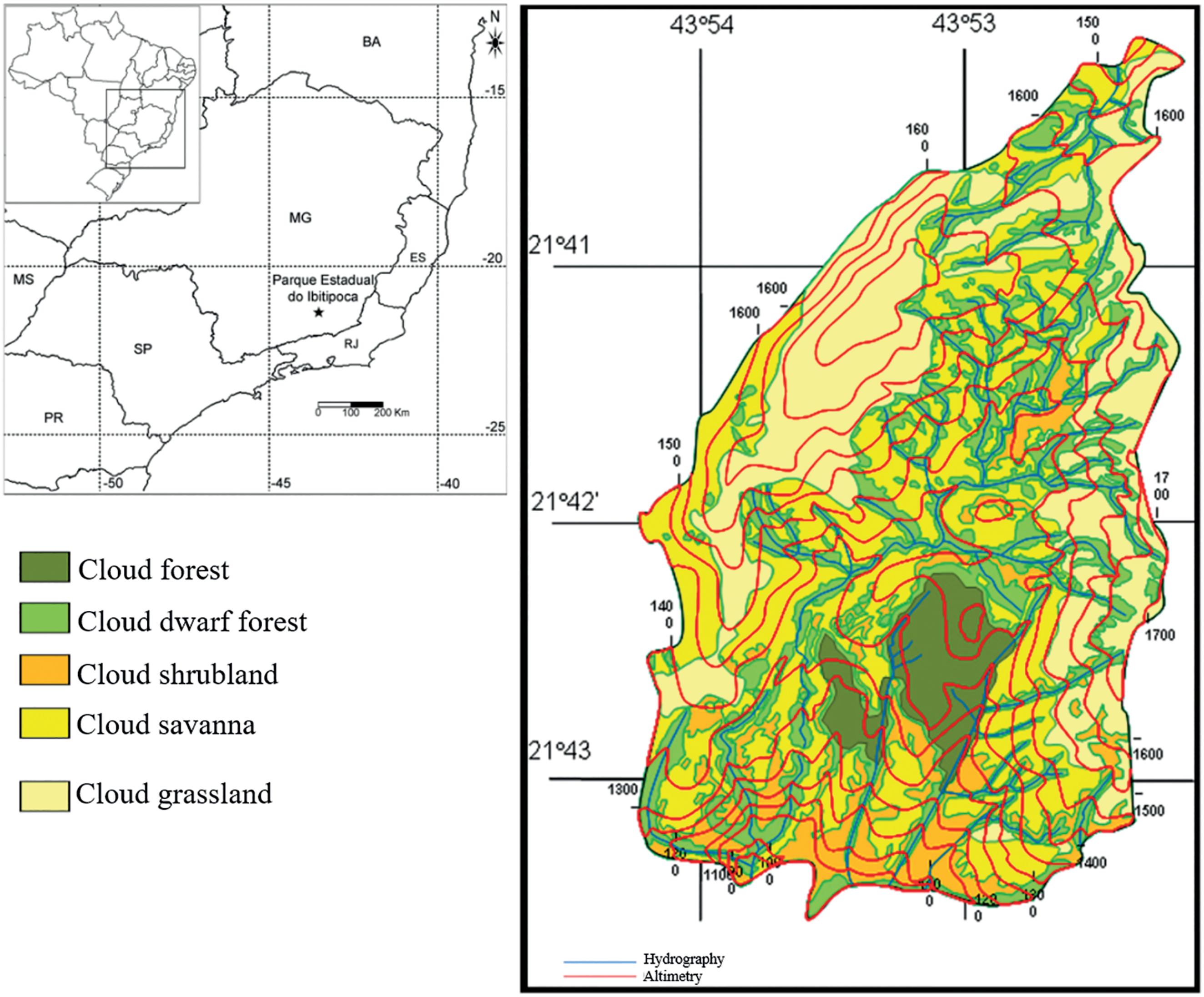

**Figure 1.** Geographic location of Ibitipoca State Park, Serra da Mantiqueira, Southeastern Brazil, with emphasis on its phytophysiognomies (adapted from Oliveira-Filho et al. 2013).

Among the species found in the cloud dwarf forests of ISP, seven have some degree of extinction threat: *Octomeria wawrae*, *Ocotea odorifera*, and *Vriesea penduliflora* classified as "endangered"; *Hindsia ibitipocensis* as "critically endangered" (CR); and *Baccharis lychnophora*, *Schlumbergera opuntioides*, and *Sinningia tuberosa* as "vulnerable" (VU) (Martinelli & Morais 2013).

### 2. *Phytogeography*

The genera with a tropical diversity center represent 86.5% of the total, distributed among 126 neotropical (60%), 45 large tropical (21.5%), and 10 endemic genera of Brazil (5%). The genus with a diversity center in temperate regions corresponded to 13.5% of the total, distributed among seven genera austral-antarctic (3.5%), one of holarian origin (0.5%), two of large temperate origin (1%), and 17 (8.5%) cosmopolitan (Table 2).

## Discussion

### 1. *Floristic composition*

In the cloud dwarf forests of ISP is the presence of a dense understory, where the arboreal individuals branch to a low height. The floristic profile presents typical characteristics of forest formations of altitude. However, it also presents characteristic species of fields and savannas (Oliveira-Filho et al. 2013). The cloud dwarf forests of ISP present a canopy of about 10 meters, with few emergent trees such as *Eugenia brasiliensis*, *Cupania zanthoxyloides*, and *Solanum mauritanium*. Just below the sub-forest, at about five meters, we can find species such as *Agarista pulchella*, *Leandra melastomoides*, *Leandra aurea*, *Myrcia splendens*, and the palm tree *Geonoma schottiana*, which has a large fruit production that serves as food for the local fauna (Oliveira-Filho et al. 2013). Soils, derived from quartzite, are generally shallow and poor in minerals, but the feedback from litter decomposition can sustain medium-sized vegetation (Oliveira-Filho et al. 2013).

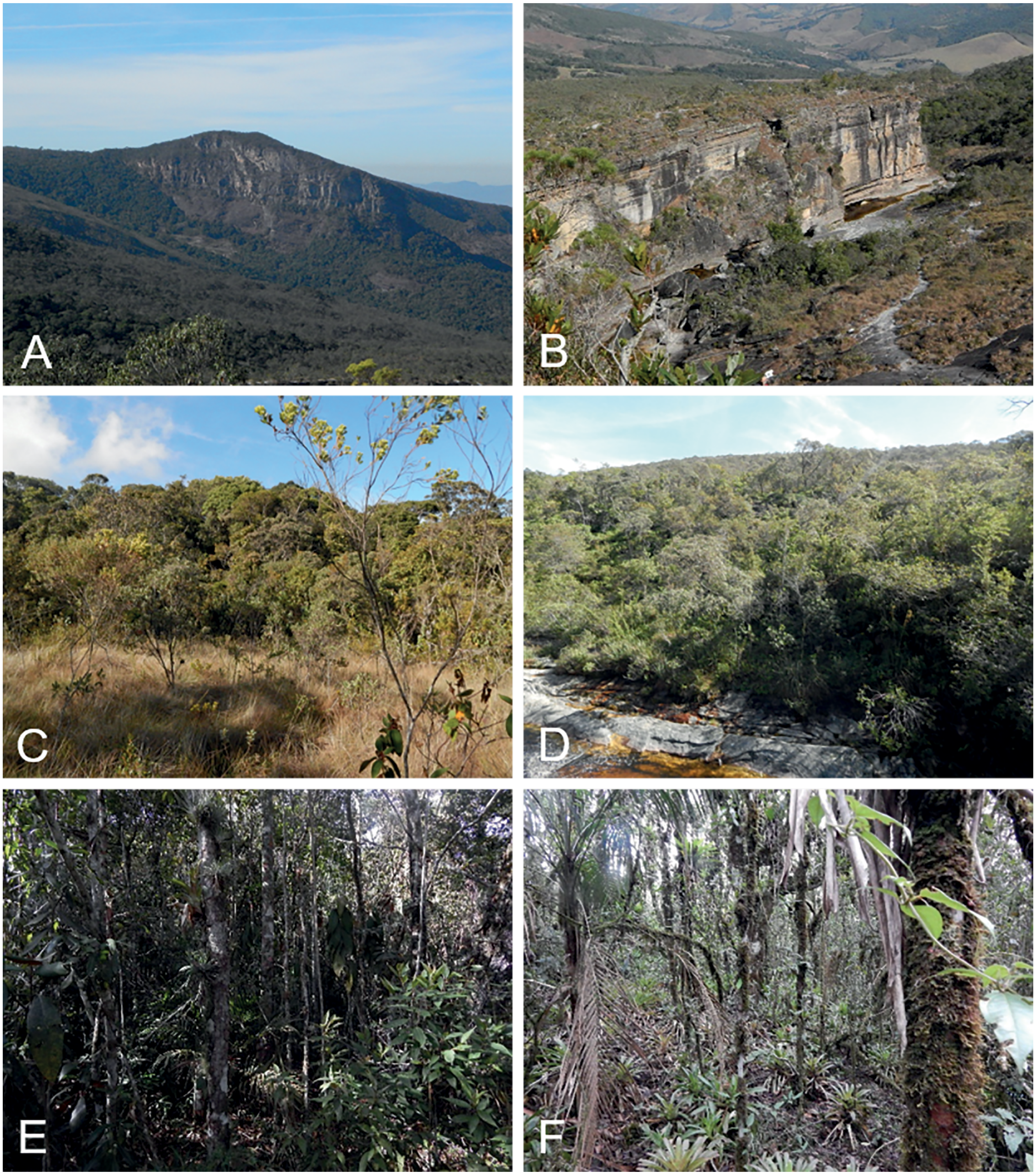

**Figure 2.** A-B. Phytophysiognomies of Ibitipoca State Park; C-D. Details of cloud dwarf forests border, highlighting the transition environments; E-F. Details of inside cloud dwarf forests, Ibitipoca State Park, Minas Gerais, Brazil.

**Table 1.** Composition of the phanerogamic flora of the cloud dwarf forests of Ibitipoca State Park, Serra da Mantiqueira, Southeastern Brazil. The species are listed by family and in alphabetical order, accompanied by the habit (Tr - tree, Sh - shrub, Li - liana, Th - terrestrial herb, Eh - epiphytic herb) and the testimonial material that is deposited in the herbariums CESJ, BHCB , ESAL, and RB.

| Family/Species | Habit | Voucher |
|---|---|---|
| **Acanthaceae** | | |
| *Justicia* sp1 | Li | B.Moreira 116 |
| *Mendoncia mollis* Lindau | Li | B.Moreira 233 |
| **Alstroemeriaceae** | | |
| *Alstroemeria cunha* Vell. | Th | B.Moreira 319 |
| **Amaranthaceae** | | |
| *Alternanthera martii* (Moq.) R.E.Fries | Sh | B.Moreira 283 |
| **Annonaceae** | | |
| *Guatteria australis* A. St-Hil. | Tr | Fontes 108 |
| **Apiaceae** | | |
| *Apiaceae* sp1 | Th | B.Moreira 332 |
| **Apocynacae** | | |
| *Aspidosperma parvifolium* A. DC. | Tr | Fontes 071 |
| *Ditassa mucronata* Mart. | Li | B.Moreira 164 |
| *Forsteronia australis* Müll.Arg. | Li | B.Moreira 036 |
| *Mandevilla pohliana* (Stadelm.) A.H.Gentry | Sh | B.Moreira 056 |
| *Oxypetalum* sp1 | Li | B.Moreira 123 |
| **Aquifoliaceae** | | |
| *Ilex paraguariensis* A.St.-Hil. | Sh | B.Moreira 060 |
| **Araceae** | | |
| *Anthurium minarum* Sakuragui & Mayo | Eh | B.Moreira 010 |
| *Anthurium scandens* (Aubl.) Engl. | Eh | B.Moreira 062 |
| *Anthurium* sp1 | Th | B.Moreira 161 |
| *Philodendron appendiculatum* Nadruz & Mayo | Th | R.C.Forzza 3638 |
| **Araliaceae** | | |
| *Schefflera angustissima* (Marchal) Frodin | Tr | B.Moreira 247 |
| *Schefflera calva* (Cham.) Frodin & Fiaschi | Tr | Fontes 068 |
| **Arecaceae** | | |
| *Geonoma schottiana* Mart. | Tr | B.Moreira 003 |
| **Asteraceae** | | |
| *Ageratum fastigiatum* (Gardner) R.M. King & H.Rob. | Sh | B.Moreira 240 |
| *Achyrocline satureioides* (Lam.) DC. | Th | B.Moreira 342 |
| *Aspilia duarteana* J.U.Santos | Sh | B.Moreira 188 |
| *Austrocritonia velutina* (Gardner) R.M.King & H.Rob | Tr | Fontes 142 |
| *Baccharis lychnophora* Gardner | Sh | B.Moreira 190 |
| *Baccharis platypoda* DC. | Sh | B.Moreira 212 |
| *Baccharis rufidula* (Spreng.) Joch. Mull. | Sh | B.Moreira 249 |
| *Baccharis serrulata* (Lam.) Pers. | Sh | B.Moreira 344 |
| *Bidens pilosa* L. | Th | B.Moreira 330 |
| *Bidens rubifolia* Kunth | Sh | B.Moreira 177 |
| *Bidens segetum* Mart. ex Colla | Sh | B.Moreira 300 |
| *Chaptalia nutans* (L.) Pol. | Th | B.Moreira 331 |
| *Chromolaena maximiliani* (Schrad. ex DC.) R.M.King & H.Rob. | Sh | B.Moreira 270 |
| *Crepis japonica* (L.) Benth. | Th | B.Moreira 277 |

**Continued Table 1.**

| Family/Species | Habit | Voucher |
|---|---|---|
| *Dendrophorbium pluricephalum* (Cabrera) C.Jeffrey | Sh | Fontes 143 |
| *Eremanthus erythropappus* (DC.) MacLeish | Tr | B.Moreira 007 |
| *Eremanthus incanus* (Less.) Less | Tr | B.Moreira 374 |
| *Eupatorium balansae* Hieron. | Sh | B.Moreira 346 |
| *Gochnatia paniculata* (Less) Cabrera | Sh | Fontes 175 |
| *Leptostelma maxima* D. Don | Th | B.Moreira 198 |
| *Lessingianthus ibitipocensis* Borges & Dematt. | Sh | B.Moreira 197 |
| *Lessingianthus* sp1 | Sh | B.Moreira 375 |
| *Mikania acuminata* DC. | Li | B.Moreira 230 |
| *Mikania buddleiifolia* DC. | Li | B.Moreira 015 |
| *Mikania burchellii* Baker | Li | B.Moreira 290 |
| *Mikania decumbens* Malme | Sh | B.Moreira 242 |
| *Mikania lindbergii* Baker | Li | B.Moreira 338 |
| *Mikania* sp1 | Li | B.Moreira 002 |
| *Mikania* sp2 | Li | B.Moreira 354 |
| *Praxelis clematidea* (Griseb.) R.M.King & H.Rob. | Sh | B.Moreira 173 |
| *Praxelis kleinioides* (Kunth) Sch. Bip. | Th | B.Moreira 238 |
| *Pseudobrickellia brasiliensis* (Spreng) R.M.King & H.Rob | Sh | Fontes 001 |
| *Senecio emiliopsis* C. Jeffrey | Th | B.Moreira 308 |
| *Taraxacum* sp1 | Th | B.Moreira 265 |
| *Trichogonia villosa* (Spreng.) Sch.Bip. ex Baker | Sh | B.Moreira 121 |
| *Tridax procumbens* L. | Th | B.Moreira 276 |
| *Trixis antimenorrhoea* (Schrank) Kuntze | Sh | B.Moreira 325 |
| *Verbesina glabrata* Hook. & Arn. | Sh | B.Moreira 137 |
| *Vernonanthura phosphorica* (Vell.) H.Rob. | Sh | B.Moreira 360 |
| **Balanophoraceae** | | |
| *Langsdorffia hypogaea* Mart. | Th | B.Moreira 262 |
| **Begoniaceae** | | |
| *Begonia angulata* Vell. | Sh | S.G.Furtado 321 |
| *Begonia rufa* Thunb. | Sh | B.Moreira 081 |
| **Bignoniaceae** | | |
| *Fridericia speciosa* Mart. | Sh | B.Moreira 049 |
| *Handroanthus albus* (Cham.) Mattos. | Tr | Fontes 133 |
| *Handroanthus chrysotrichus* (Mart. ex DC.) Mattos | Tr | Fontes 179 |
| **Boraginaceae** | | |
| *Cordia superba* Cham. | Tr | Fontes 065 |
| *Cordia* sp1 | Tr | B.Moreira 120 |
| **Bromeliaceae** | | |
| *Aechmea bromeliifolia* (Rudge) Baker | Th | Leme 1474 |
| *Aechmea nudicaulis* (L.) Griseb. | Th | R.Monteiro 13 |
| *Aechmea aiuruocensis* Leme | Th | B.Moreira 205 |
| *Billbergia alfonsijoannis* Reitz | Eh | B.Moreira 282 |
| *Billbergia distachia* (Vell.) Mez | Th | B.Moreira 005 |
| *Neoregelia ibitipocensis* (Leme) Leme | Th | R.C.Forzza 3338 |
| *Nidularium ferdinandocoburgii* Wawra | Th | B.Moreira 031 |

**Continued Table 1.**

| Family/Species | Habit | Voucher |
|---|---|---|
| *Tillandsia gardneri* Lindl. | Eh | B.Moreira 152 |
| *Tillandsia geminiflora* Brongn. | Eh | B.Moreira 026 |
| *Tillandsia stricta* Sol. | Eh | B.Moreira 038 |
| *Tillandsia tenuifolia* L. | Eh | B.Moreira 077 |
| *Tillandsia usneoides* (L.) L. | Eh | B.Moreira 288 |
| *Tillandsia* sp1 | Eh | B.Moreira 092 |
| *Vriesea bituminosa* Wawra | Th | R.F.Monteiro 28 |
| *Vriesea friburgensis* Mez | Eh | B.Moreira 030 |
| *Vriesea guttata* Linden & André | Th | R.F.Monteiro 25 |
| *Vriesea heterostachys* (Baker) L.B.Sm. | Eh | B.Moreira 185 |
| *Vriesea longicaulis* (Baker) Mez | Th | G.Martinelli 15314 |
| *Vriesea penduliflora* L.B.Sm. | Eh | B.Moreira 058 |
| *Wittrockia gigantea* (Baker) Leme | Eh | B.Moreira 232 |
| **Cactaceae** | | |
| *Hatiora salicornioides* (Haw.) Britton & Rose | Th | M.C.Brügger 21541 |
| *Lepismium houlletianum* (Lem.) Barthlott | Eh | S.G.Furtado 313 |
| *Rhipsalis floccosa* Salm-Dyck ex Pfeiff. | Th | L.Krieger 8589 |
| *Rhipsalis juengeri* Barthlott & N.P.Taylor | Eh | B.Moreira 203 |
| *Rhipsalis pulchra* Loefgr. | Th | L.Krieger 9296 |
| *Schlumbergera opuntioides* (Loefgr. & Dusén) D.R. Hunt | Eh | D.C.Zappi 258 |
| **Caryophyllaceae** | | |
| *Cerastium dicrotrichum* Fenzl ex Rohrb. | Eh | B.Moreira 227 |
| **Chloranthaceae** | | |
| *Hedyosmum brasiliense* Mart. ex Miq. | Tr | B.Moreira 103 |
| **Clethraceae** | | |
| *Clethra scabra* Pers. | Tr | B.Moreira 147 |
| **Clusiaceae** | | |
| *Clusia criuva* Cambess. | Tr | B.Moreira 111 |
| *Clusia organensis* Planch. & Triana | Tr | Fontes 094 |
| *Tovomitopsis paniculata* (Spreng.) Planch. & Triana | Tr | B.Moreira 113 |
| **Commelinaceae** | | |
| *Commelina obliqua* Vahl | Th | B.Moreira 168 |
| *Dichorisandra hexandra* (Aubl.) C.B.Clarke | Th | B.Moreira 148 |
| *Tripogandra diuretica* (Mart.) Handlos | Th | B.Moreira 166 |
| **Convolvulaceae** | | |
| *Ipomoea* sp1 | Th | B.Moreira 176 |
| **Cucurbitaceae** | | |
| *Wilbrandia hibiscoides* Silva Manso | Li | B.Moreira 102 |
| **Cunoniaceae** | | |
| *Lamanonia grandistipularis* (Taub.) Taub. | Tr | Fontes 157 |
| *Weinmannia discolor* Gardner | Sh | B.Moreira 112 |
| *Weinmannia paulliniifolia* Pohl ex Ser. | Tr | Fontes 004 |
| **Cyperaceae** | | |
| *Rhynchospora exaltata* Kunth | Th | B.Moreira 050 |
| *Scleria latifolia* Sw. | Th | B.Moreira 078 |

**Continued Table 1.**

| Family/Species | Habit | Voucher |
|---|---|---|
| **Ericaceae** | | |
| *Agarista ericoides* Taub. | Sh | B.Moreira 040 |
| *Agarista eucalyptoides* (Cham. & Schltdl.) G.Don | Sh | Fontes 040 |
| *Agarista glaberrima* (Sleumer) Judd | Tr | Fontes 005 |
| *Agarista pulchella* Cham. Ex G.Don | Sh | B.Moreira 257 |
| **Eriocaulaceae** | | |
| *Paepalanthus harmsii* Ruhland | Th | B.Moreira 039 |
| **Erythroxylaceae** | | |
| *Erythroxylum cuneifolium* (Mart.) O.E.Schulz | Sh | Fontes 158 |
| *Erythroxylum gonocladum* (Mart.) O.E. Schulz. | Sh | B.Moreira 125 |
| **Euphorbiaceae** | | |
| *Alchornea triplinervia* (Spreng.) Müll.Arg | Tr | B.Moreira 089 |
| **Fabaceae** | | |
| *Ancistrotropis peduncularis* (Kunth) A. Delgado | Li | B.Moreira 226 |
| *Centrosema coriaceum* Benth. | Li | B.Moreira 209 |
| *Chamaecrista brachyrachis* (Harms) H.S.Irwin & Barneb | Sh | B.Moreira 211 |
| *Chamaecrista catharticoides* H.S.Irwin & Barneby | Sh | Fontes 006 |
| *Chamaecrista itambana* (Benth.)Irwin & Barneby | Sh | B.Moreira 104 |
| *Chamaecrista* sp1 | Tr | B.Moreira 165 |
| *Galactia martii* DC. | Li | B.Moreira 228 |
| *Machaerium lanceolatum* (Vell.) J.F.Macbr. | Tr | Fontes 148 |
| *Mimosa dolens* Vell. | Sh | B.Moreira 193 |
| *Periandra mediterranea* (Vell.) Taub. | Sh | B.Moreira 097 |
| *Senna macranthera* (Vell.) Irwin & Barneby | Tr | B.Moreira 210 |
| *Senna pendula* (Humb.& Bonpl.ex Willd.) H.S.Irwin & Barneby | Tr | B.Moreira 210 |
| Fabaceae sp1 | Sh | B.Moreira 104 |
| Fabaceae sp2 | Tr | B.Moreira 109 |
| Fabaceae sp3 | Tr | B.Moreira 284 |
| **Gentianaceae** | | |
| *Calolisianthus pendulus* (Mart.) Gilg | Th | B.Moreira 143 |
| **Gesneriaceae** | | |
| *Anetanthus gracilis* Hiern | Th | Gonzaga 232 |
| *Nematanthus strigillosus* (Mart.) H.E.Moore | Sh | B.Moreira 027 |
| *Vanhouttea brueggeri* Chautems | Sh | B.Moreira 068 |
| *Vanhouttea hilariana* Chautems | Sh | B.Moreira 088 |
| *Sinningia magnifica* (Otto & A.Dietr.) Wiehler | Th | R.C.Forzza 27323 |
| *Sinningia tuberosa* (Mart.) H.E.Moore | Th | B.Moreira 159 |
| **Griseliniaceae** | | |
| *Griselinia ruscifolia* (Clos) Taub. | Sh | S.G.Furtado 322 |
| **Hypericaceae** | | |
| *Vismia brasiliensis* Choisy | Tr | Fontes 134 |
| **Lamiaceae** | | |
| *Eriope macrostachya* Mart. ex Benth. | Sh | B.Moreira 001 |
| *Hyptidendron asperrimum* (Sprengel) Harley | Tr | Fontes 181 |
| *Hyptis monticola* Mart. ex Benth | Sh | B.Moreira 304 |

**Continued Table 1.**

| Family/Species | Habit | Voucher |
|---|---|---|
| *Mesosphaerum suaveolens* (L.) Kuntze | Th | B.Moreira 218 |
| *Vitex sellowiana* Cham. | Tr | B.Moreira 091 |
| **Lauraceae** | | |
| *Ocotea odorifera* (Vell.) Rohwer | Tr | B.Moreira 260 |
| *Ocotea pulchella* (Nez & Mart.) Mez | Tr | B.Moreira 236 |
| *Ocotea* sp1 | Tr | B.Moreira 127 |
| *Ocotea* sp2 | Tr | B.Moreira 132 |
| *Ocotea* sp3 | Tr | B.Moreira 126 |
| *Nectandra lanceolata* Nees | Tr | B.Moreira 252 |
| **Loasaceae** | | |
| *Aosa* sp1 | Th | B.Moreira 271 |
| **Loranthaceae** | | |
| *Struthanthus concinnus* (Mart.) Mart. | Th | B.Moreira 333 |
| *Struthanthus marginatus* (Desr.) Blume | Th | B.Moreira 033 |
| **Lythraceae** | | |
| *Cuphea thymoides* Cham & Schltdl. | Sh | B.Moreira 237 |
| **Malpighiaceae** | | |
| *Byrsonima cuneifolia* Griseb. | Sh | B.Moreira 292 |
| *Byrsonima variabilis* A.Juss. | Sh | B.Moreira 028 |
| *Heteropterys pteropetala* A. Juss. | Sh | B.Moreira 094 |
| *Mascagnia sepium* (A.Juss.) Griseb. | Li | B.Moreira 048 |
| **Malvaceae** | | |
| *Callianthe montana* (A. St.-Hil.) Donell & C. Takeuch | Sh | B.Moreira 253 |
| *Abutilon fluviatile* (Vell.) K.Schum. | Sh | B.Moreira 004 |
| *Pavonia communis* A.St.-Hil. | Sh | B.Moreira 179 |
| *Pavonia viscosa* A.St.-Hil. | Sh | B.Moreira 222 |
| *Triumfetta semitriloba* Jacq. | Sh | B.Moreira 157 |
| *Triumfetta* sp1 | Sh | B.Moreira 153 |
| *Triumfetta* sp2 | Sh | B.Moreira 269 |
| **Melastomataceae** | | |
| *Leandra aurea* (Cham.) Cogn. | Tr | B.Moreira 141 |
| *Leandra carassana* (DC.) Cogn. | Tr | B.Moreira 082 |
| *Leandra foveolata* (DC.) Cogn. | Sh | B.Moreira 054 |
| *Leandra fragilis* Cogn | Tr | B.Moreira 315 |
| *Leandra gardneriana* Cogn. | Sh | B.Moreira 131 |
| *Leandra melastomoides* Raddi | Tr | B.Moreira 118 |
| *Leandra pennipilis* (Triana) Cogn. | Tr | B. Moreira 75 |
| *Leandra riedeliana* (O.Berg ex Triana) Cogn. | Sh | B.Moreira 258 |
| *Leandra vesiculosa* Cogn. | Tr | B.Moreira 201 |
| *Miconia chartacea* Triana | Tr | B.Moreira 084 |
| *Miconia cinnamomifolia* (DC.) Naudin | Tr | Fontes 150 |
| *Miconia corallina* Spring | Tr | B.Moreira 074 |
| *Miconia latecrenata* (DC.) Naudin | Tr | B.Moreira 013 |
| *Miconia pusilliflora* (DC.) Naudin | Tr | B.Moreira 225 |
| *Miconia sellowiana* Naudin | Tr | B.Moreira 053 |

**Continued Table 1.**

| Family/Species | Habit | Voucher |
|---|---|---|
| *Miconia theizans* (Bonpl.) Cogn. | Tr | B.Moreira 142 |
| *Pleroma collina* (Naudin) Triana | Sh | B.Moreira 079 |
| *Pleroma heteromalla* D. Don (D.Don) | Sh | B.Moreira 347 |
| *Pleroma semidecandra* (Schrank et Mart. ex DC.) Triana | Sh | B.Moreira 235 |
| *Tibouchina estrellensis* (Raddi) Cogn. | Sh | B.Moreira 172 |
| *Trembleya parviflora* (D.Don) Cogn. | Tr | B. Moreira 239 |
| **Meliaceae** | | |
| *Cabralea canjerana* (Vell.) Mart. | Tr | B.Moreira 019 |
| *Trichilia emarginata* (Turcz.) C. DC. | Tr | Fontes 100 |
| **Monimiaceae** | | |
| *Mollinedia clavigera* Tul. | Tr | B.Moreira 099 |
| **Moraceae** | | |
| *Ficus mexiae* Standl. | Tr | B.Moreira 182 |
| **Myrtaceae** | | |
| *Calyptranthes* sp1 | Tr | B.Moreira 149 |
| *Eugenia punicifolia* (Kunth) DC. | Tr | B. Moreira 369 |
| *Eugenia blastantha* (O.Berg) D.Legrand | Tr | B.Moreira 044 |
| *Eugenia brasiliensis* Lam. | Tr | B.Moreira 047 |
| *Eugenia cerasiflora* Miq. | Tr | B.Moreira 245 |
| *Eugenia* sp1 | Tr | B.Moreira 301 |
| *Marlierea angustifolia* (O.Berg) Mattos | Tr | B.Moreira 261 |
| *Myrceugenia* sp1 | Tr | B.Moreira 357 |
| *Myrcia eriopus* DC. | Sh | B.Moreira 326 |
| *Myrcia hartwegiana* (O.Berg) Kiaersk. | Tr | B.Moreira 115 |
| *Myrcia hebepetala* DC. | Tr | Fontes 162 |
| *Myrcia splendens* (Sw.) DC. | Tr | B.Moreira 017 |
| *Myrcia venulosa* DC. | Tr | Fontes 152 |
| *Myrcia* sp1 | Tr | B.Moreira 351 |
| *Myrciaria floribunda* (H.West ex Willd.) O.Berg | Tr | B.Moreira 130 |
| *Siphoneugena crassifolia* (DC.) Proença & Sobral | Tr | B.Moreira 055 |
| **Nyctaginaceae** | | |
| *Guapira graciliflora* (Mart. ex Schmidt) Lundell | Tr | B.Moreira 057 |
| *Guapira opposita* (Vell.) Reitz | Tr | B.Moreira 378 |
| **Ochnaceae** | | |
| *Ouratea semiserrata* (Mart. & Nees) Engl. | Sh | B.Moreira 020 |
| *Sauvagesia vellozii* (Vell. ex A.St.-Hil.) Sastre | Sh | B.Moreira 024 |
| **Onagraceae** | | |
| *Fuchsia regia* (Vell.) Munz | Li | B.Moreira 021 |
| **Orchidaceae** | | |
| *Acianthera heliconiscapa* (Hoehne) F.Barros | Eh | Souza s.n. (BHCB 9833) |
| *Anathalis liparanges* (Rchb.f.) Luer | Eh | B.Moreira208 |
| *Anathalis rubens* (Lindl.) Pridgeon & M.W.Chase | Eh | B.Moreira 134 |
| *Bifrenaria aureofulva* (Hook.) Lindl. | Eh | B.Moreira 171 |
| *Bifrenaria stefanae* V.P. Castro | Eh | B.Moreira 194 |
| *Bifrenaria vitellina* (Lindl.) Lindl. | Eh | B.Moreira 069 |

**Continued Table 1.**

| Family/Species | Habit | Voucher |
|---|---|---|
| *Brasiliorchis picta* (Hook.) R.B. Singer et.al. | Eh | B.Moreira 302 |
| *Bulbophyllum exaltatum* Lindl. | Th | D.Sucre 6839 |
| *Bulbophyllum glutinosum* (Barb.Rodr.) Cogn. | Eh | L.Menini Neto 125 |
| *Bulbophyllum granulosum* Barb.Rodr. | Eh | L.Menini Neto 107 |
| *Bulbophyllum micropetaliforme* J.E.Leite | Eh | Souza s.n. (BHCB 9834) |
| *Bulbophyllum regnellii* Rchb.f. | Eh | L.Menini Neto 124 |
| *Campylocentrum neglectum* (Rchb.f. & Warm.) Cogn. | Eh | L.Menini Neto 28 |
| *Campylocentrum robustum* Cogn. | Eh | L.Menini Neto 93 |
| *Cattleya bicolor* Lindl. | Eh | L.Menini Neto 178 |
| *Centroglossa macroceras* Rchb.f. | Eh | R.C.Forzza 59 |
| *Cranichis candida* (Barb.Rodr.) Cogn. | Th | Souza s.n. (BHCB 1620) |
| *Dichaea cogniauxiana* Schltr. | Th | L.Menini Neto 142 |
| *Encyclia patens* Hook. | Eh | B.Moreira 296 |
| *Epidendrum armeniacum* Lindl. | Eh | L.Menini Neto 175 |
| *Epidendrum chlorinum* Barb.Rodr. | Eh | L.Menini Neto 171 |
| *Epidendrum difforme* Jacq. | Eh | L.Menini Neto 97 |
| *Epidendrum martinianum* Lindl. | Th | B.Moreira 349 |
| *Epidendrum ochrochlorum* Barb.Rodr. | Eh | B.Moreira 061 |
| *Epidendrum paranaense* Barb. Rodr. | Th | B.Moreira 380 |
| *Epidendrum ramosum* Jacq. | Th | R.C.Forzza 16 |
| *Epidendrum rigidum* Jacq. | Th | L.Menini Neto 71 |
| *Epidendrum secundum* Jacq. | Th | B.Moreira 066 |
| *Eurystyles actinosophila* (Barb.Rodr.) Schltr. | Eh | S.G.Furtado 326 |
| *Eurystyles cogniauxii* (Kraenzl.) Pabst | Eh | L.Menini Neto 77 |
| *Gomesa glaziovii* Cogn. | Eh | L.Menini Neto 76 |
| *Gomesa gomezoides* (Barb.Rodr.) Pabst. | Eh | B.Moreira 146 |
| *Gomesa recurva* Lodd. | Eh | B.Moreira 264 |
| *Grobya amherstiae* Lindl. | Eh | R.C.Forzza 26 |
| *Habenaria rolfeana* Schltr. | Eh | B.Moreira 200 |
| *Hadrolaelia coccinea* (Lindl.) Chiron & V.P.Castro | Eh | B.Moreira 214 |
| *Isabelia violacea* (Lindl.) van den Berg & M.W.Chase | Eh | B.Moreira 318 |
| *Isabelia virginalis* Barb.Rodr. | Eh | L.Menini Neto 47 |
| *Isochilus linearis* (Jacq.) R.Br | Eh | L.Menini Neto 44 |
| *Lankesterella gnoma* (Kraenzl.) Hoehne | Eh | L.Menini Neto 139 |
| *Malaxis excavata* (Lindl.) Kuntze | Th | L.Menini Neto 72 |
| *Masdevallia infracta* Lindl. | Eh | R.C.Forzza 4315 |
| *Maxillaria acicularis* Herb. ex Lindl. | Eh | L.Menini Neto 86 |
| *Maxillaria brasiliensis* Brieger & Illg | Th | L.Menini Neto 88 |
| *Maxillaria notylioglossa* Rchb.f. | Eh | L.Menini Neto 119 |
| *Maxillaria ochroleuca* Lodd. ex Lindl. | Eh | L.Menini Neto 87 |
| *Maxillaria picta* Hook. | Th | R.C.Forzza 92 |
| *Mesadenella cuspidata* (Lindl.) Garay | Th | L.Menini Neto 179 |
| *Octomeria crassifolia* Lindl. | Th | L.Menini Neto 138 |
| *Octomeria diaphana* Lindl. | Eh | L.Menini Neto 111 |
| *Octomeria grandiflora* Lindl. | Eh | S.G.Furtado 300 |

**Continued Table 1.**

| Family/Species | Habit | Voucher |
|---|---|---|
| *Octomeria rubrifolia* Barb.Rodr. | Th | L.Menini Neto 40 |
| *Octomeria wawrae* Rchb.f. | Eh | L.Menini Neto 168 |
| *Oncidium gravesianum* Rolfe | Th | L.Menini Neto 112 |
| *Oncidium hookeri* Rolfe | Eh | B.Moreira 135 |
| *Oncidium longipes* Lindl. | Th | L.Menini Neto 163 |
| *Oncidium truncatum* Pabst | Eh | L.Menini Neto 95 |
| *Oncidium warmingii* Rchb.f. | Th | B.Moreira 076 |
| *Pleurothallis cryptophoranthoides* Loefgr. | Eh | L.Menini Neto 176 |
| *Pleurothallis hypnicola* Lindl. | Eh | Assis 1054 |
| *Pleurothallis luteola* Lindl. | Eh | L.Menini Neto 158 |
| *Pleurothallis malachantha* Rchb.f | Eh | L.Menini Neto 90 |
| *Pleurothallis modestissima* Rchb.f. & Warm. | Eh | L.Menini Neto 51 |
| *Pleurothallis recurva* Lindl. | Eh | L.Menini Neto 237 |
| *Pleurothallis rubens* Lindl. | Th | L.Menini Neto 31 |
| *Pleurothallis saundersiana* Rchb.f. | Eh | L.Menini Neto 37 |
| *Pleurothallis tricarinata* Poepp. & Endl. | Eh | L.Menini Neto 118 |
| *Polystachya estrellensis* Rchb.f. | Eh | L.Menini Neto 1348 |
| *Polystachya hoehneana* Kraenzl. | Eh | L.Menini Neto 91 |
| *Prescottia stachyodes* (Sw.) Lindl. | Th | B.Moreira 306 |
| *Promenaea xanthina* (Lindl.) Lindl. | Eh | Eiterer s.n. (CESJ 25549) |
| *Prosthechea allemanoides* (Hoehne) W.E.Higgins | Eh | B.Moreira 014 |
| *Prosthechea calamaria* (Lindl.) W.E.Higgins | Eh | L.Menini Neto 180 |
| *Prosthechea pachysepala* (Klotzsch) Chiron & V.P.Castro | Th | B.Moreira 032 |
| *Sacoila lanceolata* (Aubl.) Garay | Th | B.Moreira 366 |
| *Scaphyglottis modesta* (Rchb.f.) Schltr. | Th | L.Menini Neto 52 |
| *Stelis aprica* Lindl. | Eh | L.Menini Neto 127 |
| *Stelis cf. caespitosa* Lindl. | Eh | B.Moreira 138 |
| *Stelis megantha* Barb.Rodr. | Eh | R.C.Forzza 60 |
| *Stelis papaquerensis* Rchb.f. | Eh | L.Menini Neto 157 |
| *Stigmatosema polyaden* (Vell.) Garay | Eh | R.C.Forzza 58 |
| *Thysanoglossa organensis* Brade | Eh | L.Menini Neto 89 |
| *Trichosalpinx montana* (Barb.Rodr.) Luer | Eh | S.G.Furtado 283 |
| *Zygopetalum mackayi* Hook. | Th | B.Moreira 199 |
| **Peraceae** | | |
| *Pera glabrata* (Schott) Poepp. ex Baill | Tr | Fontes 146 |
| **Piperaceae** | | |
| *Peperomia crinicaulis* C.DC. | Eh | S.G.Furtado 291 |
| *Peperomia diaphanoides* Dahlst. | Eh | B.Moreira 213 |
| *Peperomia galioides* Kunth | Th | B.Moreira 272 |
| *Peperomia mandioccana* Miq. | Eh | S.G.Furtado 302 |
| *Peperomia tetraphylla* (G.Forst.) Hook. & Arn. | Eh | L.Krieger 16238 |
| **Poacae** | | |
| *Chusquea* sp1 | Li | B.Moreira 108 |
| *Ichnanthus adpressus* C. Silva & R.P. Oliveira | Th | B.Moreira 324 |
| *Loudetiopsis chrysothrix* (Ness.) Conert | Th | B.Moreira 343 |

**Continued Table 1.**

| Family/Species | Habit | Voucher |
|---|---|---|
| *Oplismenus hirtellus* (L.) P. Beauv. | Th | B.Moreira 221 |
| *Setaria* sp1 | Th | B.Moreira 154 |
| **Podocarpaceae** | | |
| *Podocarpus sellowii* Klotzsch | Tr | Fontes 064 |
| **Polygalaceae** | | |
| *Caamembeca oxyphylla* (DC.) J.F.B.Pastore | Sh | B.Moreira 006 |
| *Polygala paniculata* L. | Th | B.Moreira 341 |
| **Primulaceae** | | |
| *Myrsine coriacea* (Sw.) R. Br. ex Roem. & Schult. | Tr | B.Moreira 035 |
| *Myrsine ferruginea* (Ruiz & Pav.) Spreng. | Tr | B.Moreira 187 |
| *Myrsine lancifolia* Mart. | Tr | Fontes 151 |
| *Myrsine umbellata* Mart. | Tr | Fontes 127 |
| **Proteaceae** | | |
| *Roupala longepetiolata* Pohl | Tr | Fontes 138 |
| *Roupala montana* Aubl. | Tr | B.Moreira 305 |
| *Roupala rhombifolia* Mart. | Tr | Fontes 164 |
| **Rhamnaceae** | | |
| *Rhamnus sphaerosperma* Sw. | Tr | B.Moreira 096 |
| **Rubiaceae** | | |
| *Amaioua intermedia* Mart. ex Schult. & Schult.f. | Sh | B.Moreira 191 |
| *Borreria capitata* (Ruiz & Pav.) DC. | Th | B.Moreira 224 |
| *Borreria* sp1 | Th | B.Moreira 313 |
| *Coccocypselum condalia* (Ruiz & Pav.) Pers. | Th | B.Moreira 022 |
| *Coccocypselum erythrocephalum* Cham. & Schltdl. | Th | B.Moreira 043 |
| *Coccocypselum lanceolatum* (Ruiz & Pav.) Pers. | Th | B.Moreira 151 |
| *Cordiera concolor* (Cham.) Kuntze | Sh | B.Moreira 086 |
| *Cordiera elliptica* (Cham.) Kuntze | Sh | Fontes 110 |
| *Hillia parasitica* Jacq. | Tr | B.Moreira 114 |
| *Hindsia ibitipocensis* Di Maio | Sh | B.Moreira 064 |
| *Palicourea marcgravii* A.St.-Hil. | Sh | B.Moreira 119 |
| *Posoqueria acutifolia* Mart. | Tr | B.Moreira 178 |
| *Psychotria leiocarpa* Cham. & Schltdl. | Sh | B.Moreira 273 |
| *Psychotria ruelliifolia* (Cham. & Schltdl.) Müll.Arg. | Sh | B.Moreira 316 |
| *Psychotria stachyoides* Benth. | Sh | B.Moreira 029 |
| *Psychotria vellosiana* Benth. | Tr | B.Moreira 025 |
| *Rudgea sessilis* (Vell.) Müll.Arg. | Tr | Fontes 055 |
| **Rutaceae** | | |
| *Dictyoloma vandellianum* A. Juss. | Tr | Fontes 024 |
| *Esenbeckia grandiflora* Mart. | Sh | B.Moreira 297 |
| *Zanthoxylum rhoifolium* Lam. | Tr | Fontes 154 |
| **Sabiaceae** | | |
| *Meliosma sellowii* Urb. | Tr | Fontes 166 |
| **Santalaceae** | | |
| *Phoradendron* sp1 | Th | B.Moreira 128 |
| *Phoradendron* sp2 | Th | B.Moreira 353 |

**Continued Table 1.**

| Family/Species | Habit | Voucher |
|---|---|---|
| **Sapindaceae** | | |
| *Cupania vernalis* Cambess. | Tr | B.Moreira 018 |
| *Cupania zanthoxyloides* Cambess. | Tr | B.Moreira 268 |
| *Matayba cristae* Reitz | Tr | Fontes 167 |
| *Matayba guianensis* (Aubl.) Radlk. | Tr | B.Moreira 008 |
| *Matayba marginata* Radlk. | Tr | B.Moreira 009 |
| Sapindaceae sp1 | Tr | B.Moreira 105 |
| **Smilacaceae** | | |
| *Smilax elastica* Griseb. | Li | B.Moreira 217 |
| *Smilax staminea* Griseb. | Li | B.Moreira 379 |
| *Smilax stenophylla* A.DC. | Li | B.Moreira 359 |
| *Smilax* sp1 | Li | B.Moreira 259 |
| **Solanaceae** | | |
| *Aureliana velutina* Sendtn. | Tr | B.Moreira 085 |
| *Brunfelsia brasiliensis* (Spreng.) L.B.Sm. & Downs | Sh | B.Moreira 110 |
| *Dyssochroma viridiflorum* (Sims) Miers | Sh | B.Moreira 274 |
| *Solanum americanum* Mill. | Th | B.Moreira 250 |
| *Solanum didymum* Dunal | Sh | B.Moreira 254 |
| *Solanum kriegeri* Giacomin & Stehmann | Th | B.Moreira 063 |
| *Solanum mauritianum* Scop. | Tr | B.Moreira 278 |
| *Solanum swartzianum* Roem. & Schult. | Tr | B.Moreira 180 |
| *Solanum* sp1 | Sh | B.Moreira 090 |
| Solanaceae sp1 | Sh | B.Moreira 085 |
| Solanaceae sp2 | Tr | B.Moreira 098 |
| **Symplocaceae** | | |
| *Symplocos celastrinea* Mart. | Tr | B.Moreira 248 |
| **Theaceae** | | |
| *Laplacea fruticosa* (Schrad.) Kobuski | Sh | B.Moreira 023 |
| **Urticaceae** | | |
| *Cecropia glaziovii* Snethl. | Tr | B.Moreira 311 |
| **Verbenaceae** | | |
| *Lantana fucata* Lindl. | Sh | B.Moreira 169 |
| *Verbena litoralis* Kunth | Th | B.Moreira 080 |
| **Violaceae** | | |
| *Anchietea pyrifolia* (Mart.) G.Don | Li | B.Moreira 073 |
| **Vochysiaceae** | | |
| *Qualea cordata* (Mart.) Spreng. | Tr | B.Moreira 095 |
| *Vochysia tucanorum* Mart. | Tr | B.Moreira 133 |
| **Winteraceae** | | |
| *Drimys brasiliensis* Miers | Tr | B.Moreira 329 |

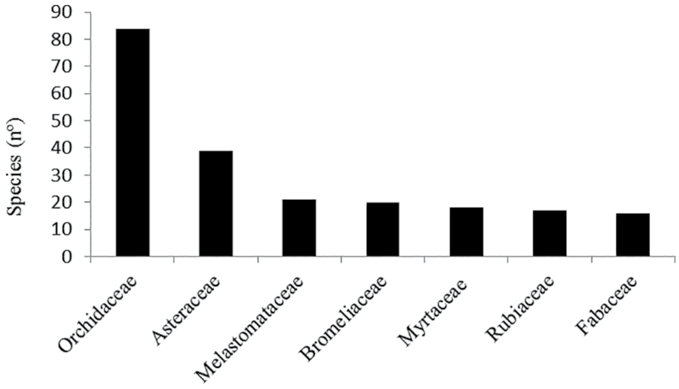

**Figure 3.** Most representative families in the cloud dwarf forests of the State Park of Ibitipoca, Serra da Mantiqueira, Brazil.

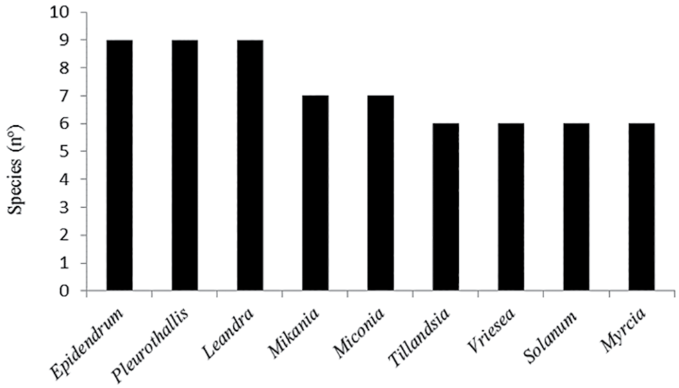

**Figure 4.** Most representative genera in the cloud dwarf forests of the State Park of Ibitipoca, Serra da Mantiqueira, Brazil.

The tree species are represented mainly by the families Melastomataceae and Myrtaceae. This floristic pattern meets the standards obtained by Oliveira-Filho & Fontes (2000), Santiago et al. (2018), and Eisenlohr & Oliveira-Filho (2015), who found Myrtaceae and Melastomataceae as the richest families in tree species for the Atlantic Forest in other regions of high altitude. These families also are found with high species richness in the survey carried out by Pereira et al. (2006) in remnants of vegetation in the Serra do Itatiaia. The families Myrtaceae and Melastomataceae are also considered Neotropical cloud forest characteristics by Webster (1995) and Scheer & Mocochinski (2009).

In the cloud dwarf forests of ISP, indicative genera of highland forests in the Neotropical Region and in Brazil include *Clethra*, *Drimys*, *Roupala*, *Weinmannia*, *Podocarpus*, and *Myrceugenia* (França & Stehmann 2004, Meireles et al. 2008). The cloud dwarf forests have a floristic composition distinct from the seasonal forests located in lower altitudes, being common to observe endemic species and several of them belonging to genera frequently observed in cloud forests all over the globe, being highlighted genera of high wealth in Andean mountain formations (Hamilton et al. 1995), such as *Clethra* and *Rhamnus*, genera shared between the ISP dwarf forests and the Andean tropical montane forests. Our results are closely related to Bertoncello et al. (2011) phytogeographic analysis, that find *Drimys brasiliensis*, *Rhamnus sphaerosperma* and *Weinmannia paulliniifolia* as preferential or indicator tree species in the cloud forests group compared to other forest subtypes in south and southeast Brazil.

The Asteraceae, Rubiaceae, and Melastomataceae families were noted for their richness in the shrub strata of the cloud dwarf forests. The high Asteraceae richness probably is associated to its diversity of habits, with species occupying different strata of the vegetation. In cloud forests located in regions of altitude in the South Region of Brazil, Asteraceae also presents high representativeness, although in Brazil, it presents greater richness in regions of rupestrian fields (Falkenberg 2003, Borges et al. 2010). Melastomataceae and Rubiaceae were also highlighted in studies in the Serra da Mantiqueira and Serra Negra (MG), due to the high richness of the shrub taxa (Salimena et al. 2013, Meireles et al. 2014). The genera *Baccharis*, *Psychotria*, *Leandra*, and *Pleroma* (three species each) were the most representative among the shrubs. These data are in agreement with Mocochinski & Scheer (2008) and Meireles et al. (2014), who found *Leandra* and *Pleroma* as shrub genera with high richness and a representative number of endemic species in high montane formations.

Terrestrial herbs are the main components of the ISP cloud dwarf forests' sub-forest, especially in humid and shady places, and are mainly represented by species of the Asteraceae and Orchidaceae families, understory plants of the genera *Coccocypselum* and *Anthurium*, as well as species of the family *Commelinaceae*, such as *Dichorisandra hexandra* and *Commelina obliqua*. The herbaceous earth species contribute to the floristic increase of forest areas and to the composition of the soil, because they have a shorter life cycle than species of arboreal habit (Martins-Ramos et al. 2011). In the present study, the terrestrial herbs correspond to about 21.5% of the total species, a value close to that obtained for the shrub species (22.3%). Pereira-Silva et al. (2007), Meireles et al. (2014), and Santiago et al. (2018), in studies carried out in different regions of the Serra da Mantiqueira, recorded Asteraceae as the family with the highest species richness. The high richness of this family in the terrestrial herbaceous stratum can be related to the direct contact of the cloud dwarf forests with the adjacent altitude fields, which facilitates the establishment of Asteraceae species in these areas (Pillar et al. 2009). The family is one of the most diverse in global terms and can be found in all types of habitats around the world (Judd et al. 2009).

Among the lianas, the *Chusquea* and *Mikania* genera are well distributed throughout the study area. Bamboos of the genus *Chusquea* are frequent in the cloud dwarf forests of ISP and generally form clusters near the areas of greater humidity, bordering the rivers and streams. *Chusquea* and *Mikania* occur preferentially in Atlantic South Atlantic formations (Safford 2007, Meireles et al. 2014).

The cloud dwarf forests have a high epiphytic rate, especially the families Orchidaceae and Bromeliaceae, which occupy diverse forest strata and collaborate for the high index of epiphytic species in a forest formation, besides the abundant presence of lichens that occupy the trunks of the trees, shrubs, and soil (Furtado 2016). In the present study, a high rate of epiphytic species was observed (22% of the species sampled). These species can often be considered typical of cloud forests and may correspond to about 25% of the species sampled (Benzing 1998). Furtado (2016) has compiled a list of vascular epiphytes occurring in the cloud forests of ISP, composed of 222 species distributed in 81 genera and 22 families, of which Orchidaceae is the richest (85 spp.), corresponding to 28% of the vascular flora formation. Both the absolute number of species and the epiphytic quotient observed by Furtado (2016) correspond to one of the greatest diversities already sampled in studies of this nature in the Brazilian Atlantic Forest.

**Table 2.** Phytogeographic groups of the genera represented in cloud dwarf forests of Ibitipoca State Park, Serra da Mantiqueira, Southeastern Brazil.

| Phytogeographic groups | Genera (nº) |
|---|---|
| **Temperate** | |
| **Austral-antartic:** *Drimys, Fuchsia, Griselinia, Myrceugenia, Podocarpus, Polygala, Weinmannia* | 7 |
| **Holartic:** *Rhamnus* | 1 |
| **Large temperate:** *Senecio, Dendrophorbium* | 2 |
| **Cosmopolitan:** *Bidens, Borreria, Brickellia, Caamembeca Cerastium, Commelina, Crepis, Ficus, Galactia, Ilex, Ipomoea, Malaxis, Oplismenus, Rhynchospora, Solanum, Setaria, Taraxacum, Verbesina* | 18 |
| **Tropical** | |
| **Endemic of Brazil:** *Eremanthus, Grobya, Nematanthus, Trembleya, Aosa, Dyssochroma, Gomesa, Periandra, Vanhouttea, Wittrockia.* | 10 |
| **Neotropical:** *Acianthera, Aechmea, Alchornea, Alstroemeria, Amaioua, Anathallis, Ancistrotropis, Anchietea, Anetanthus, Anthurium, Aspidosperma, Aureliana, Austrocritonia, Baccharis, Bifrenaria, Billbergia, Brasiliorchis, Brunfelsia, Byrsonima, Cabralea, Calolisianthus, Calyptranthes, Campylocentrum, Cattleya, Cecropia, Centroglossa, Centrosema, Chaptalia, Chromolaena, Chusquea, Coccocypselum, Clusia, Cordiera, Cranichis, Cupania, Cuphea, Dichaea, Dichorisandra, Dictyoloma, Ditassa, Emmeorhiza, Encyclia, Epidendrum, Eriope, Eupatorium, Eurystyles, Forsteronia, Fridericia, Geonoma, Gomidesia, Guapira, Guatteria, Hadrolaelia, Handroanthus, Hatiora, Hedyosmum, Heteropterys, Hillia, Hindsia, Hyptidendron, Ichnanthus, Isabelia, Isochilus, Lamanonia, Langsdorffia, Lankesterella, Laplacea, Leandra, Leptostelma, Lessingianthus, Loudetiopsis, Machaerium, Mandevilla, Marlierea, Mascagnia, Matayba, Masdevallia, Maxillaria, Mesadenella, Mesosphaerum, Miconia, Mollinedia, Myrcia, Myrciaria, Nectandra, Neoregelia, Nidularium, Octomeria, Oncidium, Oxypetalum, Palicourea, Pera, Phoradendron, Piper, Philodendron, Pleroma, Pleurothallis, Posoqueria, Praxelis, Prescottia, Promenaea, Prosthechea, Qualea, Roupala, Scaphyglottis, Schlumbergera, Siphoneugena, Sinningia, Stelis, Stigmatosema, Struthanthus, Thysanoglossa, Tibouchina, Tillandsia, Tovomitopsis, Trichogonia, Trichosalpinx, Tridax, Trixis, Verbena, Vernonanthura, Vismia, Vochysia, Vriesea, Wilbrandia, Zygopetalum.* | 126 |
| **Large tropical:** *Abutilon, Achyrocline, Agarista, Ageratum, Alternanthera, Andropogon, Aspilia, Begonia, Bulbophyllum, Chamaecrista, Clethra, Cordia, Erythroxylum, Eugenia, Gochnatia, Habenaria, Hyptis, Justicia, Lantana, Meliosma, Mendoncia, Mikania, Mimosa, Myrsine, Ocotea, Ouratea, Paepalanthus, Pavonia, Peperomia, Polystachya, Psychotria, Rhipsalis, Rudgea Sacoila, Sauvagesia, Schefflera, Scleria, Senna, Smilax, Symplocos, Trichilia, Tripogandra, Triumfetta, Vitex, Zanthoxylum.* | 45 |

In view of the above, it is possible to assume that the epiphytes play an important role in the cycles of the cloud dwarf forests. They also act in the local water cycle, since they interfere in the capture, storage, and slow release of water (Richardson et al. 2000). It is estimated that in some areas epiphytes can store about 3,000 liters/ha and provide water, nesting, and feeding materials for a wide range of animal species, from invertebrates to primates (Richardson et al. 2000). These factors alone justify the importance of the presence of epiphytes for the ecosystem as a whole.

The floristic profile of the ISP cloud dwarf forests presents floristic similarities at the family and genera levels with the Andes highland forests, also presenting characteristics that allow them to be associated with a transition environment between the rupestrian and highland Southeast Region of Brazil. Based on the predominance of the families Orchidaceae, Asteraceae, Bromeliaceae, Myrtaceae, Melastomataceae, and Rubiaceae, it can be affirmed that the cloud dwarf forests of ISP present very similar flora to the cloud dwarf forests of Serra Fina, Serra Negra (MG), and Agulhas Negras (RJ) (Oliveira-Filho & Fontes 2000, Olíveira-Filho et al. 2005, Pereira et al. 2006, Bertoncello et al. 2011, Valente et al. 2011, Meireles et al. 2014).

Fontes (1997), in a study in the PEIB cloud forest, which he called “Mata Alta” (cloud forest), found Lauraceae as the richest family, followed by Myrtaceae and Rubiaceae. The author points out that this area differs substantially from the areas of cloud dwarf forests, which he called “Mata Baixa” (cloud dwarf forest), mainly in relation to the forest structure. Fontes (1997) recorded 127 species in the “Mata Alta”, 63 in the “Mata Baixa” and only eight species common to the two habitats, indicating that they are two forest physiognomy very distinct. Menino (2013), in a study performed in the same sample area as Fontes (1997), found *Psychotria suterella*, *Aspidosperma australe* and *Psychotria vellosiana* as the species of high VI. Among these, only *Psychotria vellosiana* was sampled in the cloud dwarf forests, reinforcing the heterogeneity among the forest physiognomies. PEIB cloud forests are characterized by canopy rich in clearings, with a height of around 17 m, with emergent trees reaching 30 m, while the cloud dwarf forests have a canopy of about 10 m, with few emergent trees, reaching up to 16 m (Olveira-Filho et al., 2013).

In general, the richness of the plant community of the cloud dwarf forests of ISP reinforces its importance for local, demonstrating that relatively small areas are also relevant for preservation and that even conservation units should improve strategies for maintaining biodiversity (Drummond et al. 2005).

## 2. *Phytogeography*

The studies that seek to understand the geographic distribution of the species present in the cloud dwarf forests are of fundamental importance, since they allow to subsidize strategies of conservation and environmental restoration, and help in the prediction of the impacts of future climate changes on the natural vegetation. In this study, we classified the genera in seven phytogeographic groups delimited based on their current centers of diversity cited in Safford (2007). Among the Austral-Antarctic genera, *Drimys*, *Fuchsia*, *Polygala*, and *Weinmannia* have few Atlantic representatives, whereas *Myrceugenia* is richer to the east of Brazil, with species indicative of the high montane forests under cold and humid climates (Meireles et al. 2008). These genera were part of a past flora dispersed among Australia, Antarctica, and South America (Brade 1956).

As representative of the Holartic floristic element, only the genus *Rhamnus* was found in the cloud dwarf forests of ISP. The presence of Holartic elements in the Neotropical flora has been associated with the proximity between North and South America during the Cretaceous, continental, and volcanic island arches in the Central American region, long-distance dispersal events during the Cenozoic, and the formation of the Isthmus of Panama and elevation of the northern Andes between the Miocene and the Pliocene, about 3.5 million years ago. According to Brade (1956), the Holartic element went from North America to South America using the mountain chain of the Andes as a migration bridge and later advanced to the east of the continent towards Serra da Mantiqueira and Serra do Mar.

According to Safford (2007), the flora of the Andes and the highest points of the Brazilian mountain ranges form a group of species tropical, temperate, and cosmopolitan origin that have developed in these places through long periods of environmental changes and migrations. Safford (2007) reports that during the drought periods of the Tertiary, the Atlantic mountain ranges served as a refuge for species adapted to cold and humidity, especially the Austral-Antarctic taxa, and that during long periods of colder weather a greater contact occurred between the plant formations of east and west of South America, thus favoring colonization of the tropical Atlantic forests by Andean elements. This contact may have occurred several times, and the Atlantic rainforests may have been an important source for the colonization of the new mountainous environments developed late in the northern Andes (Safford 2007).

In ISP, the temperate floristic component is represented by the genera *Senecio* and *Dendrophorbium*, whereas the cosmopolitan elements are represented by the genera *Bidens*, *Borreria*, *Brickellia*, *Caamembeca*, *Cerastium*, *Commelina*, *Crepis*, *Ficus*, *Galactia*, *Ilex*, *Ipomoea*, *Malaxis*, *Oplismenus*, *Rhynchospora*, *Solanum*, *Setaria*, *Taraxacum*, and *Verbesina*. Temperate taxa, mainly Holartics, are much more representative in the Andean flora than in the Brazilian mountains, due to a series of geographic and historical factors, lower altitudes, and the more limited area of the mountains in Brazil. Safford (2007) suggests that many temperate and cosmopolitan species first arrived in Southern Brazil by migrating through favorable habitats, rather than dispersing over long distances.

Among the ten endemic genera of Brazil, the family Gesneriaceae, represented by the *Nematanthus* and *Vanhouttea*, stands out. The genera *Nematanthus* is endemic in South and Southeastof Brazil, except for one species that reaches the south of Bahia (Chautems 1988). *Vanhouttea* has species distributed in the states of Espírito Santo, Minas Gerais and Rio de Janeiro (Chautems 2002). The other endemic genera are *Eremanthus*, *Trembleya*, *Aosa*, *Dyssochroma*, *Gomesa* (sensu stricto), *Grobya*, *Periandra* and *Wittrockia*, which present very common species in high altitude vegetation formations in the Atlantic Forest. Among these, *Eremanthus*, *Periandra* and *Trembleya*, present a greater richness in *campos rupestres*, with some species present in altitude fields and inside the cloud dwarf forestes (Giulietti & Pirani 1988).

About 60% of the genera found are Neotropical, and among them, *Cabralea*, *Leandra*, *Miconia*, *Mollinedia*, *Myrcia*, *Myrciaria*, *Roupala*, *Siphoneugena*, *Pleroma*, and *Vernonanthura* can present species of montane forests that tolerate adverse altitude conditions (Oliveira-Filho & Fontes 2000, Meireles et al. 2014). Among the Neotropical genera, some are commonly found in the Andes mountains, such as *Baccharis* and *Chusquea*, besides being of great importance in the floristic composition of the montane vegetation of the Southeastern and Southern Region of Brazil (Brade 1956, Safford 1999, Meireles et al. 2014).

The *Hindsia* genus is richest in the mountains of eastern Brazil, and in this study the species *Hindsia ibitipocensis*, considered to be endangered, is recorded only for a small part of the Serra da Mantiqueira, represented by ISP. (Di Maio 1996, Oliveira et al. 2013). Broad tropical genera accounted for 24%, with predominance of the Asteraceae and Malvaceae families, in which attributes such as long dispersal distances, large fruit production, and seed dormancy are common, helping to increase their distributions (Lorenzi 2008).

Due to the historical process of land occupation, characterized mainly by the exploitation of timber species, forest fragmentation, and expansion of agricultural and livestock activities, the original forest areas of the Serra da Mantiqueira were drastically reduced (Almeida & Carneiro 1998, Drummond et al. 2005). In this way, conservation of the remaining forests is fundamental, since besides presenting high residual diversity, they perform environmental services, such as the sequestration of atmospheric carbon dioxide, soil protection, maintenance of the hydrological cycle, and protection of watercourses (Pounds et al. 1999). It is important to point out that the cloud dwarf forests contribute with additional water provision to the water systems, through the capture of condensed water in the clouds. Therefore, conservation of these forests will contribute to the continuous production of water in the springs, which will benefit the production of drinking water and water quality for future generations (Oliveira-Filho et al. 2004). Further studies on the biodiversity of cloud dwarf forests are needed to support the development of public policies aimed at protecting these areas, especially given their great fragility in the face of global climate change (IPCC 2014).

## Acknowledgements

We thank the employees of Ibitipoca State Park for their constant support throughout the project. We are also thankful for the great help provided by the students of the Graduate Program in Ecology (PGECOL) and the Plant Ecology Laboratory of the Federal University of Juiz de Fora (UFJF), during field activities and herbarium routines. Thanks also go to the researchers who helped in the botanical identification and to the UFJF for the support in the excursions to the study area. This work was supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) under grant 454008/2014-7 and Fundação de Apoio a Pesquisa do Estado de Minas Gerais (FAPEMIG) under grant APQ 2165/14.

## Author Contributions

Breno Moreira: responsible for conception, field work, data analysis, identification of specimens and the writing manuscript.

Fabrício Alvim Carvalho: substantial contribution in analysis and interpretation of data and manuscript preparation.

Luiz Menini Neto: substantial contribution in analysis and interpretation of data and manuscript preparation.

Fátima Regina Gonçalves Salimena: responsible for conception and coordinated the study.

## Conflicts of interest

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

## References

ALMEIDA, F.F.M. & CARNEIRO, C.D. 1998. Origem e evolução da Serra do Mar. Revista Brasileira de Geociências 28: 135-150.

APG IV. 2016. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. Botanical Journal of the Linnean Society 181: 1–20.

ARCOVA, F.C.S. 2013. Avaliação do potencial hidrológico dos nevoeiros e da precipitação oculta em ambiente de Floresta Ombrófila Densa Montana na Serra do Mar, Cunha, SP. Tese De dorutorado, Universidade de São Paulo, São Paulo.

BENZING, D.H. 1998. Vulnerabilities of tropical forests to climate change: the significance of resident epiphytes. Climate Change 39, pp. 519–5440

BERTONCELLO, R., YAMAMOTO, K., MEIRELES, L.D. & SHEPHERD, G.J. 2011. A phytogeographic analysis of cloud forests and other forest subtypes amidst the Atlantic forests in south and southeast Brazil. Biodiversity conservation 20(14): 3413–3433.

BFG. 2015. Growing knowledge: an overview of Seed Plant diversity in Brazil. Rodriguésia 66: 1085-1113.

BORGES, R.X.A., SAAVEDRA, M.M., NAKAJIMA, J.N. & FORZZA. R.C. 2010. The Asteraceae flora of the Serra do Ibitipoca: analyses of its diversity and distribution compared with selected areas in Brazilian mountain ranges. Systematics and Biodiversity 8(4): 471-479.

BRADE, A.C. 1956. A flora do Parque Nacional do Itatiaia. Boletim Parque Nacional do Itatiaia 5: 1-92.

BROWN, J.H., STEVENS, G.C. & KAUFMAN, D.M. 1996. The geographic range: size, shape, boundaries, and internal structure. Annals Review of Ecology and Systematics 27: 597-623.

BRUIJNZEEL, L.A., SCATENA, F.N. & HAMILTON, L.S. 2010. Tropical montane cloud forests: Science for conservation and management. Cambridge University Press, London, UK

BUBB, P., MAY, I., MILES, L. & SAYER, J. 2004. Cloud forest agenda. Cambridge: PNUMA-CMVC, 32 p.

CHAUTEMS, A. 1988. Revision taxonomique et possibilites d'hybridations de Nematanthus Schrader (Gesneriaceae), genre endemique de la forêt cotiere brésiliense. Dissertationes Botanicae 112:1-226.

CHAUTEMS, A. 2002. New Gesneriaceae from Minas Gerais, Brazil. Candollea 56: 261-270.

CORRÊA NETO, A.V. & BAPTISTA FILHO, J. 1997. Espeleogênes em quartzitos da Serra do Ibitipoca, Sudeste de Minas Gerais. Anuário do Instituto de Geociências, Rio de Janeiro, v. 20, p. 75-87.

COSTA, C. & HERRMANN, G. 2006. Plano de Ação do Corredor Ecológico da Mantiqueira. 1 ed. Valor Natural, 64p.

CRIA. Centro de Referência em Informação Ambiental. 2001. SpeciesLink. Disponível em <http://splink. cria.org.br/tools?criaLANG=pt> (último acesso 01/10/2017).

DIAS, H.C.T., FERNANDES FILHO, E.I., SCHAEFER, C.E.G.R., FONTES, L.E.F.F. & VENTORIM, L.B. 2002. Geoambientes do Parque Estadual do Ibitipoca, município de Lima Duarte-MG. Revista Árvore 26(6): 777-786.

DI MAIO, F.R. 1996. Revisão taxonômica do gênero Hindsia Bentham (Rubiaceae, Hedyotideae). Arquivos do Jardim Botânico do Rio de Janeiro 34: 51-92.

DRUMMOND, G.M., MARTINS, C.S., MACHADO, A.B.M., SEBAIO, F.A. & ANTONINI, Y. 2005. Biodiversidade em Minas Gerais, um atlas para sua conservação. Fundação Biodiversitas. Belo Horizonte.

EISENLOHR, P.V. & OLIVEIRA-FILHO, A.T. 2015. Revisiting Patterns of Tree Species Composition and their Driving Forces in the Atlantic Forests of Southeastern Brazil. Biotropica 47: 689-701.

FALKENBERG, D.B. 2003. Matinhas nebulares e vegetação rupícola dos Aparados da Serra Geral (SC/RS), sul do Brazil. Tese de doutorado. Universidade Estadual de Campinas, Campinas.

FILGUEIRAS, T.S., NOGUEIRA, P.E., BROCHADO, A.L. & GUALA, G.F. 1994. Caminhamento: um método expedito para levantamentos florísticos qualitativos. Cadernos de Geociências 12: 39-43.

FLORA DO BRASIL 2020. Em construção. Jardim Botânico do Rio de Janeiro. Disponível em: < http://floradobrasil.jbrj.gov.br/ > (último acesso 10/10/2017).

FONTES, M.A. 1997. Análise da composição florística das Florestas Nebulares do Parque Estadual do Ibitipoca, Minas Gerais. Dissertação de mestrado. Universidade Federal de Lavras, Lavras.

FRANÇA, G.S. & STEHMANN, J.R. 2004. Composição florística e estrutura do componente arbóreo de uma floresta altimontana no município de Camanducaia, Minas Gerais, Brasil. Revista Brasileira de Botânica 27: 19-30.

FURTADO, S.G. 2016. Ecologia de epífitas vasculares nas Florestas Nebulares do Parque Estadual do Ibitipoca, Minas Gerais, Brasil. Dissertação de mestrado, Universidade Federal de Juiz de Fora, Juiz de Fora.

GIULIETTI, A.M. & PIRANI, J.R. 1988. Patterns of geographic distribution of some species from the Espinhaco Range, Minas Gerais and Bahia, Brasil. In Proceedings of a Workshop on Neotropical Distribution Patterns (P.E. Vanzolini & W.R. Heyer, eds.). Academia Brasileira de Ciências, Rio de Janeiro, p.39-69.

GONÇALVES, E.G. & LORENZI, H. 2007. Morfologia vegetal: organografia e dicionário ilustrado de morfologia das plantas vasculares. São Paulo: Plantarum. 416p.

GRYTNES, J.A. & MCCAIN, C.M. 2007. Elevational trends in biodiversity. Encyclopedia of biodiveristy.

HAMILTON, L.S., JUVIK, J.O. & SCATENA, F.N. 1995. The Puerto Rico tropical cloud forests symposium: introduction and workshop synthesis. In Tropical montane cloud forests (L. S. Hamilton, J. O. Juvik & F. N. Scatena, eds.). Springer-Verlag, New York, p.1-23.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE - IPCC 2014 Climate Change 2014: Impacts, Adaptation and Vulnerability " (IPCC). Work Group 2. Genebra. 2014. IPCC 2014 Fifth Assessment Report. Disponível em: <http://www.ipcc-wg2.gov/AR5/> (último acesso 01/10/2017).

JUDD, W.S., CAMPBELL, C.S., KELLOGG, E.A., STEVENS, P.F. & DONOGHUE, M. J. 2009. Sistemática Vegetal: Um enfoque filogenético. Porto Alegre: Artmed. 632p.

KÖPPEN, W. 1948. Das geographische System der Klimate – handbuch der klimatologie. Vol. 1. Part C. Berlim: Gebr. Bornträger Verlag, 388 p.

KÖRNER, C. 1999. Alpine Plant Life: functional plant ecology of high mountain ecosystems. Springer-Verlag, Berlim, Heidelberg.

LORENZI, H. 2008. *Árvores brasileiras*: manual de identificação e cultivo de plantas arbóreas nativas do Brasil. 5.ed. Nova Odessa: Instituto Plantarum, v.1. 368p.

MARTINELLI, G. 2007. Mountain biodiversity in Brazil. Revista Brasileira de Botânica 30(4): 587-597.

MARTINELLI, G. & MORAES, M.A. 2013. Livro vermelho da flora do Brasil. Jardim Botânico do Rio de Janeiro. http://cncflora.jbrj.gov.br (último acesso 01/10/2017).

MARTINS-RAMOS, D., CHAVES, C.L., BORTOLUZZI, R.L.C. & MANTOVANI, A. 2011. Florística de floresta ombrófila mista alto-montana e de campos em Urupema, Santa Catarina. Brasil. Revista Brasileira de Biociências. 9(2): 156–166.

MBG. Missouri Botanical Garden. 2014. Tropicos.org. Disponível em <http://www.biologie.uni-hamburg. de/b-online/ibc99/mobot/pick.html> (último acesso 10/10/2017).

MEIRELES, L.D., SHEPHERD, G.J. & KINOSHITA, L.S. 2008. Variações na composição florística e na estrutura fitossociológica de uma floresta ombrófila densa alto-montana na Serra da Mantiqueira, Monte Verde, MG. Revista Brasileira de Botânica 31: 559-574.

MEIRELES, L.D., KINOSHITA, L.S. & SHEPHERD, G.J. 2014. Composição florística da vegetação altimontana do distrito de Monte Verde (Camanducaia, MG), Serra da Mantiqueira Meridional, Sudeste do Brasil. Rodriguésia 65: 831-859.

MENINO, G.C.O. 2013. Dinâmica da comunidade arbórea de uma floresta nebular na Serra de Ibitipoca, Minas Gerais. Tese de Doutorado Universidade Federal de Lavras, Lavras.

MOCOCHINSKI, A.Y. & SCHEER, M.B. 2008. Campos de altitude na Serra Paranaense: aspectos florísticos. Floresta 38: 625-640.

MOREIRA, A.A.N. & CAMELIER, C. 1977. Relevo. In Geografia do Brasil. Fundação Instituto Brasileiro de Geografia e Estatística, Rio de Janeiro, v.3, p.1-150.

MORI, S.A., SILVA, L.A.M., LISBOA, G. & CORADIN, L. 1989. Manual de manejo de herbário fanerogâmico. Ilhéus, BA: Centro de Pesquisas do Cacau.

NUMMER, A.R. 1991. Mapeamento geológico e tectônico experimental do grupo Andrelândia na região de Santa Rita do Ibitipoca – Lima Duarte, Sul de Minas Gerais. Dissertação de Mestrado. Universidade Federal do Rio de Janeiro, Rio de Janeiro.

OLIVEIRA, J.A., SALIMENA, R.F.G. & ZAPPI, D. 2014. Rubiaceae da Serra Negra, Minas Gerais, Brasil. Rodriguésia [online]. 65(2): 471-504.

OLIVEIRA-FILHO, A.T. & FONTES, M.A.L. 2000. Patterns of floristic differentiation among Atlantic Forests in Southeastern Brazil and the influence of climate. Biotropica 32(4): 793-810.

OLIVEIRA-FILHO, A.T., CARVALHO, D.A., FONTES, M.A.L., VAN DEN BERG, E., CURI, N. & CARVALHO, W.A.C. 2004. Variações estruturais do compartimento arbóreo de uma floresta semidecídua alto-montana na chapada das Perdizes, Carrancas, MG. Revista Brasileira de Botânica 27(2): 291- 309.

OLIVEIRA-FILHO, A.T., JARENKOW, J.A. & RODAL, M.J.N. 2005. Floristic relationships of seasonally dry forests of eastern South America based on tree species distribution patterns. In: PENNINGTON, R. T. et al. (Ed.). Neotropical savannas and dry forests: plant diversity, biogeograpgy and conservation. Boca Raton: CRC Press, p.151-184.

OLIVEIRA-FILHO, A.T. 2009. Classificação das fitofisionomias da América do Sul cisandina tropical e subtropical: proposta de um novo sistema – prático e flexível – ou uma injeção a mais de caos. Rodriguésia 60: 237-258

OLIVEIRA-FILHO, A.T., FONTES, M.A.L., VIANA, P.L., VALENTE, A.S.M., SALIMENA, F.R.G. & FERREIRA, F.M. 2013. O mosaico de fitofisionomias do Parque Estadual do Ibitipoca. In Flora do Parque Estadual do Ibitipoca e seu entorno. 1 ed. Juiz de Fora, 384p.

PEREIRA-SILVA, E.F.L., HARDT, E. & FRANCISCO, C.E.S. 2007. Caracterização florística da vegetação lenhosa de um fragmento urbano de Floresta Ombrófila Mista Alto Montana, Campos do Jordão, SP. Holos Environment 7(2*)*:154-170.

PEREIRA, I.A., OLIVEIRA-FILHO, A.T., BOTELHO, S.A., CARVALHO, W.A.C., FONTES, M.A.L., SCHIAVINI, I. & SILVA, A.F. 2006. Composição florística do compartimento arbóreo de cinco remanescentes florestais do maciço do Itatiaia, Minas Gerais e Rio de Janeiro. Rodriguésia 57(1): 103-126.

PILLAR, V.D., MÜLLER, S.C., CASTILHOS, Z. & JACQUES, A.V.A. (Orgs.). 2009. Campos Sulinos: conservação e uso sustentável da biodiversidade. Brasília: Ministério do Meio Ambiente. 403p.

POMPEU, P.V., FONTES, M.A.L., SANTOS, R.M., GARCIA, P.O., BATISTA, T. A. & CARVALHO, W.A.C.; OLIVEIRA-FILHO, A.T. 2014. Floristic composition and structure of an upper montane cloud forest in the Serra da Mantiqueira Mountain Range of Brazil. Acta Botanica Brasilica 28:456-464.

POUNDS, A., FOGDEN, M.P.L & CAMPBELL J.H. 1999 Biological response to climate change on a tropical mountain. Nature 398:611–615.

RAHBEK, C. 2005. Thee role of spatial scale and the perception of large-scale species – richness patterns. EcologyLetters 8(2):224– 239.

RICHARDSON, B.A, RICHARDSON, M.J., SCATENA, F.N. & MCDOWELL W.H. 2000. Effects of nutrient availability and other elevational changes on bromeliad populations and their invertebrate communities in a humid tropical forest in Puerto Rico J. Tropical Ecology 16: 167–188.

RODELA, L. G. & TARIFA, J. R. 2002. Clima da Serra do Ibitipoca, sudeste de Minas Gerais. Geousp: Espaço e Tempo 11: 101-113.

SAFFORD, H.D. 1999. Brazilian Páramos I. An introduction to the physical environment and vegetation of the campos de altitude. Journal of Biogeography 26(4): 693-712.

SAFFORD, H.D. 2007. Brazilian Páramos IV. Phytogeography of the campos de altitude. Journal of Biogeography 34: 1701-1722.

SALIMENA, F.R.G., MATOZINHOS, C.N., ABREU, N.L., RIBEIRO, J.H.C. SOUZA, F.S. & MENINI-NETO, L. 2013. Flora fanerogâmica da Serra Negra, Minas Gerais, Brasil. Rodriguésia 64(2): 311–320.

SANTIAGO, D.S., OLIVEIRA-FILHO, A.T., MENINI NETO, L., CARVALHO, F.A. & SALIMENA, F.R.G. 2018. Floristic composition and phytogeography of an Araucaria Forest in the Serra da Mantiqueira, Minas Gerais, Brazil. Rodriguésia 69 (no prelo).

SCHEER, M.B. & MOCOCHINSKI, A.Y. 2009. Florística vascular da Floresta Ombrófila Densa Altomontana de quatro serras no Paraná. Biota Neotropica 9(2):51-70.

SLIK, J.W., SHIN-ICHIRO, A.S.I., BREARLEY, F.Q., CANNON, C.H., FORSHED, O. & KITAYAMA, K. 2010. Environmental correlates of tree biomass, basal area, wood specific gravity and stem density gradients in Borneo's tropical forests. Global Ecology and Biogeography 19:50–60.

TEIXEIRA, W. & CORDANI, G. 2007. Caminhos do Tempo Geológico In Itatiaia: Sentinela das Alturas (W. Teixeira & R. Linsker, coords) Terra Virgem, São Paulo, p. 28-62.

THIERS, B. 2016 [continuously updated]. In: Index Herbariorum: A global directory of public herbaria and associated staff. New York Botanical Garden's Virtual Herbarium.

VALENTE, A.S.M., GARCIA, P.O., SALIMENA, F.R.G. & OLIVEIRA-FILHO, A.T. 2011. Composição, estrutura e similaridade florística da Floresta Atlântica, na Serra Negra, Rio Preto, Minas Gerais, Brasil. Rodriguésia 62(2): 321-340.

VÁZQUEZ-GARCÍA, J.A. 1995. Cloud forest archipelagos: preservation of fragmented montane ecosystems in tropical America. Pp. 315–332 in L.S. Hamilton, J.O. Juvick, and F.N. Scatena, eds., Tropical Montane Cloud Forest. Ecological Studies, no. 110. Springer Verlag, New York.

WEBSTER, G.L. 1995. The panorama of Neotropical Cloud Forests. In: Churchill, S. P.; Balslev, H.; Forero, E. & Luteyn, J. L.(eds.). Biodiversity and Conservation of Neotropical Montane Forests: Proceedings of Neotropical Montane Forest Biodiversity and Conservation Symposium. The New York Botanical Garden, New York. Pp. 53-77.

*Received: 20/12/2017*
*Revised: 03/02/2018*
*Accepted: 16/03/2018*
*Published online: 16/04/2018*

Biota Neotropica 18(2): e20170496, 2018
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)

**Inventory**

# Bat richness (Mammalia: Chiroptera) in an area of montane Atlantic Forest in the Serra da Mantiqueira, state of Minas Gerais, southeast Brazil

*Bruna da Silva Xavier[1], William Douglas Carvalho[2,3]*, Daniela Dias[4], Lorena de Oliveira Tabosa[1], Carlos Eduardo Lopes Santos[1] & Carlos Eduardo Lustosa Esbérard[1]*

*[1]Universidade Federal Rural do Rio de Janeiro, Instituto de Biologia, Departamento de Biologia Animal, Laboratório de Diversidade de Morcegos, CP 74507, 23890-000, Seropédica, RJ, Brasil*
*[2]Universidade do Amapá, Programa de Pós-graduação em Biodiversidade Tropical, Rod. Juscelino Kubitscheck, S/N, AP 68903-419, Macapá, Brasil*
*[3]Universidade Federal do Amapá, Departamento de Meio Ambiente e Desenvolvimento, Laboratório de Ecologia, AP 68903-419, Macapá, Brasil*
*[4]Fundação Oswaldo Cruz, Laboratório de Biologia e Parasitologia de Mamíferos Silvestres Reservatórios, 21040-900, Rio de Janeiro, RJ, Brasil*
**Corresponding author: William Douglas de Carvalho, e-mail: wilruoca@hotmail.com*

XAVIER, B. S., CARVALHO, W. D., DIAS, D., TABOSA, L. O., SANTOS, C. E. L., ESBÉRARD, C. E. L. **Bat richness (Mammalia: Chiroptera) in an area of montane Atlantic Forest in the Serra da Mantiqueira, state of Minas Gerais, southeast Brazil**. Biota Neotropica. 18(2): e20170496. http://dx.doi.org/10.1590/1676-0611-BN-2017-0496

***Abstract:*** In recent years there has been an increase in research interest in remnants of Atlantic Forest above 500 m a.s.l., such as in the Serra da Mantiqueira, which is considered a priority area for conservation. The chiropterofauna of the Serra da Mantiqueira remains relatively under-studied, and here we present a list of bat species from the "Reserva Particular do Patrimônio Natural (RPPN) Cachoeira do Tombo", a private conservation unit located in an area of montane Atlantic Forest in the Serra da Mantiqueira. Bats were captured with mist nets along trails and near a diurnal roost. A total of 498 individuals of 19 bat species belonging to the families Phyllostomidae, Vespertilionidae and Molossidae were captured. Phyllostomidae were captured only along the trails, Molossidae were captured only in the diurnal roost and Vespertilionidae were captured in both. The species accumulation curves did not show stabilizing trends. However, 80% of the expected richness was sampled and the species richness of bats found is similar to other studies previously carried out in the region. In contrast to other inventories carried out in the Atlantic Forest, *Desmodus rotundus* was the species most frequently captured along the trails. A large number of individuals of *Molossus aztecus* sheltering in man-made structures were caught, constituting an unusual event. Additionally, here we report cohabitation of this species with *Molossus molossus* for the first time. Our results show that this area, which appears on the map of environmental conflicts for the state of Minas Gerais, has a rich chiropterofauna and also further corroborate the importance of using mist-nets at roosts to increase the probability of capturing the richness and abundance of insectivorous bats present in the area.
***Keywords:*** *Biodiversity, high elevation, sampling, Phyllostomidae, Molossidae, Verspertilionidae.*

# Riqueza de morcegos (Mammalia: Chiroptera) em uma área de Floresta Atlântica montana na Serra da Mantiqueira, estado de Minas Gerais, sudeste do Brasil

***Resumo:*** Nos últimos anos houve um aumento no interesse em pesquisas em remanescentes de Floresta Atlântica acima de 500 m de altitude, como na Serra da Mantiqueira, a qual é considerada área prioritária para a conservação. A fauna de quirópteros na Serra da Mantiqueira ainda permanece relativamente pouco estudada, e aqui nós apresentamos uma lista de espécies de morcegos da Reserva Particular do Patrimônio Natural (RPPN) Cachoeira do Tombo, uma unidade de conservação privada localizada em área de Floresta Atlântica Montana na Serra da Mantiqueira. Os morcegos foram capturados com redes de neblina ao longo de trilhas e junto de um abrigo diurno. Um total de 498 indivíduos de 19 espécies de morcegos pertencentes às famílias Phyllostomidae, Vespertilionidae e Molossidae foram capturados. Phyllostomidae foram capturados somente em trilhas, Molossidae no abrigo diurno e Vespertilionidae em ambos. As curvas de acumulação de espécies não mostraram tendência de estabilização. No entanto, 80% da riqueza esperada foi amostrada e a riqueza de espécies encontrada foi similar a outros estudos previamente conduzidos na região. Diferente de outros inventários realizados na Mata Atlântica, *Desmodus rotundus* foi a espécie mais frequentemente capturada ao longo das trilhas. Um grande número de indivíduos de *Molossus aztecus* foi encontrado se abrigando em abrigo artificial, o que constitui um evento pouco usual. Adicionalmente, a coabitação dessa espécie com *Molossus molossus* é reportada aqui pela primeira vez. Os resultados mostram que essa área, que está inserida no mapa de conflitos ambientais do estado de Minas Gerais, possui uma rica chiropterofauna e corrobora a importância de usar redes de neblina em abrigos para aumentar a probabilidade de capturar a riqueza e abundância de morcegos insetívoros presentes na área.

***Palavras-chave:*** *Biodiversidade, altitude elevada, inventário, Phyllostomidae, Molossidae, Verspertilionidae.*

## Introduction

The southeast region of Brazil is considered to be the most well-studied of the country in terms of Chiroptera (Bergallo et al. 2003, Brito et al. 2009), owing in large part to a higher concentration of research institutes compared with other regions (Brito et al. 2009). Although most of studies on Chiroptera in the region have been conducted at elevations below 500 m a.s.l., in recent years there has been an increase in research interest in remnants of Atlantic Forest between 500 and 1,500 m a.s.l. (e.g., Dias et al. 2008, Modesto et al. 2008, Delciellos et al. 2012, Luz et al. 2013, Moras et al. 2013, Martins et al. 2015).

Among the states of the southeast of Brazil, Minas Gerais is of particular conservation importance as it encompasses three Brazilian biomes (Caatinga, Cerrado and Atlantic Forest, with the latter two considered conservation hotspots threatened by constant anthropogenic pressure) (Myers et al. 2000, Mittermeier et al. 2005, Tavares et al. 2010). The current list of bats for Minas Gerais consists of 85 species (Tavares et al. 2010, Garbino 2011, Gregorin & Loureiro 2011, Gregorin et al. 2011, Carvalho et al. 2013, Dias et al. 2015, Gregorin et al. 2015). However, the state has many areas which remain under- or un-sampled (Tavares et al. 2010), and therefore further studies are necessary, and indeed are highly likely to report new species for the state.

The largest remnants of Atlantic Forest are located in the border region between Minas Gerais, Rio de Janeiro and São Paulo (Costa et al. 2009, Ribeiro et al. 2009). This region is further characterised by areas of transition between Cerrado and Atlantic Forest, such as those found in the foothills of the Serra da Mantiqueira in Minas Gerais (IBGE 2012). Owing to the presence of these remnants and transition zones, the Serra da Mantiqueira is considered a priority area for conservation, being indicated for implementation of protected areas to safeguard native habitat remnants (Costa et al. 1998, Drummond et al. 2005). While some species lists and local occurrences of bats have recently been published for the region (e.g., Carvalho et al. 2013, Luz et al. 2013, Nobre et al. 2013a, Nobre et al. 2013b, Dias et al. 2015, Martins et al. 2015), the chiropterofauna still remains relatively under-studied.

This study presents a list of bat species mist-netted in the private conservation reserve "Reserva Particular do Patrimônio Natural (RPPN) Cachoeira do Tombo" (hereafter referred to as the Cachoeira do Tombo RPPN or simply the RPPN). The RPPN is located in an area of montane Atlantic Forest in the Serra da Mantiqueira Environmental Protection Area and within the buffer zone of the Serra do Papagaio State Park. This list contributes to knowledge of chiropterofauna in areas of montane forest, which are frequently neglected in inventories, and in particular to knowledge of the chiropterofauna of the Serra da Mantiqueira.

## Material and Methods

### 1. Study area

The study was conducted in the Cachoeira do Tombo RPPN, located in the municipality of Aiuruoca, state of Minas Gerais (22°00'23.4"S, 44°36'22.2"W; 1,100 m a.s.l.; Figure 1). The reserve has a total area of 12.02 ha and falls within the Atlantic Forest biome, although the surrounding areas include stretches of cerrado and indeed the region is considered to be an ecotone between the Atlantic Forest and Cerrado biomes (RADAM BRASIL 1983). The local climate is classified as a subtropical highland type (Cwb), with mild summers (Sá-Júnior et al. 2012). Temperatures in the hottest month are below 22°C, the average annual temperature varies between 18 and 19°C, and the average annual precipitation is in the order of 1,400 mm (Sá-Júnior et al. 2012). December, January and February are the rainiest months, and June, July and August the driest (Scolforo et al. 2002). The RPPN is a Permanent Environmental Protection Area located within the Serra da Mantiqueira Environmental Protection Area and in the buffer zone of the Serra do Papagaio State Park.

### 2. Bat captures and data analysis

Bats were captured along four different trails within the RPPN on 14 nights, though the samples were not simultaneous along all trails, but rather one trail was sampled 11 times, and each of the other trails just once each. The average distance between trails was 346.2 ± 211 m. A diurnal roost located 150 m from the edge of the RPPN was also sampled on 14 nights, 10 of which were simultaneous with the sampling on the first trail within the RPPN and four on additional nights. As such, bats were captured during a total of 18 nights between August 2012 and April 2015. The diurnal roost was located in the ceiling space of a chalet which had been abandoned as a result of the presence of the bats. The roof of the chalet consisted of asbestos roof tiles and wooden roof beams, and was lined with pinewood, on top of which a layer of polystyrene had been placed to insulate the interior of the chalet from the heat of the sun.

The bats were caught using mist-nets (9 x 2.5 m), set between dusk and midnight at the diurnal roost, and between dusk and dawn along the trails of the RPPN, during different lunar phases (see Esbérard 2007). Sampling effort was calculated by multiplying the number of hours for which the nets were kept open by the area of the nets ($m^2$), following Straube & Bianconi (2002). Adult bats greater than 5 g were marked with plastic collars individually coded, according to Esbérard & Daemon (1999). To mark juveniles and adults of species which have a body mass equal to or less than 5 g, "punch-marking" (small holes made in the

http://dx.doi.org/10.1590/1676-0611-BN-2017-0496

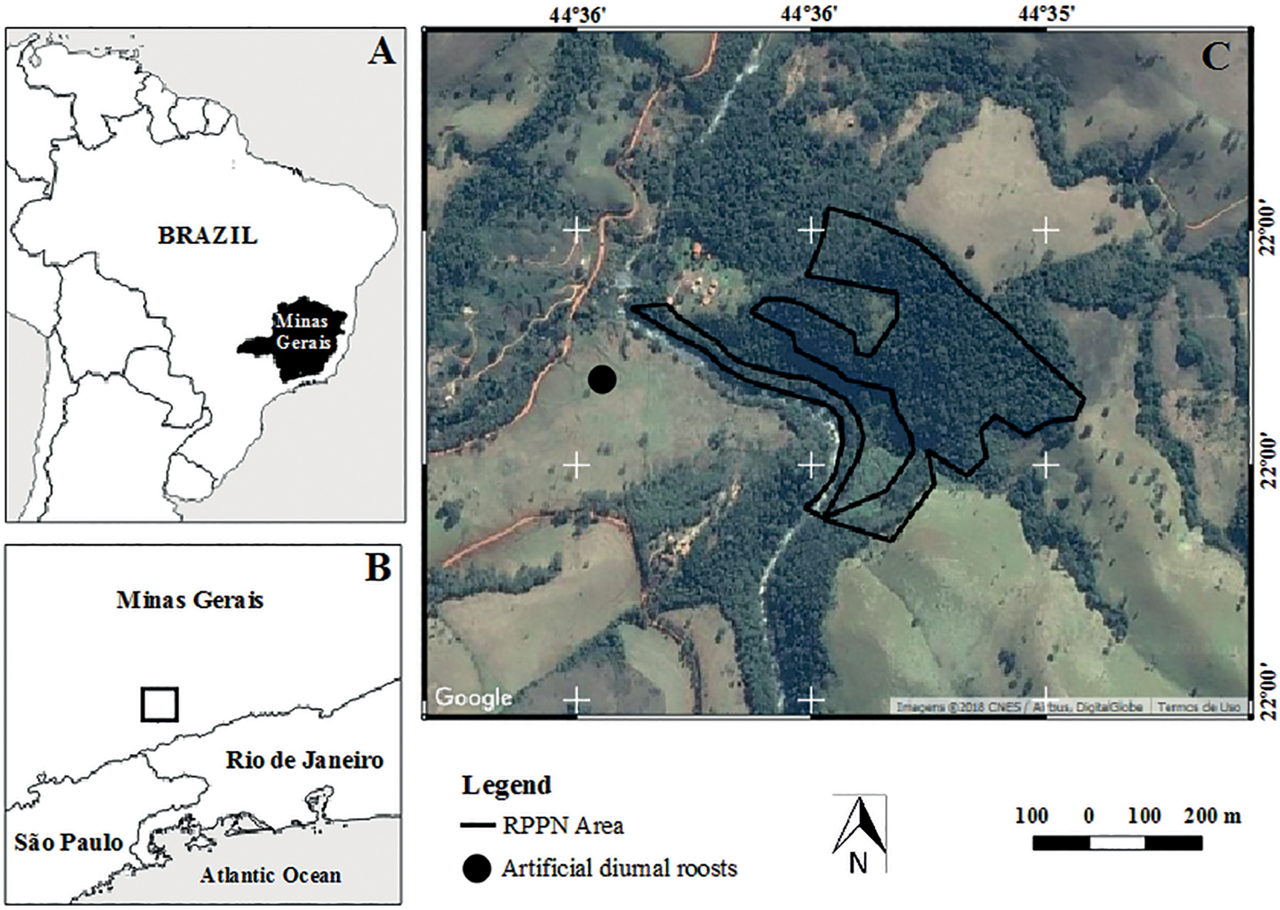

**Figure 1.** (A) South America with the state of Minas Gerais indicated. (B) States of the southeast of Brazil and the study area highlighted (square). (C) Area of the Cachoeira do Tombo RPPN, in the municipality of Aiuruoca, state of Minas Gerais, Brazil.

dactylo patagium) was used (see Bonaccorso & Smythe 1972). From 2013 onwards, all juvenile and small-bodied (less than 5g) adult bats were marked with Trevisan® microchips.

The captured animals were preliminarily identified in the field using identification keys and field guides (Reis et al. 2013). Data on length of the forearm, body mass and reproductive state were collected, and most individuals were then released where they were captured. In order to carry out morphological analyses and confirm taxonomic identifications some individuals were collected, prepared as voucher specimens, preserved in spirits, and deposited in the collection of the Bat Diversity Laboratory (LDM – IBAMA process 1755/89), Institute of Biology, Federal Rural University of Rio de Janeiro (Appendix 1). All field procedures were carried out with permission from the "Instituto Chico Mendes para Conservação da Biodiversidade" (ICMBio) (permanent licence for collection granted to C.E.L. Esbérard - number 10356-1, issued on 06/09/2007). The "Instituto Estadual de Florestas-MG" granted permission to carry out the collections within and around the Serra do Papagaio State Park (UC:151/11 - Extension I).

Observed and randomized (using 1,000 randomizations without replacement and a confidence interval of 95%) species accumulation curves were plotted for each sampling site – the diurnal roost and the four trails within the RPPN. Expected species richness, considering first-order Jacknife values, was also calculated in order to verify the percentage species richness sampled in each site. All analyses were conducted using the packet "vegan" (Oskanen et al. 2017) in R (R Development core team 2017).

## Results

A total of 498 individuals of 19 bat species belonging to three families (Phyllostomidae, Vespertilionidae and Molossidae) were captured (Table 1). Two-hundred and seventeen individuals of 13 species and 281 individuals of six species were captured along the trails within the RPPN and at the diurnal roost, respectively (Table 1). Sixty-four individuals were re-captured, nine along the trails within the RPPN and 55 at the diurnal roost.

The randomised species accumulation curves for each sampling location seem to show a decrease in the rate of species addition (Figure 2). The total species richness found in the RPPN (including the trails and the diurnal roost) represented 80.1% of the estimated richness for the RPPN (first-order Jacknife = 23.72 species; s.d. = 2.52). The species richness found along the trails within the RPPN represented only 77.75% of the estimated richness (first-order Jacknife = 16.71 species; s.d. = 2.30). The species richness found at the diurnal roost represented 86.58% of the estimated richness (first-order Jacknife = 6.93 species; s.d. = 0.93).

**Table 1.** Bats collected between 2012 and 2015 in the Cachoeira do Tombo RPPN, in Aiuruoca, Minas Gerais, including the first captures and the number of re-captures (in brackets). LC = least concern, DD = data deficient. * Conservation status according to ICMBio (2014).

| **FAMILY**<br>**Subfamily** | **Captures (Recaptures)** | | | **Conservation status*** |
|---|---|---|---|---|
| **Species** | **Trail** | **Roost** | **Total** | |
| **PHYLLOSTOMIDAE** | | | | |
| **Desmodontinae** | | | | |
| *Desmodus rotundus* (É. Geoffroy, 1810) | 83 (7) | - | 83 (7) | LC |
| **Glossophaginae** | | | | |
| *Anoura caudifer* (É. Geoffroy, 1818) | 26 | - | 26 | LC |
| *Anoura geoffroyi* Gray, 1838 | 1 | - | 1 | LC |
| **Phyllostominae** | | | | |
| *Phyllostomus hastatus* (Pallas, 1767) | 1 | - | 1 | LC |
| *Mimon bennettii* (Gray, 1838) | 3 | - | 3 | LC |
| **Carolliinae** | | | | |
| *Carollia perspicillata* (Linnaeus, 1758) | 38 (2) | - | 38 (2) | LC |
| **Stenodermatinae** | | | | |
| *Artibeus fimbriatus* Gray, 1838 | 5 | - | 5 | LC |
| *Artibeus lituratus* (Olfers, 1818) | 21 | - | 21 | LC |
| *Platyrrhinus lineatus* (É. Geoffroy, 1810) | 9 | - | 9 | LC |
| *Sturnira lilium* (É. Geoffroy, 1810) | 25 | - | 25 | LC |
| *Vampyressa pusilla* (Wagner, 1843) | 1 | - | 1 | LC |
| **VESPERTILIONIDAE** | | | | |
| *Eptesicus diminutus* Osgood, 1915 | 1 | - | 1 | LC |
| *Eptesicus* sp. | - | 133 (3) | 133 (3) | - |
| *Histiotus velatus* (I. Geoffroy, 1824) | - | 2 | 2 | DD |
| *Myotis albescens* (E. Geoffroy, 1806) | 3 | - | 3 | - |
| **MOLOSSIDAE** | | | | |
| *Eumops perotis* (Schinz, 1821) | - | 1 | 1 | LC |
| *Eumops auripendulus* (Shaw, 1800) | - | 13 (1) | 13 (1) | LC |
| *Molossus aztecus* Saussure, 1860 | - | 124 (41) | 124 (41) | LC |
| *Molossus molosssus* (Pallas, 1766) | - | 8 (10) | 8 (10) | LC |
| **TOTAL** | **217 (9)** | **281 (55)** | **498 (64)** | |
| **SAMPLING EFFORT (m²*h)** | **25,625.25** | **16,027.5** | **41,652.75** | |

Phyllostomidae were captured only along the trails within the RPPN, and at the diurnal roost only species of Vespertilionidae and Molossidae were captured. In contrast, just two species of Vespertilionidae, and no Molossidae were captured along the trails. The most frequently caught species along the trails was *Desmodus rotundus* with 83 captures (16.7% of the total), followed by *Carollia perspicillata* with 38 captures (7.6% of the total) (Table 1). The captures carried out at the diurnal roost contributed 31.58% of the richness sampled for the RPPN. The most frequently caught species at the roost was *Eptesicus* sp. with 133 captures (26.7% of the total), followed by *Molossus aztecus* with 124 captures (24.9% of the total).

## Discussion

Phyllostomidae were only caught in the mist-nets set along the trails within the RPPN. Indeed, this sampling design favours the capture of bats of this family (Kunz & Parsons 2009). Moreover, insectivorous species are known to be under-sampled by mist-netting (Kalko et al. 2008, Meyer et al. 2011, Marques et al. 2016). In order to increase the sample of such species, it is therefore recommended that other methods be used, such as acoustic recordings (Meyer et al. 2011) or setting of mist-nets above water-bodies, close to diurnal shelters (Lourenço et al. 2010, Costa et al. 2012) or even sampling in the canopy (Gregorin et al. 2017). In the present study, 31.58% of the total sampled richness was obtained from the samples at the diurnal roost.

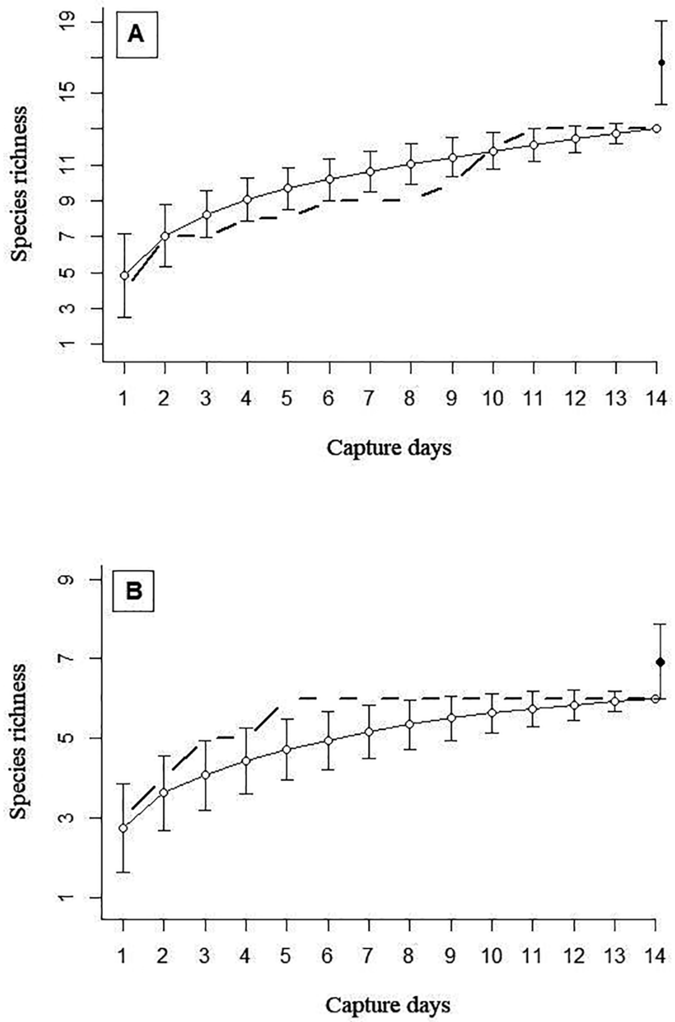

**Figure 2.** Species accumulation curve for bats captured in the Cachoeira do Tombo RPPN: (A) trails located within the RPPN; (B) diurnal roost located 150 m from the border of RPPN. The dashed line shows the observed species accumulation curve. The solid line shows the randomized species accumulation curve with the arrows showing the 95% confidence intervals. The solid circle shows the first-order Jacknife value with the arrows showing the standard deviation.

The species accumulation curves did not show stabilizing trends, however, 80% of the expected richness was sampled, both along the trails and at the roost. While it has been suggested that the ideal total number of captures to sample richness of bats of the family Phyllostomidae in tropical forests is 1,000 individuals (Bergallo et al. 2003), this number can be considered to be un-realistic and highly dependent upon numerous other factors. For example, differences in species composition, local abundance, habitat types and landscape attributes, as well as local climate, can in large part explain the observed variations in detection and capture of species between localities (Meyer et al. 2011, Stevens 2013). For example, it has been shown that along an altitudinal gradient the collection curve stabilizes at higher altitudes when the total number of captures is less than 1,000 individuals, because the climatic conditions are more extreme (i.e. colder temperatures and lower resource availability) and species richness and local abundance are lower (Carvalho 2015). However, a greater sampling effort is still required for the Cachoeira do Tombo RPPN, in order to better characterise the bat fauna of the region.

The species richness of bats found in the present study is, however, similar to that found in other studies carried out in the Serra da Mantiqueira. For example, in a mountainous area between 870 and 1,040 m a.s.l. of the Serra Negra (state of Minas Gerais) with rocky outcrops and pastures, 19 species were registered during 70 nights of sampling with mist-nets set for between 6 and 8 hours after nightfall (Nobre et al. 2013a). In dense, high-montane rainforest, boulder fields and high altitude cerrado (average altitude of 1,500 m) of the Ibitipoca State Park, 17 species were registered in 68 nights of sampling using mist-nets open for 6 hours in areas of forest, clearings and at roosts (mainly caves) (Nobre et al. 2013b). In another area of montane forest in the Visconde de Mauá region of the state of Rio de Janeiro, 13 species were registered after seven nights of sampling with mist-nets set for 12.5 hours per night (Luz et al. 2013). In the Itatiaia National Park, in areas between 500 and 2,500 m a.s.l., 22 species were captured in 32 nights of mist-netting for 6 hours per night (Martins et al. 2015). The total species richness sampled in the RPPN in this present study represents 27.94% of the species already reported for the Atlantic Forest of Minas Gerais (68 species; see Tavares et al. 2010, Garbino 2011, Gregorin & Loureiro 2011, Gregorin et al. 2011, Carvalho et al. 2013, Dias et al. 2015, Gregorin et al. 2015).

Among Phyllostomidae, *D. rotundus* was the species most frequently captured along the trails of the RPPN. This result differs from inventories carried out in the Atlantic Forest, where captures of *D. rotundus* generally represent 2% or less of the total captures, even in areas with large numbers of caves (see Costa & Esbérard 2011). This may be explained by several factors, including the presence of cattle for dairy and beef in the adjacent areas, and by the formation of large colonies owing to the high number of rocky outcrops, with natural caves, in the region. Indeed, *D. rotundus* is usually present in inventories carried out in grottos and caves (Trajano 1985, Campanha & Fowler 1993, Guimarães 2014) and close to human settlements with high densities of livestock (Costa & Esbérard 2011). In one cave, located 400 m from the edge of the RPPN, it was possible to observe around 600 individuals of *D. rotundus* (personal observation). The second most commonly sampled species of Phyllostomidae was *C. perspicillata*, a species which is frequently caught in inventories carried out in the Atlantic Forest, especially in areas with a high density of *Piper* spp., as is the case in the RPPN (personal observation). Fruits of *Piper* spp. constitute the preferred food item in the diet of *C. perspicillata* in periods of high availability of the resource (Andrade et al. 2013).

The capture of a large number of individuals of the species *M. aztecus* sheltering in man-made structures remains an unusual event (Gregorin et al. 2011) and furthermore, cohabitation of this species with *M. molossus* had not previously been reported. Indeed, this study represents the fifth report of *M. aztecus* for Minas Gerais (Gregorin et al. 2011, Oliveira 2013, Loureiro 2014, Gregorin et al. 2017). In order to verify the occurrence of *M. aztecus* in the other states of the region and improve knowledge of the biology and distribution of the species, we recommend a reassessment of the *M. molossus* specimens obtained in studies in the southeast and held in zoological collections.

The mosaic of the Serra da Mantiqueira has been altered since 2008 and continues to be threatened by the possible construction of hydroelectric dams, power lines and opening of areas for mining (see Ferreira et al. 2014). Indeed, the Cachoeira do Tombo RPPN appears on the map of environmental conflicts for the state of Minas Gerais owing to the possible construction of a small hydroelectric dam (Zhouri 2014, GESTA 2015). The results of this study show that the area, which falls within the buffer zone of the Serra do Papagaio State Park, has a rich chiropterofauna. The buffer zones of protected areas in the Cerrado have also been shown to be used by medium and large-bodied mammals, including those which are conservation dependent (Paolino et al. 2016), though the importance of these zones for bats remains to be studied.

Further effort is still required to improve knowledge of the flora and fauna of each mountain chain of the Serra da Mantiqueira, where at least 37 species of bats have already been reported (Avila-Pires & Gouveia 1977, Carvalho et al. 2013, Luz et al. 2013, Nobre et al. 2013a, Nobre et al. 2013b, Dias et al. 2015, Martins et al. 2015). The results of this study also further corroborate the importance of using mist-nets at roosts to increase the probability of capturing the richness and abundance of insectivorous bats present in the area, especially when more sophisticated methods, such as audio-recording, are not available.

## Supplementary material

The following online material is available for this article:
Appendix 1

## Acknowledgments

We thank Gilberto Ribeiro for the permits to work in RPPN Cachoeira do Tombo and we thank Adriano Senador and Jaqueline Senador for permission to work on their lands. We thank Ilda de Sá and Estalagem do Mirante for help with logistics and accommodation in the field. We thank Mayara A. Martins, Luciana M. Costa, Priscilla Peixoto, Sylvia Coelho, Egon Valle, Natália Lima, Thaisa Medeiros, Ayesha Pedrozo and Luís Gomes for their help in the field. We thank for Marcelo Nogueira for assisting in the identification of bats of the genus *Eptesicus*. WDC received a PhD scholarship from CAPES; BSX received a scholarship fund from FAPERJ and CELE received grants from FAPERJ (E-26/102.960/2012) and CNPq (Process 301061/2007-6). The present study was developed under a permit granted by IBAMA (Processes 1785/89-IBAMA and SISBIO 10356-1) and IEF (UC: 151/11 - Extension I). We are grateful to Karen Mustin for revising the English of this manuscript and the two reviewers for their helpful criticisms.

## Author contributions

Bruna da Silva Xavier: substantial contribution in the concept and design of the study, data collection, analysis and interpretation, manuscript preparation and critical revision, adding intellectual content.

William Douglas Carvalho: substantial contribution in the concept and design of the study, data collection, analysis and interpretation, manuscript preparation and critical revision, adding intellectual content.

Daniela Dias: confirmation of identification of some of the bat vouchers; contribution to data analysis and interpretation, manuscript preparation and critical revision, adding intellectual content.

Lorena de Oliveira Tabosa: contribution to data collection and critical revision of the manuscript, adding intellectual content.

Carlos Eduardo Lopes Santos: contribution to data collection and critical revision of the manuscript, adding intellectual content.

Carlos Eduardo Lustosa Esbérard: substantial contribution in the concept and design of the study, data collection, analysis and interpretation, manuscript preparation and critical revision, adding intellectual content and providing financial resources.

## Conflicts of Interest

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

## References

ANDRADE, T.Y., THIES, W., ROGERI, P.K., KALKO, E.K.V. & MELLO, M.A.R. 2013. Hierarchical fruit selection by Neotropical leaf-nosed bats (Chiroptera: Phyllostomidae). J. Mammal. 94(5):1094-1101.

ÁVILA-PIRES, F.D. & GOUVEA, E. 1977. Mamíferos do Parque Nacional do Itatiaia. Bol. Mus. Nac., Zool. 291:1-29.

BERGALLO, H.G., ESBÉRARD, C.E.L., MELLO, M.A.R., LINS, V., MANGOLIN, R. & BAPTISTA, M. 2003. Bat species richness in Atlantic Forest: What is the minimum sampling effort? Biotropica 35(2):278-288.

BONACCORSO, F.J. & SMYTHE, N. 1972. Punch-marking bats: an alternative to banding. J. Mammal. 53(2):389-390.

BRITO, D., OLIVEIRA, L.C., OPREA, M. & MELLO, M.A.R. 2009. An overview of the Brazilian mammalogy: trends, biases and future directions. Zoologia-Curitiba 26:67-73.

CAMPANHA, R.A.C. & FOWLER, H.G. 1993. Roosting assemblages of bats in arenitic caves in remnant fragments of Atlantic Forest in southeastern Brazil. Biotropica 25(3):362-365.

CARVALHO, W.D. 2015. Influência da altitude na história de vida de morcegos Phyllostomidae (Chiroptera, Mammalia) na Floresta Atlântica. Tese de Doutorado. Universidade Federal Rural do Rio de Janeiro, Seropédica.

CARVALHO, W.D., MARTINS, M.A., DIAS, D. & ESBÉRARD, C.E.L. 2013. Extension of geographic range, notes on taxonomy and roosting of *Histiotus montanus* (Chiroptera: Vespertilionidae) in southeastern Brazil. Mammalia 77(3):341-346.

COSTA, L.M. & ESBÉRARD, C.E.L. 2011. *Desmodus rotundus* (Mammalia: Chiroptera) on the southern coast of Rio de Janeiro state, Brazil. Braz. J. Biol. 71(3):739-746.

COSTA, T.C.C., FIDALGO, E.C.C., SANTOS, R.F., ROCHA, J.V., METZGER, J.P., VICENS, R.S., TANIZAKI-FONSECA, K. & BOHRER, C.B.A. 2009. Diversidade de paisagens no Estado do Rio de Janeiro. In Estratégias e ações para a conservação da Biodiversidade no Estado do Rio de Janeiro (H.G. Bergallo, E.C.C. Ficalgo, C.F.D. Rocha, M.C. Uzêda, M.B. Costa, M.A.S. Alves, M.V. Sluys, M.A. Santos, T.C.C. Costa & A.C.R. Cozzolino, eds). Instituto Biomas, Rio de Janeiro, p.101-110.

COSTA, C.M.R., HERMANN, G., MARTINS, C.S., LINS, L.V. & LAMAS, I. 1998. Biodiversidade em Minas Gerais: um atlas para sua conservação. Fundação Biodiversitas, Belo Horizonte.

COSTA, L.M., LUZ, J.L. & ESBÉRARD, C.E.L. 2012. Riqueza de morcegos insetívoros em lagoas no Estado do Rio de Janeiro, Brasil. Pap. Avulsos de Zool. 52(2):7-19.

DELCIELLOS, A.C., NOVAES, R.L.M., LOGUERCIO, M.F.C., GEISE, L., SANTORI, R.T., SOUZA, R.F., PAPI, B.S., RAÍCES, D.S.L., VIEIRA, N.R., FELIX, S., DETOGNE, N., SILVA, C.C.S., BERGALLO, H.G. & ROCHA-BARBOSA, O. 2012. Mammals of Serra da Bocaina National Park, state of Rio de Janeiro, southeastern Brazil. Check List 8(4):675-692.

DIAS, D., ESBÉRARD, C.E.L. & PERACCHI, A.L. 2008. Riqueza, diversidade de espécies e variação altitudinal de morcegos na Reserva Biológica do Tinguá, estado do Rio de Janeiro, Brasil (Mammalia, Chiroptera). In Ecologia de morcegos (N.R. REIS, A.L. PERACCHI & G.A.D. SANTOS, eds.). Technical Books Editora, Rio de Janeiro, p. 125-142.

DIAS, D., CARVALHO, W.D., TEIXEIRA, T.S.M., TAVARES, D., XAVIER, B.S., VALLE, E.L.V. & ESBÉRARD, C.E.L. 2015. First record of *Myotis izecksohni* (Chiroptera, Vespertilionidae) for the Atlantic Forest of Minas Gerais, southeastern Brazil. Mastozool. Neotrop. 22(1):149-153.

DRUMMOND, G.M., MARTINS, C.S., MACHADO, A.B.M., SEBAIO, F.A. & ANTONINI, Y. 2005. Biodiversidade em Minas Gerais, um atlas para sua conservação. 2 ed. Fundação Biodiversitas, Belo Horizonte.

ESBÉRARD, C.E.L. 2007. Influence of moon cycle in phyllostomid bat capture. Iheringia, Zool. 97(1):81-85.

ESBÉRARD, C.E.L & DAEMON, C. 1999. Novo método para marcação de morcegos. Chiropt. Neotrop. 5(1-2):116-117.

FERREIRA, J., ARAGÃO, L.E.O.C., BARLOW, J., BARRETO, P., BERENGUER, E., BUSTAMANTE, M., GARDNER, T.A., LEES, A.C., LIMA, A., LOUZADA, J., PARDINI, R., PARRY, L., PERES, C.A., POMPEU, P.S., TABARELLI, M. & ZUANON, J. 2014. Brazil's environmental leadership at risk: Mining and dams threaten protected areas. Science 346:706-707.

GARBINO, G.S.T. 2011. Chiroptera, Emballonuridae, *Saccopteryx leptura* (Schreber, 1774): Range extension and first record for the states of São Paulo and Minas Gerais, southeastern Brazil. Check List 7(3):319-322.

GESTA - Grupo de Estudos em Temáticas Ambientais. Mapa dos conflitos ambientais de Minas Gerais. 2015. http://conflitosambientaismg.lcc.ufmg.br/observatorio-de-conflitos-ambientais/mapa-dos-conflitos-ambientais/ (último acesso em 31/10/2017).

GREGORIN, R. & LOUREIRO, L.O. 2011. New records of bats for the state of Minas Gerais, with range extension of *Eptesicus chiriquinus* Thomas (Chiroptera: Vespertilionidae) to southeastern Brazil. Mammalia 75(3):291-294.

GREGORIN, R., TAHARA, A.S. & BUZZATO, D.F. 2011. *Molossus aztecus* and other small *Molossus* (Chiroptera: Molossidae) in Brazil. Acta Chiropterol. 13(2):311-317.

GREGORIN, R., VASCONCELLOS, K.L. & GIL, B.B. 2015. Two new records of bats (Chiroptera: Phyllostomidae) for the Atlantic Forest, eastern Brazil. Mammalia 79(1):121-124.

GREGORIN, R., BERNARD, E., LOBÃO, K.W., OLIVEIRA, L.F., MACHADO, F.S., GIL, B.B. & TAVARES, V.C. 2017. Vertical stratification in bat assemblages of the Atlantic Forest of South-eastern Brazil. J. Trop. Ecol. 33(5):299-308.

GUIMARÃES, M.M. 2014. Morcegos cavernícolas do Brasil: composição, distribuição e serviços ambientais. Dissertação de Mestrado. Universidade Federal de Lavras, Lavras.

IBGE (Instituto Brasileiro de Geografia e Estatística). 2012. Manual técnico da vegetação brasileira: sistema fitogeográfico, inventário das formações florestais e campestres, técnicas e manejo de coleções botânicas, procedimentos para mapeamento, 2 ed. Ministério do Planejamento Orçamento e Gestão, Rio de Janeiro.

ICMBIO. 2014. Espécies ameaçadas. http://www.icmbio.gov.br/portal/faunabrasileira/lista-de-especies (último acesso em 31/10/2017).

KALKO E.K.V., ESTRADA-VILLEGAS, S., WEGMANN, M.S.M. & MEYER, C.F.J. 2008. Flying high: assessing the use of the aerosphere by bats. Integr. Comp. Biol. (1):1–14.

KUNZ, T.H & PARSONS, S. 2009. Ecological and behavioural methods for the study of bats. The Johns Hopkins University Press, Baltimore.

LOUREIRO, L.O. 2014. Sistemática de *Molossus* (Mammalia: Chiroptera: Molossidae) com ênfase nas espécies ocorrendo no Brasil. Dissertação de Mestrado. Universidade Federal de Minas Gerais, Belo Horizonte.

LOURENÇO, E.C., COSTA, L.M., SILVA, R.M. & ESBÉRARD, C.E.L. 2010. Bat diversity of Ilha da Marambaia, southern Rio de Janeiro State, Brazil (Chiroptera, Mammalia). Rev. Bras. Biol. 70(3):511-519.

LUZ, J.L., COSTA, L.M., JORDÃO-NOGUEIRA, T., ESBÉRARD, C.E.L. & BERGALLO, H.G. 2013. Morcegos em área de Floresta Montana, Visconde de Mauá, Resende, Rio de Janeiro. Biota Neotrop. 13(2):190-195 http://www.biotaneotropica.org.br/v13n2/en/abstract?inventory+bn02513022013 (último acesso em 31/10/2017).

MARQUES, J.T., RAMOS-PEREIRA, M.J. & PALMEIRIM, J.M. 2016. Patterns in the use of rainforest vertical space by Neotropical aerial insectivorous bats: all the action is up in the canopy. Ecography 39(5):476-486.

MARTINS, M.A., CARVALHO, W.D., DIAS, D., FRANÇAS, D.S., OLIVEIRA, M.B. & PERACCHI, A.L. 2015. Bat species richness (Mammalia, Chiroptera) along an elevational gradiente in the Atlantic Forest of Southeastern Brazil. Acta Chiropterol. 17(2):401-409.

MEYER, C.F., AGUIAR, L.M.S., AGUIRRE, L.F., BAUMGARTEN, J., CLARKE, F.M., COSSON, J.F., VILLEGAS, S.E., FAHR, J., FARIA, D., FUREY, N., HENRY, M., HODGKISON, R., JENKINS, R.K.B., JUNG, K.G., KINGSTON, T., KUNZ, T.H., GONZALEZ, M.C.M., MOYA, I., PATTERSON, B.D., PONS, J.M., RACEY, P.A., REX, K., SAMPAIO, E.M., SOLARI, S., STONER, K.E., VOIGT, C.C., STADEN, D., WEISE, C.D. & KALKO, E.K.V. 2011. Accounting for detectability improves estimates of species richness in tropical bat surveys. J. Appl. Ecol. 48(3):777-787.

MITTERMEIER, R.A., GIL, R.P., HOFFMAN, M., PILGRIM, J., BROOKS, T., MITTERMEIER, C.G., LAMOREUX, J. & FONSECA, G.A.B. 2005. Hotspots revisited: earth's biologically richest and most endangered terrestrial ecoregions, 2. ed. University of Chicago Press, Boston.

MODESTO, T.C., PESSÔA, F.S., ENRICI, M.C., ATTIAS, N., JORDÃO-NOGUEIRA, T., COSTA, L.M., ALBUQUERQUE, H.G. & BERGALLO, H.G. 2008. Mamíferos do Parque Estadual do Desengano, Rio de Janeiro, Brasil. Biota Neotrop. 8(4):153-158 http://www.biotaneotropica.org.br/v8n4/pt/abstract?article+bn01408042008 (último acesso em 31/10/2017).

MORAS, L.M, BERNARD, E. & GREGORIN, R. 2013. Bat assemblages at a high altitude area in the Atlantic Forest of southeastern Brazil. Mastozool. Neotrop. 20:269-278.

MYERS, N., MITTERMEIER, R.A., MITTERMEIER, C.G., FONSECA, G.A.B. & KENT, J. 2000. Biodiversity hotspots for conservation priorities. Nature 403:853-858.

NOBRE, P.H., MANHAES, M.A., BASTOS NETO, O.J., REZENDE, A.C., RODRIGUES, A.S. 2013a. Bat assemblages from montain forest areas in the Serra Negra region, southeastern Brazil. Mastozool. Neotrop. 20:279-287.

NOBRE, P.H., MELLO, R.M., MANHAES, M.A., REZENDE, A.C. 2013b. Morcegos (Chiroptera, Mammalia) do Parque Estadual do Ibitipoca, Minas Gerais - Brasil. MG.Biota 6(2):4-29.

OKSANEN, J., BLANCHET, F.G., FRIENDLY, M., KINDT, R., LEGENDRE, P., MCGLINN, D., MINCHIN, P.R., O'HARA, R.B., SIMPSON, G.L., SOLYMOS, P., STEVENS, M.H.H., SZOECS, E. & WAGNER, H. 2017. Vegan: community ecology package. R package version 2.4-3. https://CRAN.R-project.org/package=vegan

OLIVEIRA, L.F. 2013. Assembleia de Chiroptera (Mammalia) no Parque Estadual do Rio Doce, Minas Gerais: riqueza, composição e estratificação vertical. Dissertação de Mestrado, Universidade Federal de Juiz de Fora, Juiz de Fora.

PAOLINO, R.M., VERSIANI, N.F., SALVADOR, N.A.P., RODRIGUES, T.F., KREPSCHI, V.G. & CHIARELLO, A.G. 2016. Buffer zone use by mammals in a Cerrado protected area. Biota Neotrop. 16(2):e20140117 http://dx.doi.org/10.1590/1676-0611-BN-2014-0117 (último acesso em 31/10/2017).

RADAM BRASIL. 1983. Levantamento de recursos naturais, v. 32, folha S/ F. 23/ 24. Rio de Janeiro/Vitória. Ministério das Minas e Energias, Rio de Janeiro.

R CORE TEAM 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

REIS N.R., FREGONEZI, M.N., PERACCHI, A.L. & SHIBATTA O.A. 2013. Morcegos do Brasil – Guia de Campo. Technical Books, Rio de Janeiro.

RIBEIRO, M.C., METZGER, J.P., MARTENSEN, A.C., PONZONI, F.J. & HIROTA, M.M. 2009. The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. Biol. Conserv. 142:1141-1153.

SÁ-JÚNIOR, A., CARVALHO, L.G., SILVA, F.F. & ALVES, M.C. 2012. Application of the Köppen classification for climatic zoning in the state of Minas Gerais, Brazil. Theor. Appl. Climatol. 108:1-7.

SCOLFORO, J.R.S., OLIVERIRA, A.D., DAVIDE, A.C. & CAMOLESI, J.F. 2002. Manejo sustentável da candeia *Eremanthus erythropappus* e *Eremanthus incanus*: relatório técnico científico. Universidade Federal de Lavras, Lavras.

STEVENS, R.D. 2013. Gradients of bats diversity in Atlantic Forest of South America: environmental seasonality, sampling effort and spatial autocorrelation. Biotropica 45(6):764-770.

STRAUBE, F. & G. BIANCONI. 2002. Sobre a grandeza e a unidade utilizada para estimar esforço de captura com utilização de redes-de-neblina. Chiropt. Neotrop. 8(1-2):150-152

TAVARES, V.C., AGUIAR, L.M.S., PERINI, F.A., FALCÃO, F.C. & GREGORIN, R. 2010. Bats of the state of Minas Gerais, southeastern Brasil. Chiropt. Neotrop. 16(1):675-705.

TRAJANO, E. 1985. Ecologia de populações de morcegos cavernícolas em uma região cárstica do sudeste do Brasil. Rev. Bras. Zool. 2(5):255-320.

ZHOURI, A. 2014. Mapping environmental inequalities in Brazil: mining, environmental conflicts and impasses of mediation. desiguALdades.net Working Paper Series 75:2-39.

*Received: 11/12/2017*
*Revised: 12/02/2018*
*Accepted: 11/03/2018*

Biota Neotropica 18(2): e20170417, 2018
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
Article

# The bats of Rio Grande do Norte state, northeastern Brazil

***Juan Carlos Vargas-Mena*[1]*, Kleytone Alves-Pereira*[2]*, Marília Abero Sá Barros*[3]*, Eder Barbier*[3]*, Eugenia Cordero-Schmidt*[1]*, Sergio Maia Queiroz Lima*[4]*, Bernal Rodríguez-Herrera*[5] *& Eduardo Martins Venticinque*[1]**

*[1]Universidade Federal do Rio Grande do Norte, Departamento de Ecologia, Centro de Biociências, Campus Lagoa Nova, 59072-970, Natal, RN, Brasil*
*[2]Universidade Federal do Rio Grande do Norte, Departamento de Psicobiologia, Centro de Biociências, Campus Lagoa Nova, 59072-970, Natal, RN, Brasil*
*[3]Universidade Federal de Pernambuco, Departamento de Zoologia, Centro de Biociências, Rua Nelson Chaves, Cidade Universitária, 50670-901, Recife, PE, Brasil*
*[4]Universidade Federal do Rio Grande do Norte, Departamento de Botânica e Zoologia, Centro de Biociências, Campus Lagoa Nova, 59072-970, Natal, RN, Brasil*
*[5]Universidad de Costa Rica, Escuela de Biología, 2060, Montes de Oca, San José, Costa Rica*
**Corresponding author: Juan Carlos Vargas-Mena, e-mail: jcvargasmena@gmail.com*

VARGAS-MENA, J. C., ALVES-PEREIRA, K., BARROS, M. A. S., BARBIER, E., CORDERO-SCHMIDT, E., LIMA, S. M. Q., RODRÍGUEZ-HERRERA, B., VENTICINQUE, E. M. **The bats of Rio Grande do Norte state, northeastern Brazil**. Biota Neotropica. 18(2): e20170417. http://dx.doi.org/10.1590/1676-0611-BN-2017-0417

***Abstract:*** Rio Grande do Norte is one of the smallest states in Brazil but has a rich diversity of ecosystems, including Caatinga vegetation, remnants of Atlantic Forest, coastal habitats, mangroves and large karstic areas with caves. However, its chiropteran fauna is little known, and the state contains conspicuous gaps of information on the occurrence and distribution of bats in Brazil. In order to reduce this information gap, based on a review of scientific literature and regional mammal collections, we list 42 species of bats, including new occurrences for 13 species and discussion on their conservation status. Results show that more than half (54%) of the recorded species are phyllostomid bats, and about one third of the bats in the state roosts in underground cavities. The Caatinga harbored the highest bat richness in the state, including the occurrence of four vulnerable species (*Furipterus horrens*, *Lonchorhina aurita*, *Natalus macrourus* and *Xeronycteris vieirai*). The Atlantic Forest needs to be more sampled, including mangroves, coastal habitats and areas of Caatinga in the central region of the state (Borborema highlands), which are virtually unsurveyed. Although the recent increase of studies on bats in the state, future studies should complement conventional mistnetting with active roost search and bioacoustical records in order to obtain better data for unraveling the bat fauna of Rio Grande do Norte.
***Keywords:*** *Atlantic Forest, Caatinga, Chiroptera, Species distribution, Vulnerable species.*

# Morcegos do estado do Rio Grande do Norte, nordeste do Brasil

***Resumo:*** O Rio Grande do Norte é um dos menores estados do Brasil, mas possui grande diversidade de ecossistemas, incluindo vegetação de Caatinga, Mata Atlântica, habitats costeiros, manguezais e grandes áreas cársticas com cavernas. No entanto, a fauna de quirópteros é pouco conhecida, e o estado contém lacunas importantes sobre a ocorrência e distribuição de morcegos no Brasil. Para reduzir essa lacuna de informação, com base em uma revisão da literatura científica e coleções regionais de mamíferos, listamos 42 espécies de morcegos, incluindo novas ocorrências para 13 espécies e discusões sobre seu estado de conservação. Os resultados mostram que mais de metade (54%) das espécies registradas são morcegos filostomídeos e cerca de um terço dos morcegos no estado se abrigam em cavidades subterrâneas. A Caatinga abrigou a maior riqueza de morcegos no estado, incluindo a ocorrência de quatro espécies vulneráveis (*Furipterus horrens*, *Lonchorhina aurita*, *Natalus macrourus* e *Xeronycteris vieirai*). A Mata Atlântica precisa ser mais amostradas, incluindo manguezais, habitats costeiros e áreas de Caatinga principalmente na região central do estado (planalto da Borborema), que são virtualmente inexplorados. Embora o recente aumento das investigações no estado em relação aos morcegos, estudos futuros devem complementar os métodos convencionais de captura com procura ativa de abrigos e monitoramento bioacústico para obter melhores dados na tarefa de desvendar a diversidade de morcegos do Rio Grande do Norte.
***Palavras-chave:*** *Caatinga, Chiroptera, Espécies vulneráveis, Distribuição de espécies, Mata Atlântica.*

## Introduction

About one-quarter of the Brazilian mammal species are bats (Paglia et al. 2012), currently comprising 183 known species (Nogueira et al. 2014, Feijó et al. 2015a, Fischer et al. 2015, Moratelli & Dias 2015, Gregorin et al. 2016, Rocha et al. 2016). Considering that Brazil harbors one of the largest mammal diversities in the world, its bat fauna is poorly known. Bat records indicate that less than 10% of the Brazilian territory can be considered minimally sampled, and about 60% has no single formal record of bat species (Bernard et al. 2011).

The state of Rio Grande do Norte (RN) represents a conspicuous gap of bat information in Brazil (Bernard et al. 2011). The earliest records of bats in RN date back to the past century, when Sanborn (1937), Goodwin (1959), Webster (1993), and Jones & Hood (1993) reported few bat records from the coastal region of the state (municipality of Natal) and deposited the specimens in biological collections in United States. Studies on bats in RN slowly began to increase in this century, with new records and distributional expansions (Feijó & Nunes 2010, Barros 2014, Basílio et al. 2017), ecology and natural history (Cordero-Schmidt et al. 2016, Cordero-Schmidt et al. 2017), community diversity (Barros et al. 2017, Vargas-Mena et al. *in press*), and subterranean fauna inventories (Ferreira et al. 2010); including a bilbliographic review on the bat fauna in northeastern Brazil by Garcia et al. (2014). Such studies together have recorded a richness of 38 species of bats in the state.

Despite the recent efforts in describing the bat fauna of RN, there are still gaps of knowledge. In addition, bat diversity and species distribution are poorly known in the state, and it is important for conservation strategies and policies (Costa et al. 2005). Therefore, we present an updated list of bat species based on available mammal collections and literature review in order to describe the bat species composition, distribution and richness that occur within the state's political boundaries and discuss conservation concerns based on the available data. We expect that this study will inform the scientific community, government agencies, non-governmental organizations, and general society about the diversity of bats that occurr in RN; will point out sites that need increased research efforts; and will be a reference baseline for ecological and diversity assessments, including those for environmental impact studies, to be carried out in the state.

## Material and Methods

### 1. *Study Site*

The state of Rio Grande do Norte (RN) is located in the northeastern region of Brazil between the latitudes 4°49'53" S and 6°58'57" S and longitudes 35°58'03" W and 38°36'12" W. It is limited to the north and the east by the Atlantic Ocean; to the west by the Ceará State, and the south with the state of Paraíba. RN has a territorial extension of 52,797 km² and is composed of 167 municipalities, being one of the smallest states in Brazil (IDEMA 2015).

The 95% of the state is characterized by a semiarid climate where the Caatinga domain occurs (IDEMA 2015). According to Köppen classification, the climate in this portion of the state is BShw (hot and dry), with a mean annual rainfall of less than 800 mm (Alvares *et al*., 2013). The Caatinga is a seasonally dry tropical forest composed by mosaics of xeric spiny shrub lands, columnar cacti, succulents, and deciduous woody forest stands (arboreal caatingas) (Leal et al. 2003). Physiognomy and plant composition variations determine eight different ecoregions in the Caatinga; however, only two occur in RN: the Northern Sertaneja Depression (NSD) and the Borborema Highlands (BH) (see Velloso et al. 2002). The NSD is characterized by extensive low plains, with elevations varying from 20-500 meters. The vegetation type is spiny shrub lands with herbaceous plants and remnants of arboreal Caatinga on slopes and low mountain ranges, and on the main river valleys there are ciliary remnants of Carnaúba palms (*Copernicia prunifera*). The BH ecoregion is mountainous with steep slopes and rugged relief, with rocky outcrops of granite. The altitude varies from 150-650 m and the vegetation is characterized by a shrubby-arboreal Caatinga with columnar cacti and arboreal Caatingas in more humid areas on the tops of the mountains.

On the east coast of the state, according to Köppen classification, the climate type is Aw with precipitations varying from 700-1500 mm (Alvares *et al*., 2013). This region harbors the northernmost distribution of the Atlantic Forest in Brazil (IDEMA 2015). The RN's Atlantic Forest is composed of remnants of evergreen and semi-evergreen forests stands, dunes, short bushy-forests on fixed dunes (known as "restingas"), and mangroves (INPE/SOS Mata Atlântica 2014). Ecotones occur in contact areas of Caatinga and Atlantic Forest.

Finally, RN contains an important speleological heritage with the occurrence of extensive calcareous outcrops or "lajedos" that harbors numerous caves. Most caves occur in the northern and western region of the state in the Caatinga (Cruz et al. 2010), with the majority of caves located in the NSD ecoregion. RN has the fourth highest number of underground cavities in Brazil with more than 1000 recorded caves (Bento et al. 2017).

### 2. *Data collection*

To find bat records within the political boundaries of RN, we searched in regional mammal collections (as primary data) and specialized bibliographic reviews (as secondary data). Primary data consisted of bat records in the mammal collections of the Universidade Federal de Pernambuco (UFPE) and the Universidade Federal of Rio Grande do Norte (UFRN) (Coleção Mastozoológica Adalberto Varela, CMAV). We only considered specimens with voucher number and location (geographic coordinates and municipality). We examined all bat specimens (N = 166) currently deposited at CMAV (except one specimen without specific collection site data), and all bat specimens deposited at UFPE (N = 128) that where collected in RN. The species were identified using taxonomic keys of Neotropical bats, such as Simmons (1996), Gardner (2008), Gregorin & Taddei (2002) and Díaz et al. (2016), as well as the original description of species on scientific articles. Specimens with doubtful identifications were confirmed by experts.

Secondary data were obtained from academic online databases (Google Scholar, Periódicos Capes, ScieELO, Science Direct, and Web of Science) using "Atlantic Forest", "bat", "Caatinga", "Chiroptera", "Mata Atlântica", "morcego", "quiróptero", and "Rio Grande do Norte" as keywords. Also, we consulted books and book chapters that deal with the subject. We compiled all the information available about bats in the state of RN and then selected only records originally published in peer-reviewed literature and books. Among the bat records from peer-reviewed literature and books, we selected only those supported by voucher specimens deposited in public scientific collections. Only the records that met both requirements (publication in peer-reviewed literature/books and availability of vouchers) were included in our list. However, all the bat records found in RN, regardless of presence of voucher specimens, are included in the Supplementary Material.

The species nomenclature and taxonomic arrangement followed Nogueira et al. (2014) and Phyllostomidae species followed Baker et al. (2016). We recognized *Lonchophylla inexpectata* Moratelli & Dias, 2015 as a different species from *Lonchophylla mordax* Thomas, 1903 (see Moratelli & Dias 2015). Finally, we assigned for each species its current international and national conservation status following the IUCN Red List of Threatened Species (IUCN 2016) and Brazil Red Book of Threatened Species of Fauna (ICMBio/MMA 2016) respectively; its region (Caatinga and Atlantic Forest) of occurrence; locality(ies) of record(s); literature reference(s) and/or collection number(s) when available.

## Results

We found 75 published records, of which 38 satisfied our criteria (peer-reviewed literature/books with voucher specimens), plus 66 unpublished records (CMAV and UFPE collections), totalizing 104 bat records included in the final species list (Table 1) from 141 bat records inspected (Table S1, Supplementary Material). We found records of 50 bat species among the 141 records (Supplementary Materials) and just 42 species according to our criteria for inclusion in the RN list (Table 1). These 42 species represented eight families: Phyllostomidae (23 species), Molossidae (6), Vespertilionidae (5), Emballonuridae (3), Noctilionidae (2), Furipteridae (1), Mormoopidae (1), and Natalidae (1). Eight species cited in the literature did not entered in the official list due to absence of voucher specimens, *Peropteryx kappleri* Peters, 1867; *Saccopteryx canescens* Thomas, 1901; *S. leptura* Thomas, 1901; *Anoura caudifer* (É. Geoffroy, 1818); *Artibeus fimbriatus* Gray, 1838; *Chiroderma villosum* Peters, 1860; *Myotis riparius* Handley 1960 and *M. simus* Thomas, 1901.

Records were reported in 21 localities, 18 in the Caatinga and three in the Atlantic Forest (Figure 1). All localities in the Caatinga corresponded to the NSD, with no records for the BH. The state's Caatinga presented an accumulated richness of 32 bat species whereas the Atlantic Forest did 22 species. Nineteen species were exclusive to the Caatinga and nine to the Atlantic Forest (Table 1). The species with the highest number of collected specimens (with voucher numbers) were *Myotis lavali* (31 specimens), *Pteronotus gymnonotus* (30), *Molossus molossus* (28), *Artibeus planirostris* (26), and *Glossophaga soricina* (22). The species found in more than one locality were *G. soricina* (eight localities), *Peropteryx macrotis* (seven), *Myotis lavali* (six); and *Desmodus rotundus*, *Carollia perspicillata*, and *Molossus molossus* (four) (Table 1).

Regarding the conservation status, 31 species are categorized as Least Concern (LC), three as Data Deficient (DD), two as Not Evaluated (NE), and only *Natalus macrourus* is regarded as Near Threatened (NT) in the IUCN Red List of Threatened Species (IUCN 2016). In the Brazil Red Book of Threatened Species of Fauna (ICMBio/MMA 2016), 34 species are regarded as LC, two as DD, two as NE, and four species are considered Vulnerable (VU), *Furipterus horrens*, *Lonchorhina aurita*, *Natalus macrourus* and *Xeronycteris vieira* (Table 1).

Of the 42 species of bats presented herein, 13 are new records for RN which are listed below.

**Family Emballonuridae Gervais, 1856**

*Rhynchonycteris naso* (Wied-Neuwied, 1820)

The only known records of this species in the state are two specimens collected close to water in the Poço Branco dam (5°37'48.96" S, 35°39'8.31" W) at 65 m a.s.l. on 16 November 1990 in a transition area between the Atlantic Forest and Caatinga. Specimens presented pointed and elongated snout, two light and weak stripes on back and forearms (35.9-37.8 mm) with whitish tufts. Specimens are deposited in CMAV. Specimens examined: CMAV 105, 106.

**Family Phyllostomidae Gray, 1825**

Subfamily Micronycterinae

*Micronycteris megalotis* (Gray, 1842)

One specimen collected in a small calcareous outcrop surrounded by scrubby Caatinga vegetation close to the Porco do Mato cave in the Furna Feia National Park, Mossoró-Baraúna municipalities 5°3'24.13" S, 37°30'54.03"W) at 131 m a.s.l. It presented notch in ear band shallow; similar ventral and dorsal fur coloration; calcar longer than foot; and length of hair on the inner edge of the ear >4 mm. Specimen examined: CMAV 134.

*Micronycteris schmidtorum* Sanborn, 1935

Known from only one locality in Sítio Santa Rosa in Lajes municipality, where two individuals were captured in a riparian Caatinga close to a water dam (05°49'56.2"S, 36°12'16.0"W) at 295 m a.s.l. Both specimens presented ventral fur very pale gray to almost white and calcar (10.2 -10.4mm) longer than the foot (6.5-8.5 mm) which differentiates it from other *Micronycteris* bats with pale ventral fur (Fig 2A). Specimens examined: CMVA 140, 145.

*Micronycteris sanborni* Simmons, 1996

Only one recorded site in the Seridó Ecological Station in Serra Negra do Norte municipality (6°34'55.4" S, 37°15'9.91" W) at 200 m a.s.l. One adult male, and two females were collected at the edge of a natural lake in Caatinga vegetation. Specimens presented diagnostic characteristics of *M. sanborni*: gap between I2 and canine, length of calcar similar or shorter (6.6-8.0 mm) than foot (7.6-8.1 mm), thumb shorter than 7.5 mm (6.8-7.7 mm) and pure white color in ventral fur (Fig 2B). Specimens examined: UFPE 3436, 3439, 3440.

Subfamily Glossophaginae

*Anoura geoffroyi* Gray, 1838

One male collected in Sítio Joazeiro at 230 m above sea level (a.s.l.) at the foothill of the Serra do Feiticeiro in a semi-open area with patches of scrubby caatinga vegetation, cacti, and some woody trees in Lajes municipality (05º45'55.7"S, 36º12'55.7"W). The specimen presented diagnostic characteristics of *A. geoffroyi* with no lower incisors, short semicircular uropatagium, and forearm length of 40.2mm. (*A. caudifer* has forearm of 34-39mm). Specimens examined: CMAV 144.

Subfamily Lonchophyllinae

*Lonchophylla inexpectata* Moratelli & Dias, 2015

**Table 1.** List of bat species recorded in the state of Rio Grande do Norte, northeastern Brazil, including conservation status according to International Union for Conservation of Nature (IUCN) and Brazilian Ministry of Environment (Ministério do Meio Ambiente, MMA), localities, voucher numbers and references of original records. Conservation status: LC – Least Concern; DD – Data Deficient; NE – Not Evaluated; NT – Near Threatened, and VU - Vulnerable. Regions are Atlantic Forest (AF) and Caatinga (CA). Localities are: Natal (**1**), Macaíba (**2**), Maxaranguape (**3**), Ceará-Mirim (**4**), Taipu (**5**), João Câmara (**6**), Guamaré (**7**), Galinhos (**8**), Jandaíra (**9**), Nísia Floresta National Forest, Nísia Floresta (**10**), Lagoa Salgada (**11**), Nova Cruz (**12**), Poço Branco (**13**), Lajes (**14**), Seridó Ecological Station, Serra Negra do Norte (**15**), Mossoró (**16**), Furna Feia National Park, Baraúna/Mossoró (**17**), Governador Dix-Sept Rosado (**18**), Felipe Guerra (**19**), Caraúbas (**20**), and Martins (**21**); coordinates are found in Fig. 1. Voucher specimens presented in collection number column correspond to the oldest specimen recorded in each locality. All collection numbers of revised specimens are found in Supplementary table. References in the original record column corresponds to the study who first recorded the species in the state. Collections abbreviations: CAS – California Academy of Science; CMAV – Coleção de Mamíferos Adalberto Varela, Universidade Federal do Rio Grande do Norte; CMUFS – Coleção de Mamíferos da Universidade Federal de Sergipe; MZUSP – Museu de Zoologia da Universidade de São Paulo; UFPB – Coleção de Mamíferos da Universidade Federal da Paraíba; UFPE – Coleção de Mamíferos da Universidade Federal de Pernambuco; USNM – United States National Museum. New species records are indicated with an asterisk (*).

| **Family**/Subfamily/*Species* | **IUCN/MMA** | **Region** | | **Localities** | **Collection number** | **Original record** |
|---|---|---|---|---|---|---|
| | | **AF** | **CA** | | | |
| **Emballonuridae Gervais, 1856** | | | | | | |
| Emballonurinae | | | | | | |
| *Peropteryx leucoptera* Peters, 1867 | LC | X | | 10 | UFPE 3193 | Barros et al. 2017 |
| *Peropteryx macrotis* (Wagner, 1843) | LC | X | X | 1, 9, 13, 14, 18, 19, 20 | USNM (not informed), CMAV 111, CMAV 107, CMAV 122, CMAV 130, CMAV 129, CMAV 131 | Sanborn 1937; Vargas-Mena et al. in press; This study |
| *Rhynchonycteris naso* (Wied-Neuwied, 1820)* | LC | | X | 13 | CMAV 105 | This study |
| **Phyllostomidae Gray, 1825** | | | | | | |
| Micronycterinae | | | | | | |
| *Micronycteris megalotis* (Gray, 1842) * | LC | | X | 17 | CMAV 134 | This study |
| *Micronycteris schmidtorum* Sanborn, 1935* | DD | | X | 15 | CMAV 140, CMAV 145 | This study |
| *Micronycteris sanborni* Simmons, 1996* | LC | | X | 14 | UFPE 3436 | This study |
| Desmodontinae | | | | | | |
| *Desmodus rotundus* (É. Geoffroy, 1810) | LC | X | X | 6, 10, 13, 17 | CMAV 117, UFPE 3306, CMAV 038, CMAV 070 | Barros et al. 2017; This study |
| *Diphylla ecaudata* Spix, 1823 | LC | | X | 20 | CMAV 135 | Vargas-Mena et al. in press |
| Lonchorhininae | | | | | | |
| *Lonchorhina aurita* Tomes, 1863 | LC/VU | | X | 19 | CMAV 128 | Vargas-Mena et al. in press |
| Phyllostominae | | | | | | |
| *Chrotopterus auritus* (Peters, 1856) | LC | | X | 21 | CMUFS 259 | Basílio et al. 2017 |
| *Lophostoma brasiliense* Peters, 1866 | LC | X | | 10 | UFPE 2181 | Barros et al. 2017 |
| *Phyllostomus discolor* (Wagner, 1843) | LC | X | X | 2, 5, 10 | CMAV 018, CMAV 039, UFPE 3247 | Barros et al. 2017; This study |
| *Phyllostomus hastatus* (Pallas, 1767) | LC | X | | 10 | UFPE 3225 | Barros et al. 2017 |
| *Tonatia bidens* (Spix, 1823) | DD | | X | 20 | CMAV 138 | Vargas-Mena et al. in press |
| *Trachops cirrhosus* (Spix, 1823) | LC | X | X | 10, 14 | UFPE 3266, CMAV 069 | Barros et al. 2017; This study |
| Glossophaginae | | | | | | |
| *Anoura geoffroyi* Gray, 1838* | LC | | X | 14 | CMAV 144 | This study |
| *Glossophaga soricina* (Pallas, 1766) | LC | X | X | 1, 4, 5, 10, 12, 14, 15, 16 | CAS (not informed number), CMAV 015, CMAV 061, UFPE 3257, CMAV 002, CMAV 124, UFPE 3423, CMAV 147 | Barros et al. 2017; Vargas-Mena et al. in press; Webster 1993; This study |
| Lonchophyllinae | | | | | | |
| *Lonchophylla mordax* Thomas, 1903* | NT / LC | | X | 15, 16 | CMAV 149, UFPE 3424, | Vargas-Mena et al. in press<br>This study |
| *Lonchophylla inexpectata* Moratelli & Dias, 2015* | NE | | X | 14 | CMAV 167 | This study |
| *Xeronycteris vieirai* Gregorin & Ditchfield, 2005 | DD/VU | | X | 14 | CMAV 143 | Cordero-Schmidt et al. 2017 |

**Continued Table 1.**

| **Family**/Subfamily/*Species* | **IUCN/MMA** | **Region** | | **Localities** | **Collection number** | **Original record** |
|---|---|---|---|---|---|---|
| | | **AF** | **CA** | | | |
| Carolliinae | | | | | | |
| *Carollia perspicillata* (Linnaeus, 1758) | LC | X | X | 5, 6, 10, 17 | CMAV 044, CMAV 120, UFPE 3290, CMAV 136 | Barros et al. 2017; This study |
| Subfamily Stenodermatinae | | | | | | |
| *Artibeus lituratus* (Olfers, 1818) | LC | X | | 1, 10 | CMAV 159, UFPE 3288 | Barros et al. 2017; This study |
| *Artibeus planirostris* (Spix, 1823) | LC | X | X | 1, 5, 10, 15 | CMAV 004, CMAV 067, UFPE 3200, UFPE 3083 | Barros et al. 2017; This study |
| *Dermanura cinerea* Gervais, 1856 | LC | X | | 1, 10 | USNM (not informed number), UFPE 3299 | Barros et al. 2017; Handley 1987 |
| *Platyrrhinus lineatus* (É. Geoffroy, 1810) | LC | X | | 1, 10 | CMAV 012, UFPE 3208 | Barros et al. 2017; This study |
| *Sturnira lilium* (É. Geoffroy, 1810) | LC | X | | 1, 10 | CMAV 161, UFPE 3265 | Barros et al. 2017; This study |
| **Mormoopidae Saussure, 1860** | | | | | | |
| *Pteronotus gymnonotus* (Wagner, 1843) | LC | | X | 6, 19 | CMAV 075, CMAV 125 | Vargas-Mena et al. in press; This study |
| **Noctilionidae Gray, 1821** | | | | | | |
| *Noctilio albiventris* Desmarest, 1818* | LC | | X | 15 | UFPE 3427 | This study |
| *Noctilio leporinus* (Linnaeus, 1758)* | LC | | X | 5, 15 | CMAV 037, UFPE 3426 | This study |
| **Furipteridae Gray, 1866** | | | | | | |
| *Furipterus horrens* (Cuvier, 1828) | LC / VU | | X | 17, 20 | CMAV 137, CMAV 132 | Vargas-Mena et al. in press |
| **Natalidae Gray, 1866** | | | | | | |
| *Natalus macrourus* (Gervais, 1856) | NT / VU | X | X | 1, 16, 19 | USNM 242830, CMAV 148, CMAV 126 | Goodwin 1959; Vargas-Mena et al. in press |
| **Molossidae P. Gervais, 1856** | | | | | | |
| Molossinae | | | | | | |
| *Molossops temminckii* (Burmeister, 1854)* | LC | | X | 15 | UFPE 3433 | This study |
| *Molossus molossus* (Pallas, 1766) | LC | X | X | 1, 2, 8, 11 | CMAV 001, CMAV 023, CMAV 152, UFPE 3068 | Barros 2014; This study |
| *Neoplatymops mattogrossensis* (Vieira, 1942)* | LC | | X | 15 | UFPE 3421 | This study |
| *Nyctinomops aurispinosus* (Peale, 1848) | LC | X | | 3 | USNM 3726 | Shamel 1931 |
| *Nyctinomops macrotis* (Gray, 1840)* | LC | | X | 7 | CMAV 156 | This study |
| *Promops nasutus* (Spix, 1823) | LC | X | X | 7, 10 | CMAV 154, UFPE 3218 | Barros et al. 2017; This study |
| **Vespertilionidae Gray, 1821** | | | | | | |
| Vespertilioninae | | | | | | |
| *Eptesicus furinalis* (d'Orbigny & Gervais, 1847)* | LC | X | X | 1, 8 | CMAV 164, CMAV 150 | This study |
| *Lasiurus blossevillii* ([Lesson, 1826]) | LC | X | | 10 | UFPE 3199 | Barros et al. 2017 |
| *Lasiurus ega* (Gervais, 1856)* | LC | | X | 7 | CMAV 151 | This study |
| Myotinae | | | | | | |
| *Myotis lavali* Moratelli, Peracchi, Dias & Oliveira, 2011 | NE | X | X | 1, 2, 6, 8, 10, 15 | CMAV 010, CMAV 043, CMAV 005, CMAV 153, UFPE 3181, UFPE 3442 | Barros et al. 2017; This study |
| *Myotis nigricans* (Schinz, 1821) | LC | | X | 12 | UFPB 1631 | Feijó & Nunes 2010 |

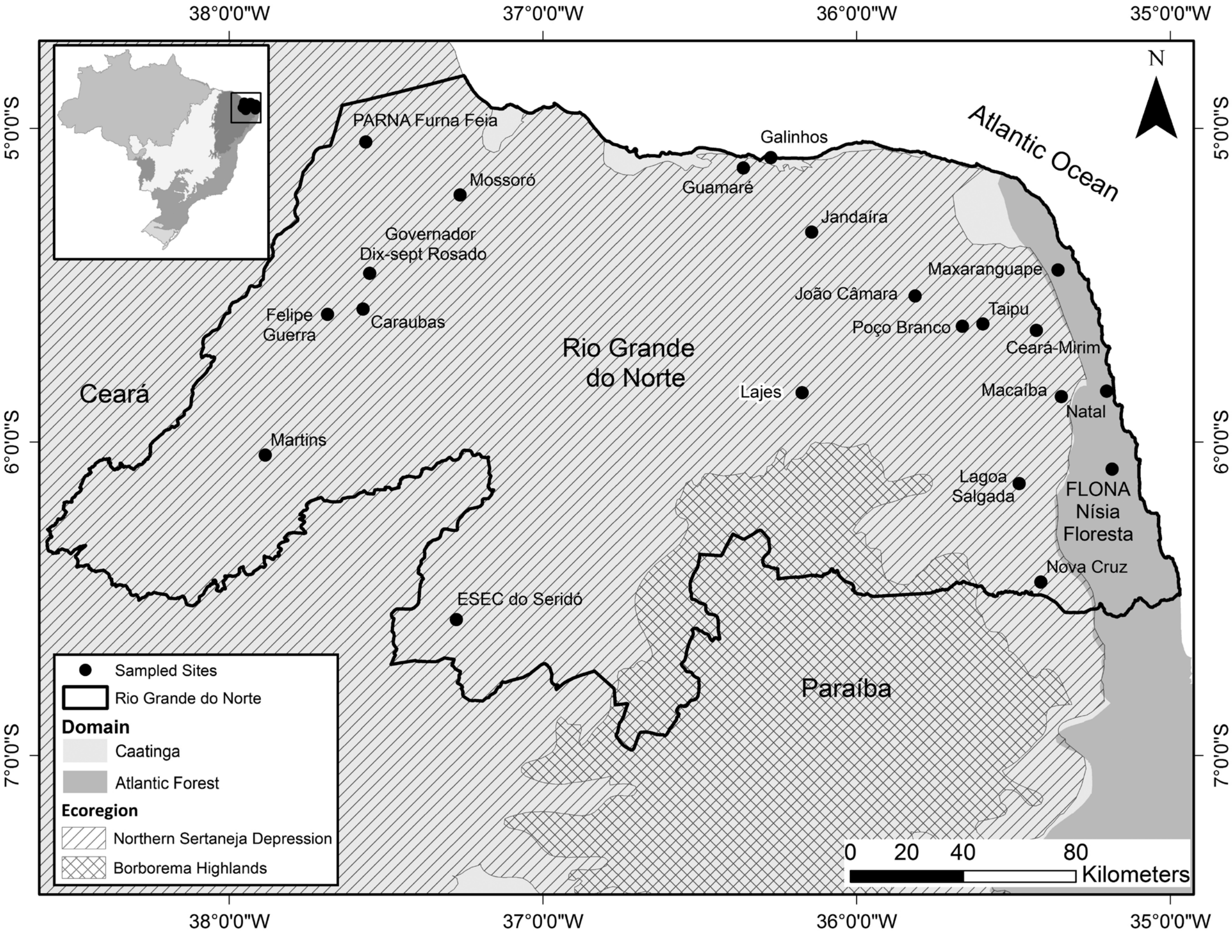

**Figure 1.** Map showing site localities where at least one bat has been sampled within the state of Rio Grande do Norte, northeastern Brazil. Coordinates of localities are: Natal (5°50'16.77" S, 35°12'7.38" W), Macaíba (5°51'19.17" S, 35°12'7.38" W), Maxaranguape (5°26'23.35" S, 35°21'19.26" W), Ceará-Mirim (5°37'40.82" S, 35°26'4.45" W), Taipu (5°36'52.07" S, 35°35'38.54" W), João Câmara (5°31'48.98" S, 35°49'59.06" W), Guamaré (5°7'35.42" S, 36°21'38.56" W), Galinhos (5°5'28.63" S, 36°16'54.60" W), Jandaíra (5°22'47.46" S, 36° 8'45.14" W), Nísia Floresta National Forest (FLONA Nísia Floresta), Nísia Floresta (6°5'5.44." S, 35°11'2.65" W), Lagoa Salgada (6° 8'59.54" S, 35°31'23.24" W), Nova Cruz (6°26'41.54" S, 35°24'7.17" W), Poço Branco (5°37'48.96" S, 35°39'8.31" W), Lajes (5°51'7.17" S, 36° 9'31.45" W), Seridó Ecological Station (ESEC do Seridó), Serra Negra do Norte (6°34'55.46" S, 37°15'9.91" W), Mossoró (5°12'29.13" S, 37°20'50.97" W), Furna Feia National Park (PARNA Furna Feia), Baraúna/Mossoró (5°3'24.13" S, 37°30'54.03" W), Governador Dix-Sept Rosado (5°23'37.14" S, 37°34'8.54" W), Felipe Guerra (5°34'38.75" S, 37°39'57.03" W), Caraúbas (5°41'10.09" S, 37°35'38.00" W), and Martins (6°2'54.68" S, 37°53'43.99" W).

This recently described species was recorded only at the Serra do Feticeiro in Lajes municipality (5°51'7.1"S, 36°9'31.4"W) at 325 m a.s.l. Six specimens were collected and identified as *L. inexpectata* by their pale-greyish ventral fur on the throat and abdomen that differs from *L. mordax* which has pale-brownish ventral fur as indicated by Moratelli & Dias (2015) (Fig 3A). Specimens examined: CMAV 121, 123, 141, 142, 146, 167.

**Family Noctilionidae Gray, 1821**

*Noctilio albiventris* Desmarest, 1818

One adult female collected in the Seridó Ecological Station, Serra Negra do Norte on the edge of a natural lake (6°34'55.4" S, 37°15'9.91" W) at 200 m a.s.l. We also captured an adult in Sítio Santa Rosa, Lajes municipality (05º49'56.2" S, 36º12'16.0" W) in a drying water reservoir on 10 May 2015, but only biometrical data and photographs data were taken. Specimens presented forearm length less than 70 mm (55.7 mm) which differentiates it from the similar but larger *N. leporinus* (FA: >70 mm) Specimens examined: UFPE 3427.

*Noctilio leporinus* (Linnaeus, 1758)

Collected only in two localities of Caatinga. The first record is of an adult male collected and deposited in CMAV on 17 January 1990 in Taipu municipality (5°36'52.07" S, 35°35'38.54" W) in an ecotone area close to the BR-404 highway with no habitat specification at 30 m of altitude. The second record corresponds to an adult male captured near a lake (6°34'55.4" S, 37°15'9.91" W) on 18 July 2012 in the Seridó Ecological Station, Serra Negra do Norte municipality at 200 m a.s.l. The specimens presented diagnostic characteristics of *N. leporinus,* forearm length of >70 mm (82.5-85.4 mm) and legs length exceeding head length that differentiates it from the smaller *N. albiventris*. Specimens examined: CMAV 037; UFPE 3426.

**Figure 2.** Ventral pelage of **A** *Micronycteris schmidtorum* (CMAV 145) and **B** *Micronycteris sanborni* (UFPE 3440). Note very pale gray almost white color of the ventral fur of A that differs from pure white color of B. Lengths of foots, calcars and thumbs of A and B are found in results. Scale bar 10 mm.

### Family Molossidae Gervais, 1856

*Molossops temminckii* (Burmeister, 1854)

One adult female captured on 9 March 2013 in an semi-open area in the Seridó Ecological Station (6°34'55.4" S, 37°15'9.91" W) at 200 m a.s.l. It presented triangular ears, semi-squared antitragus and forearm less than 34 mm (30.2 mm), which differentiates it from its congener in Brazil (*M. neglectus*) that has a forearm greater than 36 mm. Specimen examined: UFPE 3433.

*Neoplatymops mattogrossensis* (Vieira, 1942)

This molossid bat has been captured only in the Seridó Ecological Station in open areas near a natural lake (6°34'55.4" S, 37°15'9.91" W) at 200 m a.s.l. All six captured specimens presented flattened head, upper incisors separated by a space and granulations or small protrusion in forearms; these characteristics separate *N. mattogrossensis* from other Neotropical small flat-headed molossids. Specimen examined: UFPE 3421, 3422, 3435, 3437, 3438, 3441.

*Nyctinomops macrotis* (Gray, 1840)

One adult female found dead on the ground at a wind farm in a coastal Caatinga in Guamaré municipality, north coast of the state (5°7'35.42" S, 36°21'38.56" W) near sea level. The bat presented damages on head, neck and dorsal area probably caused by a direct collision with the turbine blades. The specimen presented deeply wrinkled lips; joined ears; incisors 1/2, upper incisors parallel to each other; and forearm greater than 55mm (FA=58.2 mm), characteristic that differentiates it from other smaller *Nyctinomops* bats in Brazil (FA<55mm). Specimen examined: CMAV 156.

### Family Vespertilionidae Gray, 1821

*Eptesicus furinalis* (d'Orbigny & Gervais, 1847)

Two specimens collected in different localities. An adult male captured in a house roof in Galinhos municipality in the coastal Caatinga (5°5'28.63" S, 36°16'54.60" W) at sea level and another adult male captured in garden area on the *campus* of the Federal University of Rio Grande do Norte (5°50'16.77"S, 35°12'7.38"W), at 45 m.a.s.l. Despite specimens presented forearms lengths of 40.1-41.0 mm that overlaps with smaller individuals of *E. brasiliensis* (forearm length of *E. furinalis* = 37.0 - 41.0 mm and *E. brasiliensis* = 40-46 mm), both presented characteristics of *E. furinalis*, narrow but not tapered tragus, short fur (5-6 mm), lower teeth row length less than 6.3 mm, and skull length less than 16.3 mm. Specimens examined: CMAV 150, 164.

*Lasiurus ega* (Gervais, 1856)

One adult male found dead at a wind farm in Guamaré municipality (5°7'35.42" S, 36°21'38.56" W) near sea level. The bat had damages on the head and dorsal region, probably caused by a collision with turbine blades; however, the skull suffered no damages. The specimen

**Figure 3.** Ventral pelage of **A** *Lonchophylla inexpectata* (CMAV 167) and **B** *Lonchophylla mordax* (CMAV 149). Note the pale-greyish ventral fur on the throat and abdomen of A that differs from the pale-brownish ventral fur of B. Scale bar 10 mm.

was identified as *L. ega* due to its olive-yellowish coloration in ventral and dorsal region; hairs covering down to the half of the uropatagium on the dorsal side; and single upper premolars. Specimen examined: CMAV 151.

## Discussion

### 1. *Species richness*

The richness of bats in RN is greater than previously known. Of the 38 species of bats previously reported in RN (Feijó & Nunes 2010, Ferreira et al. 2010, Barros 2014, Garcia et al. 2014, Cordero-Schmidt et al. 2016, Basílio et al. 2017, Cordero-Schmidt et al. 2017*,* Vargas-Mena et al. *in press*) we found vouchers for only 29 species. However, by adding the 13 new species records that we present herein, the number of species with confirmed occurrence in the state is 42 (Table 1).

Compared to the neighboring states of Ceará and Paraíba, RN presents a lower bat richness. The state of Paraíba, with a diversity of 58 species (Feijó & Langguth 2011, Ferreira et al. 2013, Nunes et al. 2013, Leal et al. 2014, Beltrão et al. 2015, Vilar et al. 2015), is similar to RN in size and proportion of Caatinga and Atlantic Forest, however, it has been more sampled (Bernard et al. 2011). Similarly, the state of Ceará contains a richer bat diversity (66 species) (Gurgel-Filho et al. 2015, Silva et al. 2015), but its bat fauna has been more studied than for RN, including the firsts surveys on Caatingas' mammal communities (e.g., Mares et al. 1981, 1985, Willig 1983).

The bat richness found in RNs' Caatinga was higher than in the states' Atlantic Forest, probably because of the lower number of collection sites in the latter (Fig 1). Since all of sites in Caatinga are in the NSD, our study contributes to fill the knowledge gap in this part of the ecoregion by adding 15 new localities of bat data collection in relation to the records reported by Carvalho-Neto et al. (2016). Previous authors, after reviewing the bat species richness in the Caatinga, warned that the eastern part of the NSD and the north of the BH have not been comprehensively investigated. Based on Velloso et al. (2002) ecoregions of Caatinga, our map (Fig. 1) does not show records in the Borborema Highlands, thus the bat fauna of the northern distribution of this ecoregion is poorly known.

Although the Atlantic Forest showed only three localities of bat collections, the richness difference with the Caatinga is not large – a difference of 10 species. Considering that the Atlantic Forest in Brazil is richer in bat species than the Caatinga (Paglia et al. 2012), it is likely that an increase in research in this region will yield a higher richness than what was found in this study.

Phyllostomid bats represented more than half of the species records (54%). This proportion is similar to other Brazilian states, with the occurrence of Atlantic forest and Caatinga, like in Paraíba (Feijó & Langguth 2011) and Sergipe (Leal et al. 2013). Such dominance was expected since Phyllostomidae is the richest family in Brazil (Nogueira et al. 2014) and in the Neotropics (Solari & Martínez-Arias 2014).

Furthermore, all bat studies in RN were done using mist nets, a type of methodology heavily biased towards the capture of phyllostomids than species of other families (Barnett et al*.* 2006). Consequently, the diversity of aerial insectivorous bats, such as members of the Emballonuridae, Molossidae, and Vespertilionidae families, are poorly known in RN, probably because all of the studies conducted in RN used mainly mist-nets. Acoustic samplings (recordings of bat echolocation calls) detect aerial insectivores not sampled by conventional capture methods (Simmons & Voss 1998) and, thus, this method should be used together with bat captures to increase inventory completeness (MacSwiney et al. 2008). Moreover, in Neotropical dry forests where nearly half of the species are open-space insectivores, Silva & Bernard (2017) found that different bat species were detected using solely mist nets or bioacoustics, therefore authors conclude that a combination of both techniques is essential to achieve the local bat diversity in Caatinga areas.

The search for day roosts is another good alternative to increase the knowledge on bat species richness of the state. Caves are an important roost for local bat populations considering the high number of underground cavities that occur in RN. Inventories in such areas are likely to provide new species occurrences, and to contribute to a better understanding of the bat species distribution in the state. For instance, 17 species of bats have been already recorded to roost in RN's caves (Vargas-Mena et al. *in press*, Cordero-Schmidt et al. 2017), this is one-third of the total bat species presented herein.

The bat diversity in Brazil is still being discovered as recent taxonomic revisions of specimens in the biological collections have led to the description of new bat species. For instance, of these recently described species, *Myotis lavali* (Moratelli et al. 2011) and *Lonchophylla inexpectata* occur in RN. *Myotis lavali* was recently described from the *Myotis nigricans* (Schinz, 1821) complex after specimens' revision in biological collections. We revised *M. nigricans* specimens from CMAV and UFPE that occur in RN and all of them corresponded to *M. lavali.* The only record of *M. nigricans* in the state was provided by Feijó & Nunes (2010) from Nova Cruz municipality, close to Paraíba state; however, we did not have access to the collected specimen to confirm the taxon. Similarly, *L. inexpectata* was described from *L. mordax* by Moratelli & Dias (2015) after specimens' revision in biological collection, and is currently considered endemic to Caatinga.

The confirmation of the species that we found in the literature review without vouchered specimens is needed. Of those seven non-confirmed species, for *Peropteryx kappleri* we did not find any locality or record whatsoever, despite Garcia et al. (2014) record it in the state. The remaining six species were recorded by Farias (2009) (see Supplementary Material) in a small Atlantic Forest patch in the Jiquí Public Park in Parnamirim municipality. Considering the possible presence of these species in the state, we call the attention to future bat studies in the Atlantic Forest to collect and confirm their occurrence.

## 2. *New species records*

Here, we presented 13 bat species with no previous record in RN, which increases our knowledge on the occurrence and distribution of the chiropteran fauna of RN and Brazil. Species such as *Rhynchonycteris naso*, *Micronycteris megalotis*, *M. sanborni*, *Anoura geoffroyi*, *Noctilio albiventris*, *N. leporinus*, *Molossops temminckii*, *Neoplatymops mattogrossensis*, *Eptesicus furinalis*, and *Lasiurus ega* have been already recorded in the neighboring states of Paraíba (Feijó & Langguth 2011) and Ceará (Gurguel-Filho et al. 2015), therefore, their occurrence was expected in RN.

Two pale-bellied species of *Micronycteris* (*M. schmidtorum* and *M. sanborni*) were found to occur in the state (Fig. 2). Both records represent a northward expansion of the distribution of these species in Brazil. *Micronycteris schmidtorum* has a wide distribution in Brazil but records in the Caatinga are scarce (Rocha et al. 2017) and the closest locality is from Exu, Pernambuco State (Ascorra et al. 1991) – about 430 km from our record in Lajes. However, there is a closer record about 146 km southeast from Lajes in the Atlantic Forest in Guaribas Biological Reserve in Paraíba State (Rocha et al. 2017). *M. sanborni* is endemic to Brazil and known from 10 scattered localities (Feijó et al. 2015b). We only found it in the Seridó Biological Station and its closest previous record is from 42.6 km south in Patos in the Caatinga of Paraíba State (Feijó et al. 2015b). However, *M. sanborni* might be more common than previously thought because it is difficult to differentiate from other sympatric pale-bellied *Micronycteris* bats in Brazil. We encourage special attention when identifying this bat species to avoid misidentification and to better understand their distribution and habitat preferences.

The record of *L. inexpectata* in RN, specifically at the Serra do Feticeiro in Lajes, expands the distribution of the species northeastwards about 430 km from the closest record in Exu, Pernambuco State (Moratelli & Dias 2015). This record is noteworthy since the species has been registered only in the states of Bahia and Pernambuco (Moratelli & Dias 2015), where it is considered endemic to the Caatinga (Gutiérrez & Marinho-Filho 2017). However, sympatry in certain areas of the Caatinga of *L. inexpectata* with *L. mordax* can be found – *L. mordax* occurs along the eastern border of the Caatinga and the Atlantic Forest-Caatinga ecotone. We found both species in sympatry in Lajes, however its differentiation in the field is fuzzy which difficult identification (R. Moratelli pers. comm.). Although these two species can be differentiated by mandibular length (MAL) and ventral fur color (VFC) (*L. mordax*, MAL 15.5-17.0 mm, VFC pale brown; *L. inexpectata* MAL 14.1-16.3 mm, VFC whitish or pale gray on neck and abdomen), the six analyzed specimens of *Lonchophylla* of Lajes presented overlapping MAL (15.4-16.2 mm). Therefore, external characters for differentiating these species were restricted to the VFC (Fig. 3).

Regarding *Nyctinomops macrotis*, the species has been recorded mainly in the Atlantic Forest but as well in other regions; in Caatinga it is known for just one locality (Rocha et al. 2015). However, the record of *N. macrotis* in Guamaré expands the species distribution northeastward about 740 km from the closest record in Boqueirão da Onça in Bahia State (Rocha et al. 2015). This second record suggest that the species might occur in other areas of the Caatinga, thus, acoustic surveys should be done in order to detect this or other molossid bats in RN.

## 3. *Conservation panorama*

Four threatened bat species in Brazil occur in RN, corresponding to the 57% of the Brazilian threatened bat species (see ICMBio/MMA 2016). *Furipterus horrens*, *Natalus macrourus*, *Lonchorhina aurita* and *Xeronycteris vieirai* are vulnerable species (VU), a high extinction risk category (ICMBio/MMA 2016). Moreover*, F. horrens* and *L. aurita* roost mainly in caves (Reis et al. 2007), *N. macrourus* is cave-dependent (Tejedor & Davalos 2016) and, *X. vieirai,* is only known to roost in caves (Cordero-Schmidt et al. 2017). Therefore, their conservation status is linked to their dependence on cave roosts (Sagot & Chaverri 2015). Bats species that rely on a single roost type are linked to higher extinction risks, and management actions to preserve such species should prioritize the protection of roosting sites (e.g., cave-dependent species) (Sagot & Chaverri 2015). Consequently, the possible presence of these species should be considered when biospeleological inventories and cave-use licensing are carried out in the states' caves.

On the other hand, according to the IUCN international criteria, all bats that occur in RN are at lower risk of extinction, where just *N. macrourus* and *L. mordax* are near threatened (NT). This categorization was different from what we found at national level. Such a mismatch between these assessments, where species are considered nationally but not globally threatened, represents cases of globally common and stable species that are rather rare or declining at a local or regional level (Brito et al. 2010). However, *L. mordax*, previously classified as least concern (LC), is categorized as NT because now its distribution is restricted to just in three localities in eastern Brazil as consequence of its separation with *L. inexpectata* (Sampaio et al. 2016). Regarding this latter species*,* the IUCN has not yet evaluated its conservation status in Brazil, and it was therefore not included in threatened species lists (Gutiérrez & Marinho-Filho 2017). Given the endemic condition of *L. inexpectata* (Caatinga) and *L. mordax* (Eastern Brazil) their extinction risks should be assessed soon at the national and global level.

The evaluation of the distribution and analysis of pressures and threats to these vulnerable species is needed to assess their conservation needs. For instance, the vulnerable *N. macrourus* has already lost 54% of its habitat in Brazil, and only 4% of its potential distribution of the species is located within fully protected areas (Delgado-Jaramillo et al. 2017). In RN, only *F. horrens* and *N. macrourus* have populations integrally protected in the Furna Feia National Park in Baraúna and Mossoró municipalities (Vargas-Mena et al. *in press*), while *X. vieirai* and *L. aurita* occur in no protected areas.

The natural vegetation in RN has suffered substantial human impacts, only the 11% the state is under some protected area (Bento et al. 2013). The Atlantic Forest has been reduced by agricultural activities and urban expansion in coastal areas (INPE/SOS Mata Atlântica 2014), whereas Caatinga has suffered deforestation for human use and cattle activities that make it susceptible to desertification (Santos et al. 2011). Such human activities are already known to negatively affect the integrity of bat communities and their populations around the world (Furey & Racey 2016). Furthermore, RN has currently 125 wind farms, being the largest producer of wind energy in Brazil (ABBEólica 2017). Wind turbine facilities can cause high mortality among aerial insectivore bats (Barros et al. 2015; Schuster et al. 2015; Hein & Schirmacher 2016; O'Shea et al. 2016; Frick et al. 2017). Bat occurrences in the areas of wind farms, as well as the possible impacts of wind turbines on bats, are still unknown (Bernard et al. 2014). For instance, some of the new species records presented herein (e.g*., N. macrotis* and *L. ega*) are based on single specimens found dead probably by wind turbines in wind parks.

## 4. *Main knowledge gaps*

Although this study updates information regarding the bat fauna of RN, several gaps of knowledge on the distribution of bat species still remains in the state (Fig 1). Therefore, we propose additional effort of research and inventories in the following areas:

- The Northern Sertaneja Depression: all records of bats in the states' Caatinga are in this ecoregion. According to the distribution of the bat records, however the central region presented the most evident gap, and bat inventories are encouraged in such area. Moreover, most of protected areas of the state are found in this ecoregion and the Seridó Ecological Station in Serra Negra do Norte, the Açu National Forest in Açu and the Furna Feia National Park in Mossoró-Baraúna are areas where the bat fauna is poorly known and should be priorities for inventories in the state.
- The Borborema Highlands and other mountainous ranges in the central and southwestern region: this mountain ranges (ranging from 400–800 m of altitude), characterized by more humid areas with Caatinga vegetations, are virtually unexplored regarding bats, and particular assemblages are expected to occur in these areas. For instance, in the Serra do Feticeiro in Lajes do Cabugi, all five species of nectar feeding bats registered in the state are found in this sierra, including endemic and vulnerable species such as *Xeronycteris vieirai* and *Lonchophylla inexpectata* (Cordero-Schmidt et al. 2017). Considering that no conservation units are found in BH and other mountainous ranges, the sierras in the municipalities of Serra de Santana, Cerro Corá, Coronel Ezequiel, São Tomé Martins, Portalegre, Serrinha dos Pintos, and Luís Gomes, should be explored.
- Transitional areas of Caatinga with mangroves and coastal habitats all along the north coast such as in the municipalities of Dunas do Rosado, Galinhos, and Caiçara do Norte are unique ecotones with no data regarding bats, including the State Sustainable Development Reserve (RDS) Ponta do Tubarão, in Macau and Guamaré municipalities.
- Ecotone areas alongside the contact of Caatinga and Atlantic Forest are known as "Agreste", where bat communities may contain a mixture of species of both ecoregions.
- The southeastern region where there are remnants of Atlantic Forest; some of them in protected areas such as Private Reserve of Natural Heritage Mata da Estrela, in Baía Formosa municipality (the largest Atlantic Forest patch of RN), the northern part of the Nísia Floresta National Forest, in Nísia Floresta municipality (Barros et al. 2017), the Environmental Protection Area (APA) Jenipabú in Natal and Extremoz municipalities, and the Dunas State Park in Natal, one of the biggest urban park in Brazil.

- The Mangrove in the east and north coast are also unexplored.
- Finally, the karstic areas located in Mossoró, Baraúna, Felipe Guerra, Apodi, Governador Dix-Sept Rosado, and Jandaíra municipalities are sites with high density of underground cavities and potential sites to roost a wide diversity of bats. For instance, the Furna Feia cave located in the Furna Feia National Park harbors up to 10 species, the richest in the state (Vargas-Mena et al. *in press*).

Despite the small size of RN, the state has a potential to be an important refuge for bat diversity in northeastern Brazil, as long as bat inventories and specimens' collection increases in the future. Finally, bat inventories, including those for environmental impact studies, should complement conventional capture methods with bioacoustical monitoring and active searching of roost places to obtain a complete understanding of the bat fauna of Rio Grande do Norte.

## Supplementary material

The following online material is available for this article:

**Table S1** - List of bat records (Mammalia, Chiroptera) in the state of Rio Grande do Norte, northeastern Brazil, based on review of literature and specimens in collections. Abbreviations: CAS – California Academy of Science; CMAV – Coleção de Mamíferos Adalberto Varela, Universidade Federal do Rio Grande do Norte; CMUFS – Coleção de Mamíferos da Universidade Federal de Sergipe; MZUSP – Museu de Zoologia da Universidade de São Paulo; UFPB – Coleção de Mamíferos da Universidade Federal da Paraíba; UFPE – Coleção de Mamíferos da Universidade Federal de Pernambuco; USNM – United States National Museum.

## Acknowledgments

We thanks to National Council for Scientific and Technological Development (CNPq) for research grants (Pesquisador Visitante Especial-PVE Project: 401467/2014-7; and CNPq/ICMBio 13/2011 – Project 552006/2011-4; to the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for the post-graduation scholarship to JCVM, KAP, MASB, EB and ECS; and CNPq for the productivity grant (309458/2013-7) to EMV. To Wildlife Conservation Society (WCS) Brazil for the logistical support. We are very grateful to Enrico Bernard for providing data of the Seridó Ecological Station; to Francisco Sagot-Martin for donating specimens from the municipality of Guamaré to CMAV; to Edson Leal for providing bibliographic material; to Ricardo Moratelli and Daniela Dias for the discussions and identification of *Lonchophylla* bats; to Cynthia Christina Ito for the photos of some specimens; to Diego Astúa for allowing the access to the collection; and to Christina M. Smith for English revision of the manuscript. We dedicate this paper to Prof. Adalberto Antônio Varela Freire (*in memorian*) for his pioneering work in collecting bats of Rio Grande do Norte, which provided most of the material recently organized in the mastozoological collection of the Federal University of Rio Grande do Norte, named – Coleção Mastozoológica Adalberto Varela.

## Author Contributions

Juan Carlos Vargas-Mena: contributed with the concept and design of the study and manuscript preparation;

Kleytone Alves-Pereira, Marília Abero Sá Barros, Eder Barbier, Eugenia Cordero-Schmidt: contributed with data collection, analysis and interpretation;

Sergio Maia Queiroz Lima, Bernal Rodríguez-Herrera, Eduardo Martins Venticinque: contributed with analysis, interpretation and critical revision.

## Conflicts of interest

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

## References

ABBEÓLICA. 2017. Dados Mensais da Associação Brasileira de Energia Eólica – Abril de 2017. São Paulo, ABEEólica. Available in: http://www.abeeolica.org.br/wp-content/uploads/2017/04/Dados-Mensais-ABEEolica-04.2017.pdf

ALVARES, C.A., STAPE, J.L., SENTELHAS, P.C., DE MORAES, G., LEONARDO, J. & SPAROVEK, G. 2013. Köppen's climate classification map for Brazil. Meteorol. Z. 22(6), 711–728.

ASCORRA, C. F., WILSON, D. E., & GARDNER, A. L. 1991. Geographic distribution of *Micronycteris schmidtorum* sanborn (Chiroptera: phyllostomidae). P. Biol. Soc. Wash. 104(2):351–355.

BAKER, R.J., SOLARI, S., CIRRANELLO, A. & SIMMONS, N. B. 2016. Higher level classification of phyllostomid bats with a summary of DNA synapomorphies. Acta Chiropterol. 18(1):1–38.

BARNETT, A.A., SAMPAIO, E.M., KALKO, E.K.V., SHAPLEY, R.L., FISCHER, E., CAMARGO, G. & RODRÍGUEZ-HERRERA, B. 2006. Bats of Jaú National Park, central Amazonia, Brazil. Acta Chiropterol. 8: 103–128.

BARROS, M.A.S. 2014. First record of *Molossus molossus* (Pallas, 1766) (Mammalia: Chiroptera) in the state of Rio Grande do Norte, northeastern Brazil. Check List 10(6):1520–1524.

BARROS, M.A.S., MAGALHÃES, R.G. & RUI, A.M. 2015. Species composition and mortality of bats at the Osório Wind Farm, southern Brazil. Stud. Neotrop. Fauna E. 50(1):31–39.

BARROS, M.A.S., MORAIS, C.M.G., FIGUEIREDO, B.M.B., MOURA JÚNIOR, G.B.D., RIBEIRO, F.F.D.S., PESSOA, D.M.A., ITO, F. & BERNARD, E. 2017. Bats (Mammalia, Chiroptera) from the Nísia Floresta National Forest, with new records for the state of Rio Grande do Norte, northeastern Brazil. Biota Neotrop. 17(2): e20170351.

BASÍLIO, G.H.N., ARAUJO, J.P.M., VARGAS-MENA, J.C., ROCHA, P.A. & KRAMER, M.A.F. 2017. *Chrotopterus auritus* (Chiroptera, Phyllostomidae): first record for the state of Rio Grande do Norte, northeastern Brazil. Check List. 13(3): 2110.

BENTO, D.M., BRANDÃO, J.C., DOS SANTOS, D.J., FREITAS, J.I.M., CAMPOS, U.P. & SOUZA, R.F.R. 2013. Parque Nacional da Furna Feia: o parque nacional com a maior quantidade de cavernas do brasil. In Congresso Brasileiro de Espeleologia (M.A. Rasteiro & L. Morato, coord.). Sociedade Brasileira de Espeleologia Barreiras, Bahia, p.31–43.

BENTO, D.M., CRUZ, J.B., FREITAS, J.I.M., CAMPOS, U.P. & OLIVEIRA, A.F. 2017. A mais de 1000! O patrimônio espeleológico potiguar após a descoberta da milésima caverna. In Congresso Brasileiro de Espeleologia (R.M. Rasteiro, C.M. Teixeira-Silva, S.G. Lacerda, coord.). Sociedade Brasileira de Espeleologia, Ouro Preto, p.227–237.

BELTRÃO, M.G., ZEPPELINI, C.G., FRACASSO, M.P.A. & LOPEZ, L.C.S. 2015. Bat inventory in a Caatinga area in Northeastern Brazil, with a new occurrence in the state of Paraíba. Neotrop. Biol. Conserv. 10(1):15–20.

BERNARD, E., AGUIAR, L. & MACHADO, R.B. 2011. Discovering the Brazilian bat fauna: a task for two centuries? Mammal Rev. 41:23–39.

BERNARD, E., PAESE, A., MACHADO, R.B. & DE SOUZA AGUIAR, L.M. 2014. Blown in the wind: bats and wind farms in Brazil. Nat. Conservação 12(2):106–111.

BRITO, D., AMBAL, R.G., BROOKS, T., DE SILVA, N., FOSTER, M., HAO, W., HILTON-TAYLOR, C., PAGLIA, A., RODRÍGUEZ, J.P. & RODRÍGUEZ, J.V. 2010. How similar are national red lists and the IUCN Red List? Biol. Conserv. 143(5):1154–1158.

CARVALHO-NETO, F.G., DA SILVA, J.R., SANTOS, N., ROHDE, C., GARCIA, A.C.L. & MONTES, M.A. 2017. The heterogeneity of Caatinga biome: an overview of the bat fauna. Mammalia, 81(3):257–264.

CORDERO-SCHMIDT, E., MEDEIROS-GUIMARÃES, M., VARGAS-MENA, J.C., CARVALHO, B., FERREIRA, R.L., RODRIGUEZ-HERRERA, B. & VENTICINQUE, E.M. 2016. Are leaves a good option in Caatinga's menu? First record of folivory in *Artibeus planirostris* (Phyllostomidae) in the semiarid forest, Brazil. Acta Chiropterol. 18(2):489-497.

CORDERO-SCHMIDT, E., BARBIER, E., VARGAS-MENA, J.C., OLIVEIRA, P.P., SANTOS, F.A.R., MEDELLÍN, R.A., RODRIGUEZ-HERRERA, B. & VENTICINQUE, E.M. 2017. Natural history of the Caatinga endemic Vieira's Flower Bat, *Xeronycteris vieirai*. Acta Chiropterol. 19(2):399-408.

COSTA, L.P., LEITE, Y.L.R., MENDES, S.L. & DICHTFIELD, A.D. 2005. Conservação de Mamíferos no Brasil. Megadiversidade 1(1):103–112.

CRUZ, J.B., BENTO, D.M., BEZERRA, F.H.R., FREITAS, J.I. & CAMPOS, U.P. 2010. Diagnóstico Espeleológico do Rio Grande do Norte. Rev. Bras. Espeleo. 1:1–24.

DELGADO-JARAMILLO, M., BARBIER, E. & BERNARD, E. 2017. New records, potential distribution, and conservation of the Near Threatened cave bat *Natalus macrourus* in Brazil. Oryx 1–8 doi:10.1017/S0030605316001186.

DÍAZ, M.M., SOLARI, S., AGUIRRE, L.F., AGUIAR, L. & BARQUEZ, R.M. 2016. Clave de identificación de los murciélagos de Sudamérica/Chave de identificação dos morcegos da América do Sul. Publicación Especial 2, Programa de Conservación de los Murciélagos de Argentina, Tucumán, Argentina, p.160.

FARIAS, F.H.C. 2009. Caracterização biológica e zoneamento ambiental do Parque Estadual do Jiquí/RN, Brasil: subsídios ao plano de manejo. Master thesis, Animal biology department, Science faculty, Lisbon University, Lisbon, Portugal.

FEIJÓ, J.A. & NUNES, H.L. 2010. Primeiro registro de *Myotis nigricans* (Schinz, 1821) para o estado do Rio Grande do Norte, nordeste do Brasil. Chiropt. Neotrop. 16(1):531–534.

FEIJÓ, J.A. & LANGGUTH, A. 2011. Lista de quirópteros da Paraíba, Brasil com 25 novos registros. Chiropt. Neotrop. 17(2):1055–1062.

FEIJÓ, A., ROCHA, P.A. & ALTHOFF, S.L. 2015a. New species of *Histiotus* (Chiroptera: Vespertilionidae) from northeastern Brazil. Zootaxa 4048(3):412–427.

FEIJÓ, A., ROCHA, P.A. & FERRARI, S. F. 2015b. How do we identify *Micronycteris sanborni* Simmons, 1996 (Chiroptera, Phyllostomidae) reliably and where we can find this species in South America? Pap. Avulsos de Zool. (São Paulo) 55(20).

FERREIRA, R.P., PROUS, X., BERNARDI, L.O.F. & SOUZA-SILVA, M. 2010. Fauna subterrânea do estado do Rio Grande do Norte: caracterização e impactos. Rev. Bras. Espeleo. 1(1):25–51.

FERREIRA, A.P., CARVALHO-MELO, D. & LOURES-RIBEIRO, A. 2013. *Diclidurus albus* Wied-Neuwied, 1820 (Chiroptera: Emballonuridae): first record of the species in the state of Paraíba, Brazil. Check List 9(4):793–796.

FISCHER, E., SANTOS, C.F., CARVALHO, L.F.A.C., CAMARGO, G., CUNHA, N.L., SILVEIRA, M., BORDIGNON, M.O. & SILVA, C.L. 2015. Bat fauna of Mato Grosso do Sul, southwestern Brazil. Biota Neotrop. 15(2):e20140066. http://dx.doi.org/10.1590/1676-06032015006614 (last access on 25/Apr/2017).

FRICK, W.F., BAERWALD, E.F., POLLOCK, J.F., BARCLAY, R.M.R., SZYMANSKI, J.A., WELLER, T.J., RUSSELL, A.L., LOEB, S.C., MEDELLIN, R.A. & MCGUIRE, L.P. 2017. Fatalities at wind turbines may threaten population viability of a migratory bat. Biol. Conserv. 209:172–177.

FUREY, N. & RACEY, P.A. 2016. Conservation ecology of cave bats. In Bats in the Anthropocene: Conservation of bats in a changing world (C.C. Voigt and T. Kingston eds.). Springer, USA, p.606.

GARCIA, A.C.L., LEAL, E.S., ROHDE, C., CARVALHO-NETO, F.G. & MONTES, M.A. 2014. The bats of northeastern Brazil: a panorama. Anim. Biol. 64(2):141–150.

GARDNER, A.L. 2008. Mammals of South America - Volume 1: Marsupials, Xenarthrans, Shrews, and Bats. Chicago and London, The University of Chicago Press.

GOODWIN, G.G. 1959. Bats of the subgenus *Natalus*. Am. Mus. Novit. 1977:1–22.

GREGORIN, R. & TADDEI, V.A. 2002. Chave artificial para a identificação de molossídeos brasileiros (Mammalia, Chiroptera). Mastozool. Neotrop. 9(1):13–32.

GREGORIN, R., MORAS, L.M., ACOSTA, L.H., VASCONCELLOS, K.L., POMA, J.L., DOS SANTOS, F.R. & PACA, R.C. 2016. A new species of *Eumops* (Chiroptera: Molossidae) from southeastern Brazil and Bolivia. Mamm. Biol. 81(3):235–246.

GURGEL-FILHO, N.M., FEIJÓ, A. & LANGGUTH, A. 2015. Pequenos Mamíferos do Ceará (Marsupiais, Morcegos e Roedores sigmodontineos) com discussão taxonômica de algumas espécies. Rev. Nordestina Biol. 23(3):3–150.

GUTIÉRREZ, E. & MARINHO-FILHO, J. 2017. The mammalian faunas endemic to the Cerrado and the Caatinga. ZooKeys 644:105–157

HEIN, C.D. & SCHIRMACHER, M.R. 2016. Impact of wind energy on bats: a summary of our current knowledge. Hum-Wildl. Interact. 10(1):19–27.

ICMBio/MMA – Instituto Chico Mendes de Conservação da Biodiversidade/ Ministério de Meio Ambiente. 2016. Sumário Executivo do Livro Vermelho da Fauna Ameaçada de Extinção. Distrito Federal, Brasília, Brazil, p. 1–17.

IUCN – International Union for Conservation of Nature. 2016. The IUCN Red List of Threatened Species. Version 2016–3. http://www.iucnredlist.org (last access on 17/Apr/2017).

IDEMA - Instituto De Desenvolvimento Sustentável e Meio Ambiente. 2015. Anuário estatístico 2015. Rio Grande do Norte: Governo do Rio Grande do Norte. http://www.idema.rn.gov.br/Conteudo.asp?TRAN=ITEM&TARG=1357&ACT=null&PAGE=0&PARM=null&LBL=Socioecon%C3%B4micos (last access on 15/Dec/2016).

INPE/SOS MATA ATLANTICA. 2014. Atlas dos remanescentes florestais da Mata Atlântica período 2011-2012 - relatório técnico. Fundação SOS Mata Atlântica, Instituto Nacional de Pesquisas Espaciais -INPE, São Paulo, p.1–60.

JONES, J.K. & HOOD, C.S. 1993. Synopsis of South American bats of the family Emballonuridae. Occas. Pap. Tex. Tech. Univ. Mus. 155:1–32.

LEAL, I.R., TABARELLI, M. & SILVA, J.M.C. 2003. Ecologia e conservação da Caatinga. 3 ed. Editora Universitária da Universidade Federal de Pernambuco, Recife, Brasil.

LEAL, E.S.B., AZEVÊDO-JÚNIOR, S.M., NOVA, F.V.P.V., QUEIRÓZ-GUERRA, D. & TELINO-JÚNIOR, W.R. 2013. Updated compilation of bat species (Chiroptera) for the Brazilian state of Sergipe, including new records. Chiropt. Neotrop. 19(1):1163–1178.

LEAL, E.S.B., SILVA, D.Q., FIGUEIREDO-RAMALHO, D., MILLER, B.G., PASSOS-FILHO, P.B., PRADO-NETO, J.G., QUEIRÓZ-GUERRA, D., MOURA, G.J.B., LYRA-NEVES, R.M. & TELINO-JÚNIOR, W.R. 2014. Extension of the geographical distribution of *Lonchophylla dekeyseri* Taddei, Vizotto and Sazima, 1983 (Chiroptera: Phyllostomidae): new record in northeastern Brazil. Chiropt. Neotrop. 19(2):1220–1225.

MACSWINEY, G., CRISTINA, M., CLARKE, F.M. & RACEY, P.A. 2008. What you see is not what you get: the role of ultrasonic detectors in increasing inventory completeness in Neotropical bat assemblages. J. Appl. Ecol. 45(5):1364–1371.

MARES, M.A., WILLIG, M.R., SRTEILEIN, K.E. & LACHER JR. T.E. 1981. The mammals of northeastern Brazil: a preliminary assessment. Ann. Carnegie Mus. 50:81–137.

MARES, M.A., WILLIG, M.R. & LACHER JR, T.E. 1985. The Brazilian Caatinga in South American zoogeography: tropical mammals in a dry region. J. Biogeogr. 12:57–69.

MORATELLI, R., PERACCHI, A. L., DIAS, D. & DE OLIVEIRA, J. A. 2011. Geographic variation in South American populations of *Myotis nigricans* (Schinz, 1821) (Chiroptera, Vespertilionidae), with the description of two new species. Mamm. Biol. 76(5): 592–607.

MORATELLI, R. & DIAS, D. 2015. A new species of nectar-feeding bat, genus *Lonchophylla*, from the Caatinga of Brazil (Chiroptera, Phyllostomidae). ZooKeys 514:73–91.

NOGUEIRA, M.R., LIMA, I.P., MORATELLI, R., TAVARES, V.C., GREGORIN, R. & PERACCHI, A.L. 2014. Checklist of Brazilian bats, with comments on original records. Check List 10(4):808–821.

NUNES, H.L., FEIJÓ, J.A., BELTRÃO, M., LOPEZ, L.C.S. & FRACASSO, M.P.A. 2013. First and easternmost record of *Molossops temminckii* (Burmeister, 1854) (Chiroptera: Molossidae) for the state of Paraíba, northeastern Brazil. Check List 9(2):436–439.

O'SHEA, T.J., CRYAN, P.M., HAYMAN, D.T., PLOWRIGHT, R.K. & STREICKER, D.G. 2016. Multiple mortality events in bats: a global review. Mammal Rev. 46(3):175–190.

PAGLIA, A.P., FONSECA, G.A.B., RYLANDS, A.B., HERRMANN, G., AGUIAR, L.M.S., CHIARELLO, A.G., LEITE, Y.L.R., COSTA, L.P., SICILIANO, S., KIERULFF, M.C.M., MENDES, S.L., TAVARES. V.C., MITTERMEIER, R.A. & PATTON, J.L. 2012. Lista Anotada dos Mamíferos do Brasil. 2 ed. Occ. Pap. In Conservat. Biology.

REIS, N.R., PERACCHI, A.L., PEDRO, W.A. & LIMA, I.P. 2007. Morcegos do brasil. Universidade Estadual de Londrina, Londrina, Brazil.

ROCHA, P.A., FEIJÓ, A., PEDROSO, M.A., & FERRARI, S.F. 2015. First record of the big free-tailed bat, *Nyctinomops macrotis* (chiroptera, molossidae), for the semi-arid caatinga scrublands of northeastern Brazil. Mastoz. Neotrop. 22(1):195–200.

ROCHA, P.A., BRANDÃO, M.V., GARBINO, G.S.T., CUNHA, I.N. & AIRES, C.C. 2016. First record of Salvini's big-eyed bat *Chiroderma salvini* Dobson, 1878 for Brazil. Mammalia 80(5):573–578.

ROCHA, P.A., SOARES, F.A., DIAS, D., MIKALAUSKAS, J.S., VILAR, E.M., FEIJÓ, A., & DAHER, M. R. 2017. New records of *Micronycteris schmidtorum* Sanborn, 1935 (Phyllostomidae, Chiroptera) for northeastern Brazil. Mastoz. Neotrop. 24:1–8.

SAGOT, M. & CHAVERRI, G. 2015. Effects of roost specialization on extinction risk in bats. Conserv. Biol. 29(6):1666–1673.

SAMPAIO, E., LIM, B. & PETERS, S. 2016. *Lonchophylla mordax*. The IUCN Red List of Threatened Species 2016. e.T12267A22038521. http://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T12267A22038521.en.

SANBORN, C.C. 1937. American bats of the subfamily Emballonuridae. Field Mus. Nat. Hist. Zool. Series 29(24):321–354.

SANTOS, J.C., LEAL, I.R., ALMEIDA-CORTEZ, J.S., FERNANDES, G.W. & TABARELLI, M. 2011. Caatinga: the scientific negligence experienced by a dry tropical forest. Trop. Conserv. Sci. 4(3):276–286.

SCHUSTER, E., BULLING, L. & KÖPPEL, J. 2015. Consolidating the state of knowledge: a synoptical review of wind energy's wildlife effects. Environ. Manage. 56(2):300–331.

SILVA, S.S., DIAS, D., MARTINS, M.A., GUEDES, P.G., DE ALMEIDA, J.C., CRUZ, A.P., SERRA-FREIRE, N.M., DAMASCENA, J.S. & PERACCHI, A.L. 2015. Bats (Mammalia: Chiroptera) from the caatinga scrublands of the Crateús region, northeastern Brazil, with new records for the state of Ceará. Mastozool. Neotrop. 22(2):335–348.

SILVA, C.R. & BERNARD, E. 2017. Bioacoustics as an important complementary tool in bat inventories in the Caatinga drylands of Brazil. Acta Chiropterol. 19(2):409-418.

SIMMONS, N.B. 1996. A new species of *Micronycteris* (Chiroptera, Phyllostomidae) from northeastern Brazil: with comments on phylogenetic relationships. Am. Mus. Novit. 3158:1–34.

SIMMONS, N.B. & VOSS, R.S. 1998. The mammals of Paracou, French Guiana, a Neotropical lowland rainforest fauna. Part 1, Bats. Bull. Am. Mus. Nat. Hist. 237:1–219.

SOLARI, S. & MARTÍNEZ-ARIAS, V. 2014. Cambios recientes en la sistemática y taxonomía de murciélagos Neotropicales (Mammalia: Chiroptera). Therya 5(1):167–196.

TEJEDOR, A. & DAVALOS, L. 2016. *Natalus espiritosantensis.* The IUCN Red List of Threatened Species 2016: e.T136448A21983924. http://dx.doi.org/10.2305/IUCN.UK.2016-2.RLTS.T136448A21983924.en (last access on 15/Feb/2017).

VARGAS-MENA, J.C., CORDERO-SCHMIDT, E., BENTO, D.M., RODRÍGUEZ-HERRERA, B., MEDELLÍN, R.A., VENTICINQUE, E.M. *in press*. Diversity of cave bats in the Brazilian tropical dry forest of Rio Grande do Norte State. Mastozool. Neotrop.

VELLOSO, A.L., SAMPAIO, E.V.S.B. & PAREIN, F.G.C. 2002. Ecorregiões propostas para o bioma Caatinga – Resultado do Seminário de Planejamento Ecorregional da Caatinga. Associação Plantas do Nordeste, Instituto de Conservação Ambiental, The Nature Consercancy, Recife, p. 1–76.

VILAR, E.M., NUNES, H., NASCIMENTO, J.L. & ESTRELA, P.C. 2015. Distribution extension of *Ametrida centurio* Gray, 1847 (Chiroptera, Phyllostomidae): first record in the Brazilian Atlantic Forest. Check List 11(1):1503.

WEBSTER, W.D. 1993. Systematics and evolution of bats of the genus *Glossophaga*. Tex. Tech. Univ. Mus. Spec. Publ. 36:1–184.

WILLIG, M.R. 1983. Composition, microgeographic variation and sexual dimorphism in Caatingas and Cerrado bat communities from northeast Brazil. Bull. Carnegie Mus. Nat His. 23:1–131.

*Received: 02/08/2017*
*Revised: 06/03/2018*
*Accepted: 09/03/2018*
*Published online: 16/04/2018*

Biota Neotropica 18(2): e20170399, 2018
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
Inventory

# Inventory of cyanobacteria and microalgae cited for the National Park of the Chapada dos Guimarães (MT) and 80 new records from the region

*Gisele Fernanda Pereira Assis*[1]*, *Samiris Pereira da Silva*[1], *Ludmylla Fernanda de Siqueira Silva*[1], *Regiane Luiza da Costa*[1], *Luany Weiler da Fonseca*[2], *Ermelinda Maria De-Lamonica-Freire*[2], *Daniela Maimoni de Figueiredo*[3] & *Márcia Teixeira de Oliveira*[1]

[1]*Universidade Federal de Mato Grosso, Av. Fernando Corrêa da Costa, 78060-900, Cuiabá, MT, Brasil*
[2]*Centro Universitário de Várzea Grande, Av. Dom Orlando Chaves, 2655, 78118-000, Várzea Grande, MT, Brasil*
[3]*Universidade Federal de Mato Grosso, Programa de Pós-Graduação em Recursos Hídricos, Av. Fernando Corrêa da Costa, 78060-900, Cuiabá, MT, Brasil*
**Corresponding author: Gisele Fernanda Pereira Assis, e-mail: gisele.fernanda2@gmail.com*

ASSIS, G. F. P., SILVA, S. P., SILVA, L. F. S., COSTA, R. L., FONSECA, L. W., De-LAMONICA- FREIRE, E. M., FIGUEIREIDO, D. M., TEIXEIRA-OLIVEIRA, M. **Inventory of cyanobacteria and microalgae cited for the National Park of the Chapada dos Guimarães (MT) and 80 new records from the region**. Biota Neotropica. 18(2): e20170399. http://dx.doi.org/10.1590/1676-0611-BN-2017-0399

***Abstract:*** Cyanobacteria and microalgae make up a very diverse group and exhibit diverse morphological, biochemical and physiological differences. The knowledge of these organisms that inhabit epicontinental waters in Brazil is extremely heterogeneous in relation to the geographic region and the taxonomic group. Taxonomically there is much more knowledge about the algae of the South and Southeast regions of the country than there is about the algae of the North and Central-West regions. Therefore, this research presents a revised and updated knowledge of the algae that occur in the National Park of the Chapada dos Guimarães (PNCG) and surrounding areas. Our area of study is located in the state of Mato Grosso, in the center-west region of Brazil. The database was obtained from published literature related to taxonomic and ecological inventories, as well as new collections carried out in the area. The collection methods were quite diverse to cover all types of organisms, in plankton, periphyton, filamentous masses, sludge and water accumulated in bromeliads, the new collections are samples collected exclusively in the plankton. They were listed 182 taxa, distributed in 83 genera, 45 families, 11 classes and seven taxonomic divisions. In total, 89 taxa were found in the new samplings, of which nine taxa were already registered in the existing literature, so 80 taxa are new records for the region. A large number of taxa previously mentioned in the literature were not recorded in the sampled environments, most of them composed of Bacillariophyceae, Conjugatophyceae and Euglenophyceae. As well as three species of cyanobacteria of great sanitary importance were registered. Therefore, CGNP has great importance in the maintenance of aquatic biodiversity and to know this community becomes increasingly important to support management measures.
***Keywords:*** *cerrado, algae, Planktothrix, taxonomy, streams.*

# Inventário de cianobactérias e microalgas citadas para o Parque Nacional da Chapada dos Guimarães (MT) e 80 novos registros da região

***Resumo:*** As cianobactérias e as microalgas compõem um grupo bastante diversificado e exibem diversas diferenças morfológicas, bioquímicas e fisiológicas. O conhecimento desses organismos que habitam as águas epicontinentais no Brasil é extremamente heterogêneo em relação à região geográfica e ao grupo taxonômico. Taxonomicamente, há muito mais conhecimento sobre as algas das regiões Sul e Sudeste do país do que sobre as algas das regiões Norte e Centro-Oeste. Portanto, esta pesquisa apresenta um conhecimento revisado e atualizado das algas que ocorrem no Parque Nacional da Chapada dos Guimarães (PNCG) e arredores. Nossa área de estudo está localizada no estado de Mato Grosso, na região centro-oeste do Brasil. O banco de dados foi obtido a partir de literatura publicada relacionada a inventários taxonômicos e ecológicos, assim como novas coletas realizadas na área. Os métodos de coletas foram bastante diversos de modo que abrangesse todo tipo de organismos, no plâncton, perifíton, massas filamentosas, lodo e água acumulada em bromélias, as novas coletas são amostras coletadas exclusivamente no plâncton. Foram listados 182 táxons, distribuídos em 83 gêneros, 45 famílias, 11 classes e sete divisões taxonômicas. No total, 89 táxons foram encontrados nas novas amostragens realizadas, destes, nove táxons, já haviam sido registrados na literatura existente, portanto 80 táxons são novos registros para a região. Um grande número de táxons citados anteriormente na literatura, não foram registrados nos ambientes amostrados, na sua grande maioria constituído por Bacillariophyceae, Conjugatophyceae e Euglenophyceae. Como também foram registradas três espécies de cianobactérias de grande importância sanitária. Sendo assim o PNCG possui grande importância na manutenção da biodiversidade aquática e conhecer essa comunidade torna-se cada vez mais importante para embasar medidas de manejo.

***Palavras-chave:*** *cerrado, algas, Planktothrix, taxonomia, riachos.*

## Introduction

Cyanobacteria and microalgae comprise a very diverse group of forms, sizes and strategies (Nishimura et al. 2015). However, knowledge about cyanobacteria and microalgae species number and distribution in the epicontinental waters of Brazil is extremely heterogeneous. Taxonomically there is much more knowledge about cyanobacteria and algae of the South and Southeast regions of the country than there is about the algae of the North and Central-West regions (Bicudo & Menezes 2010), nonetheless Menezes et al (2015) showed increase in species numbers from 2010 to 2015, for state of Mato Grosso.

The Upper Paraguay River Basin (UPB), located in the states of Mato Grosso and Mato Grosso do Sul in the Central-West region of Brazil, is divided into three geomorphologically distinct portions: the plateaus, the depressions and the Pantanal plain. Located in the region of the plateaus is Chapada dos Guimarães National Park (CGNP), an important conservation unit of the Cerrado biome. The CGNP possesses great biological diversity and numerous water sources that form several tributaries of the Pantanal, in particular the Coxipó river, which drains more than 55% of the total area of CGNP (Lima & Lima 2009). The CGNP has a fundamental role in conserving the aquatic biota and preserving the water quality of the rivers of the region, whose downstream uses include irrigation, water supply to small farms, fish farming and bathing, as well as the dilution of domestic effluents. Furthermore, the Coxipó river provides more than 30% of the total water supply of the city of Cuiabá, the capital of Mato Grosso (Gomes-Silva 2015). Even in light of the social and environmental relevance of the rivers that drain CGNP, there have been few studies on its aquatic biota, especially the algal community.

Studies on cyanobacteria and microalgae in state Mato Grosso are scarce, being concentrated in the region of the Pantanal wetland (Freitas & Loverde-Oliveira 2013; Menezes et al. 2015; Marçal & Loverde-Oliveira 2015), which makes comparative studies difficult. The first studies carried out in the Chapada dos Guimarães region contributed records of 14 species; *Closterium gracile, Closterium tumidum* and *Pleurotaenium maximum* cataloged by Borge (1903a); three of the genus *Spirogyra* and one of the genus *Zygogonium* cataloged by Dias (1986); and seven species of pigmented Euglenaceae cataloged by Menezes (1986).

Dias (1986) employed a variety of techniques and sampling of plankton from different types of substrates, reporting the importance of the watercourses present in the region. Three years after the publication of Dias (1986), CGNP was created by Federal Decree 97.656 on 12 April, 1989, when several local groups and civil entities began to develop environmental education projects in an attempt to revert the current situation of degradation that was visible in several areas of the region (Teixeira de Oliveira & Hardoim 2010).

In the same year that CGNP was created, Sophia and Silva (1989) contributed to the knowledge of Conjugatophyceae by recording six species. Among these was *Desmidium grevillei* (Syn.: *Desmidium cylindricum*), whose occurrence was not reported again until 25 years later by Fonseca et al. (2014) from the urban area of the municipality of Chapada dos Guimarães. Menezes and Fernandes (1990) are the only ones to have recorded the class Dinophyceae in plankton samples of the region; no other work has since reported the occurrence of this group.

After the work of Menezes & Fernandes (1990), two course-completion papers recorded new occurrences of microalgae in the region, Bazanella (2003; unpublished data), with 32 species of Bacillariophyceae, from plankton samples, and Souza (2004; unpublished data) with 34 taxa of Bacillariophyceae found in phytotelmatic environments of bromeliads. In 2014, Fonseca and collaborators published a list of species from the Quineira river in the Casca river basin, recording 19 species of Zygnematophyceae. The authors did not provide a description of the taxa but presented photographic records of the identified species. As far as we know, there is no synthesis work with registration of cyanobacteria and microalgae for the CGNP region. The data are fragments in articles, dissertations, and course completion papers.

Here we provide an inventory of the cyanobacteria and microalgae recorded in the literature for CGNP and the surrounding area. In doing so, we also reported 80 new records of occurrences from new collections for the park region.

## Materials and Methods

### 1. *Study site*

The Chapada dos Guimarães National Park (CGNP) is one of the principal conservation and protection units of the Cerrado biome in Brazil. It is located in the Central-West region of the country in the state of Mato Grosso, within the municipalities of Chapada dos Guimarães and Cuiabá. It encompasses approximately 32.630 ha (Lopes et al. 2009), and includes numerous springs, trails, streams, rivers, backwaters and waterfalls, and whose rivers flow into the Cuiabá river, one of the main tributaries of Pantanal (Figure 1). The CGNP is buffered from the intense anthropogenic activities that occur in the region by an Environmental Protection Area (EPA).

Edition: Silva, S.P. Adapted from Gomes-Silva, 2015

**Figure 1.** Illustrative map indicating the location of the planktonic algae sampling stations in the watercourses of Chapada dos Guimarães National Park (CGNP) - MT, Brazil, and its surrounding area. (Map adapted from Gomes-Silva 2015).

The region experiences two very different, well-defined seasons with regard to rainfall; a drought (dry season) from May to September, and rains (rainy season) from November to April. According to the Koppen classification, the predominant climate type of the region is included in the categories AW and CW (Padilha Junior & Nunes 2014).

## 2. *Data collection*

This research was developed from literature related to taxonomic and ecological inventories, what included articles published in scientific journals, course-completion papers, dissertations and theses that have a list of species of algae from CGNP and the surrounding area. The authors of these works applied the following methods: phytoplankton was collected with a plankton net (25 µm); periphyton and sludge was removed from substrates by scraping; filamentous masses and the waters accumulated in bromeliads was collected directly. In all studies, samples were fixed with Transeau solution. Due to the scarcity of work done in the region, all of these sampling methods were considered, however, only taxa identified to species level were included in the current list.

Aiming to broaden the knowledge about cyanobacteria and microalgae taxa already registered for the area, we carried out a taxonomic inventory at ten collection stations in the region (E1 a E10), between August and October of 2013 and in the months of March and June of 2014. We analyzed a total of 44 samples of plankton from Claro, Coxipó, Coxipozinho, Paciência and Mutuca rivers (Figure 1; Table 1).

Samples were collected using a plankton net (20-µm mesh) in the subsurface of the water and preserved in 500 mL flasks containing 4% formalin solution (Bicudo & Menezes 2006). Species identification was based on morphological and metric characteristics of the populations by observing at least 20 individuals of each species on slides with coverslips. Observations were made using a Carl Zeiss optical microscope coupled to an Axiocam 105 color LAB.A1 with maximum resolution of 400X and a digital camera.

For taxonomic analysis of diatoms, samples were oxidized with heated hydrogen peroxide ($H_2O_2$) and hydrochloric acid (HCl), according to the protocol of the European Committee for Standardization. For the observation of frustules, permanent slides were mounted with Naphrax as an inclusion medium. Measurements of length, width, and number of striations in a range of 10 µm were taken. Identification of diatoms, when possible, was based on population analysis.

The classification systems used were Komárek (2014) and Rugiero et al. (2015), and the analyzed material was deposited in the liquid phycological collection of the Herbário Central da Universidade Federal de Mato Grosso (UFMTAlgae), campus Cuiabá.

**Table 1.** Rivers, sampling station, registration number and geographic coordinates of the planktonic microalgae collection areas of the Chapada dos Guimarães National Park - MT, Brazil, and surrounding area.

| Rivers | Sampling station | Register Nº | Geographic coordinates |
|---|---|---|---|
| Claro | E1 | UFMTAlgae 01,06, 08 e 11 | 15°18′55,00″S, 055°52′57,00″W |
| Claro | E2 | UFMTAlgae 09,13 e 622 | 15°18′36,90″S, 055°53′23,30″W |
| Claro | E3 | UFMTAlgae 03,15,657, 658, 623 e 624. | 15°18′30,70″S, 055°53′08,60″W |
| Claro | E4 | UFMTAlgae 17,626,627e 628 | 15°18′52,31″S, 055°52′31,84″W |
| Claro | E5 | UFMTAlgae 05, 19,20,629,630 e 631 | 15°19′23,81″S, 055°52′04,15″W |
| Coxipozinho | E6 | UFMTAlgae 82,98,276 e 637 | 15°24′33,5″S, 055°49′54,548″W |
| Claro | E7 | UFMTAlgae 97,268,636 | 15°21′13,151″S, 055°54′52,375″W |
| Paciência | E8 | UFMTAlgae 82,98,276,637 | 15º21′13″S, 055º54′52″W |
| Mutuca | E9 | UFMTAlgae 83,158,239,284 e 638 | 15º21′52″S; 055º57′21″W |
| Coxipó | E10 | UFMTAlgae 76,96,152, 258 e 635. | 15º 22′25″S; 055º57′50″W |

## Results and Discussion

Our dataset totaled 182 taxa distributed among 83 genera, 45 families, 11 classes and 7 taxonomic divisions. The most representative class in terms of number of families was Bacillariophyceae (16 families), followed by Cyanophyceae (9 families). The largest number of taxa was from Bacillariophyceae, with 65 taxa (35.71%), followed by Conjugatophyceae with 53 taxa (29.12%), Chlorophyceae with 20 taxa (10.98%), Cyanophyceae with 15 taxa (8.24%), and Euglenophyceae with 13 taxa (7.14%) (Figure 2). A total of 102 taxa were acquired from six published articles and two course-conclusion papers (56.04%). Figure 3 presents some representatives of the groups found in new collections carried out in the park.

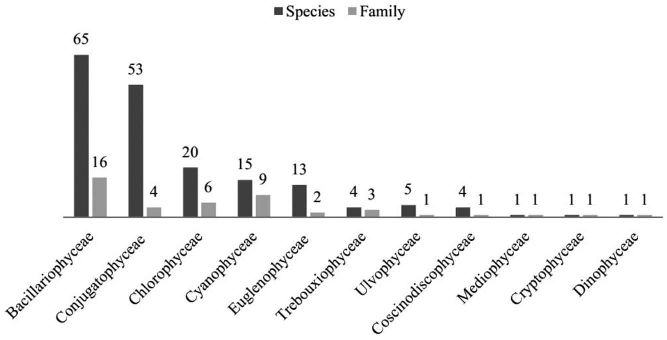

**Figure 2.** Number of family and species distributed by classes.

In total, 89 taxa were found in the new sampling performed in the study area, of which nine (*Eunotia camelus*, *Gomphonema gracile*, *Aulacoseira granulata, Bambusina borreri, Cosmarium pseudoconnatum, Cosmarium obsoletum,Cosmarium contractum* and *Micrasterias papillifera*) had already been recorded in the literature and 80 representing new records for the region (43.95%) (Table 2). Ninety-three previously cited taxa were not recorded in the sampled environments, most of which were of Bacillariophyceae (45 taxa), Conjugatophyceae (23 taxa) and Euglenophyceae (9 taxa). The high representation of Bacillariophyceae in the literature is due to the different types of environments sampled that favor the development of diatomaceous species.

Bacillariophyceae are one of the most common and dominant groups in both plankton and periphyton (Stevenson 1996; Bellinger & Sigee 2010), due to their variety of forms that allows colonization of different types of substrates. They also have high species richness, play an important role as primary producers and are considered bioindicators of the trophic state of these aquatic environments (Bellinger & Sigee 2010). With regard to diatom diversity in general, the Neotropics is considered quite rich compared to the well-studied temperate regions of Europe and North America, and each new published flora results in dozens of new proposed taxa, some of which are particularly endemic (Cavalcante et al. 2014), but no endemism was found in CGNP for this group of algae. Although the occurrence of diatoms is related to water flow and success of substrate colonization, the ability of these organisms to survive in these environments depends on factors associated with their distribution, such as nutrients, light, temperature, among others (Reynolds et al. 2006).

The families with the greatest species richness were Desmidiaceae, with 35 taxa (19.23%), and Eunotiaceae, with 19 taxa (10.44%). Desmids are remarkable because of the great diversity of species that are distributed in a variety of different environments, such as plankton, periphyton and metaphyton (Menezes et al. 2011), and their preference for acidic environments – oligotrophic to eutrophic (Bicudo & Menezes 2006), characteristics that favor the development of the group in the region with its crystalline waters, rivers with waterfalls and preserved riparian vegetation. As with desmids, representatives of the family Eunotiaceae are favored by acidic and nutrient poor environments (Round et al. 1990), prevailing conditions in the rivers and streams sampled in this study (Gomes-Silva 2015).

There was an increase in the records of cyanobacteria in the region, with two species described by Bazanella (2003; unpublished data), *Kamptonema proteus* and *Pseudanabaena galeata*, and 13 species found in current collections (*Cylindrospermopsis raciborskii, Asterocapsa submersa, Chroococcus dispersus, Chroococcus minor, Snowella lacustris, Komvophoron crassum, Komvophoron schmidlei, Merismopedia tenuissima, Planktothrix agardhii, Microcystis aeruginosa, Sphaerocavum brasiliense, Lyngbya major* and *Pseudanabaena galeata*). Three cyanotoxin-producing species of major public health importance were recorded in the study area, *Cylindrospermopsis raciborskii*, *Planktothrix agardhii* and

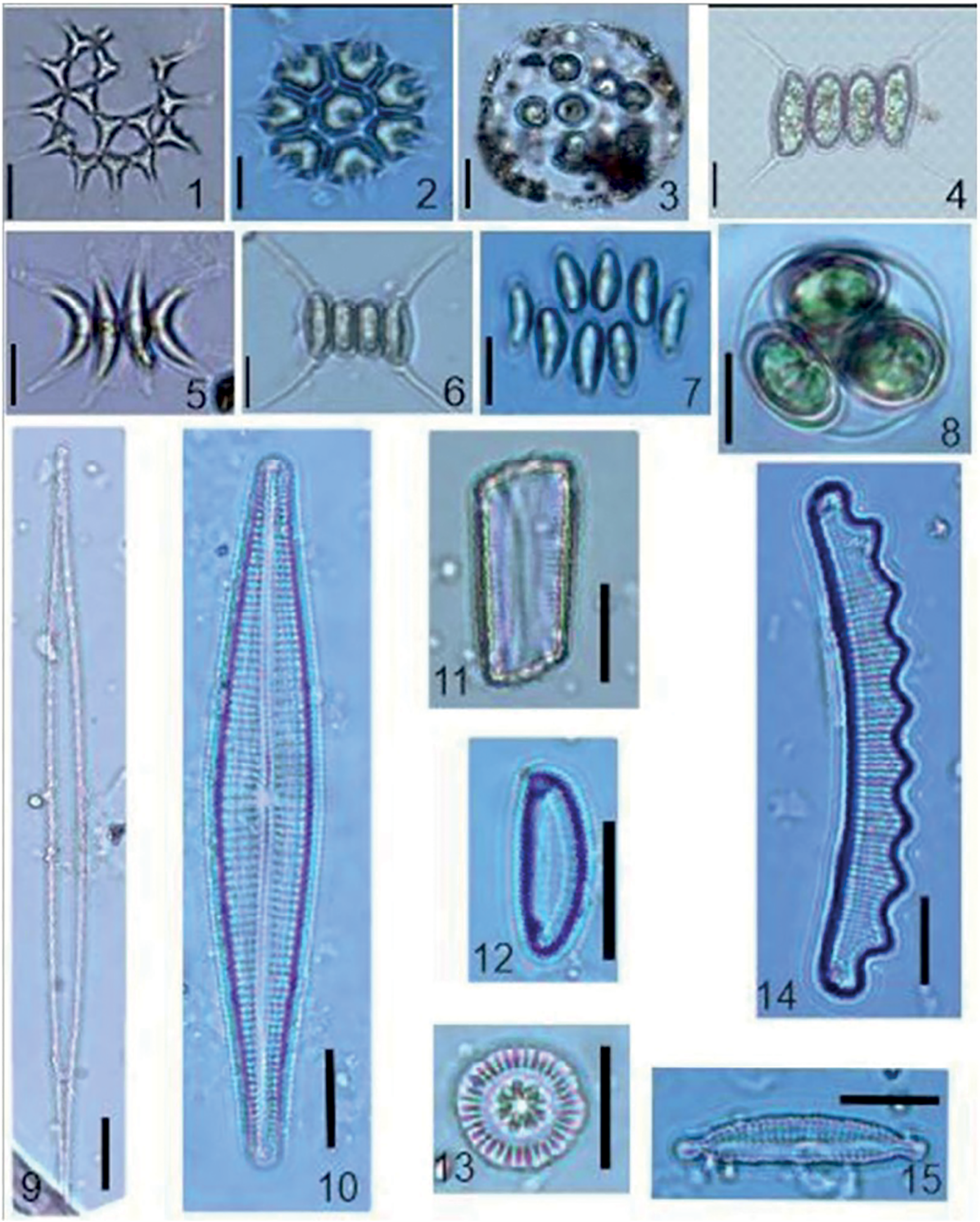

**Figure 3.** 1. *Monactinus simplex*, 2. *Stauridium tetras*, 3. *Sphaerocystis planctonica*, 4. *Desmodesmus communis*, 5. *Acutodesmus acuminatus*, 6. *Desmodesmus opoliensis*, 7. *Scenedesmus obtusus*, 8. *Oocystis borgei*, 9. *Stenopterobia delicatissima*; 10. *Gomphonema gracile*; 11-12. *Eunotia botuliformis*; 13. *Discostella pseudostelligera*; 14. *Eunotia georgii*; 15. *Encyonema angustecapitatum*. Scale bar: 10 µm.

**Table 2.** List of microalgae recorded in the Chapada dos Guimarães National Park and surroundings, Mato Grosso, Central-West Brazil. * new records for the Chapada dos Guimarães National Park and surroundings.

| Division/Class/Family/Species | References | Occurrence |
|---|---|---|
| **Bacillariophyta/ Bacillariophyceae** | | |
| **Achnanthaceae** | | |
| *Achnanthes longipes* C. Agardh | S.I. Bazanella, 2003, unpublished data | -- |
| **Achnanthidiaceae** | | |
| *Planothidium lanceolatum* (Brébisson ex Kützing) Lange-Bertalot, cited as *Achnanthes lanceolata* (Brébisson ex Kützing) Grunow | S.I. Bazanella, 2003, unpublished data | -- |
| **Amphipleuraceae** | | |
| *Frustulia rhomboides* (Ehrenberg) De Toni | S.I. Bazanella, 2003, unpublished data | -- |
| **Bacillariaceae** | | |
| *Denticula thermalis* Kützing | S.F. Sousa, 2004, unpublished data | -- |
| *Nitzschia linearis* W. Smith | S.F. Sousa, 2004, unpublished data | -- |
| *Nitzschia modesta* Hustedt | S.I. Bazanella, 2003, unpublished data | -- |
| *Nitzschia palea* (Kützing) W. Smith | S.F. Sousa, 2004, unpublished data | -- |
| *Nitzschia sigma* (Kützing) W. Smith | S.I. Bazanella, 2003, unpublished data | -- |
| **Diadesmidaceae** | | |
| *Diadesmis confervacea* Kützing, cited as *Navicula confervacea* (Kützing) Grunow | S.I. Bazanella, 2003, unpublished data | -- |
| **Eunotiaceae** | | |
| *Actinella curvatula* Kociolek * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E2, E4 |
| *Actinella guianensis* Grunow * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1 |
| *Eunotia bidentula* W. Smith | S.I. Bazanella, 2003, unpublished data | -- |
| *Eunotia botuliformis* F. Wild, Nörpel & Lange-Bertalot * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E2, E3, E4, E5 |
| *Eunotia camelus* Ehrenberg | S.I. Bazanella, 2003, unpublished data; Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014), ; S.F. Sousa, 2004, unpublished data | E2, E3, E5 |
| *Eunotioforma curvula* (Hustedt) J.P.Kociolek & A.L.Burliga * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1, E2, E3, E4, E5 |
| *Eunotia diadema* Ehrenberg, citado como *Eunotia serra* var. *diadema* (Ehrenberg) R. M. Patrick | S.F. Sousa, 2004, unpublished data | -- |
| *Eunotia faba* (Ehrenberg) Grunow | S.I. Bazanella, 2003, unpublished data | -- |
| *Eunotia georgii* Metzeltin & Lange-Bertalot * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E2, E3, E4, E5, E10 |
| *Eunotia guyanensis* (Ehrenberg) De Toni | S.I. Bazanella, 2003, unpublished data | -- |
| *Eunotia intricans* H. Lange-Bertalot & D. Metzeltin * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E2, E3, E4 |
| *Eunotia monodon* Ehrenberg | S.I. Bazanella, 2003, unpublished data | -- |
| *Eunotia pseudoserra* P. E. De Oliveira & M. Steinitz-Kannan * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1, E3, E4 |
| *Eunotia robusta* Ralfs | S.I. Bazanella, 2003, unpublished data S.F. Sousa, 2004, unpublished data | -- |
| *Eunotia serra* Ralfs * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E2, E3, E4 |
| *Eunotia sphagnophila* Krasske * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1, E3 |

**Continued Table 2.**

| **Division/Class/Family/Species** | **References** | **Occurrence** |
|---|---|---|
| *Eunotia subrobusta* Hustedt * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E3, E4 |
| *Eunotia trigibba* Hustedt * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E2, E3, E4 |
| *Eunotia triodon* Ehrenberg | S.F. Sousa, 2004, unpublished data | -- |
| **Fragilariaceae** | | |
| *Fragilaria crotonensis* Kitton | S.I. Bazanella, 2003, unpublished data | -- |
| *Fragilaria rolandschmidtii* Metzeltin & Lange-Bertalot * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E2, E3 |
| *Fragilariforma virescens* (Ralfs) D. M. Williams & Round, citado como *Fragilaria virescens* Ralfs | S.I. Bazanella, 2003, unpublished data | -- |
| **Gomphonemataceae** | | |
| *Encyonema angustecapitatum* Krammer * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E2, E3, E4, E5 |
| *Encyonopsis frequentis* Krammer * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E2, E4 |
| *Gomphonema angustatum* (Kützing) Rabenhorst | S.I. Bazanella, 2003, unpublished data | -- |
| *Gomphonema brasiliense* Grunow | S.I. Bazanella, 2003, unpublished data | -- |
| *Gomphonema gracile* Ehrenberg * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014); S.F. Sousa, 2004, unpublished data | E1, E2, E3, E4, E10 |
| *Gomphonema martini* F. Fricke | S.F. Sousa, 2004, unpublished data | -- |
| *Gomphonema olivaceum* (Hornemann) Brébisson | S.I. Bazanella, 2003, unpublished data | -- |
| *Gomphonema parvulum* (Kützing) Kützing | S.F. Sousa, 2004, unpublished data | -- |
| *Gomphonema turris* Ehrenberg citado como *Gomphonema augur* var. *turris* (Ehrenberg) Lange-Bertalot | S.F. Sousa, 2004, unpublished data | -- |
| *Placoneis pseudanglica* E. J. Cox * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E2, E3 |
| **Naviculaceae** | | |
| *Navicula cryptocephala* Kützing * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E2, E4, E5 |
| *Navicula oblonga* (Kützing) Kützing | S.I. Bazanella, 2003, unpublished data | -- |
| *Navicula cuspidata* (Kutzing) Kutzing | S.I. Bazanella, 2003, unpublished data | -- |
| **Neidiaceae** | | |
| *Neidium affine* var. *ceylonicum* (Skvortsov) Reimer * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E2, E3 |
| **Pinnulariaceae** | | |
| *Pinnularia gibba* var. *sancta* (Grunow ex Cleve) F. Meister | S.F. Sousa, 2004, unpublished data | -- |
| *Pinnularia lata* (Brébisson) W. Smith | S.F. Sousa, 2004, unpublished data | -- |
| *Pinnularia mayeri* Krammer, citado como *Pinnularia braunii* var. *amphicephala* (Ant. Mayer) Hustedt | S.F. Sousa, 2004, unpublished data | -- |
| *Pinnularia viridis* (Nitzsch) Ehrenberg | S.I. Bazanella, 2003, unpublished data | -- |
| **Rhopalodiaceae** | | |
| *Epithemia adnata* (Kützing) Brébisson citado como *Epithemia zebra* (Ehrenberg) Ehrenberg | S.F. Sousa, 2004, unpublished data | -- |
| *Epithemia argus* (Ehrenberg) Kützing | S.I. Bazanella, 2003, unpublished data | -- |
| *Epithemia argus* var. *longicornis* (Ehrenberg) Grunow | S.F. Sousa, 2004, unpublished data | -- |

**Continued Table 2.**

| Division/Class/Family/Species | References | Occurrence |
|---|---|---|
| **Surirellaceae** | | |
| *Iconella curvula* (Smith) Ruck & Nakov cited as *Stenopterobia curvula* (W. Smith) Krammer * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E2, E4 |
| *Iconella delicatissima* (F.W.Lewis) Ruck & Nakov cited as *Stenopterobia delicatissima* (F. W. Lewis) Brébisson ex Van Heurck * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1, E2, E4 |
| *Surirella elegans* Ehrenberg | S.I. Bazanella, 2003, unpublished data | -- |
| *Iconella guatimalensis* (Ehrenberg) Ruck & Nakov cited as *Surirella guatimalensis* Ehrenberg | S.I. Bazanella, 2003, unpublished data | -- |
| *Surirella minuta* Brébisson ex Kützing, citado como *Surirella ovata* Kützing | S.I. Bazanella, 2003, unpublished data | -- |
| *Surirella robusta* Ehrenberg | S.I. Bazanella, 2003, unpublished data | -- |
| **Stauroneidaceae** | | |
| *Craticula cuspidata* (Kützing) D. G. Mann, citada como *Navicula cuspidata* (Kützing) Kutzing | S.I. Bazanella, 2003, unpublished data | -- |
| *Stauroneis deperdita* Manguin | S.I. Bazanella, 2003, unpublished data | -- |
| **Tabellariaceae** | | |
| *Diatoma anceps* (Ehrenberg) Kirchner | S.I. Bazanella, 2003, unpublished data | -- |
| *Diatoma vulgaris* Bory | S.I. Bazanella, 2003, unpublished data | -- |
| *Tabellaria fenestrata* (Lyngbye) Kützin | S.I. Bazanella, 2003, unpublished data | -- |
| **Ulnariaceae** | | |
| *Hannaea arcus* (Ehrenberg) R. M. Patrick, citado como *Ceratoneis arcus* (Ehrenberg) Kützing | S.I. Bazanella, 2003, unpublished data | -- |
| *Ulnaria capitata* (Ehrenberg) Compère, citado como *Synedra capitata* Ehrenberg | S.I. Bazanella, 2003, unpublished data | -- |
| **Bacillariophyta/Coscinodiscophyceae** | | |
| **Aulacoseiraceae** | | |
| *Aulacoseira distans* (Ehrenberg) Simonsen | S.F. Sousa, 2004, unpublished data | -- |
| *Aulacoseira granulata* (Ehrenberg) Simonsen | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014); S.F. Sousa, 2004, unpublished data | E1, E2, E3, E4, E5, E9 |
| *Aulacoseira herzogii* (Lemmermann) Simonsen | S.I. Bazanella, 2003, unpublished data S.F. Sousa, 2004, unpublished data | -- |
| *Aulacoseira italica* (Ehrenberg) Simonsen | S.I. Bazanella, 2003, unpublished data ; S.F. Sousa, 2004, unpublished data | -- |
| **Bacillariophyta/Mediophyceae** | | |
| **Stephanodiscaceae** | | |
| *Discostella pseudostelligera* (Hustedt) Houk & Klee * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014); | E1, E2, E4 |
| **Chlorophyta/Chlorophyceae** | | |
| **Hydrodictyaceae** | | |
| *Lacunastrum gracillimum* (West & G. S. West) H. McManus * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| *Monactinus simplex* (Meyen) Corda * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E4, E5 |
| *Stauridium tetras* (Ehrenberg) E. Hegewald * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| **Microsporaceae** | | |
| *Microspora membranacea* Wang | S.F. Sousa, 2004, unpublished data | -- |

**Continued Table 2.**

| Division/Class/Family/Species | References | Occurrence |
|---|---|---|
| **Neochloridaceae** | | |
| *Golenkinia radiata* Chodat * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| **Scenedesmaceae** | | |
| *Acutodesmus acuminatus* (Lagerheim) P. M. Tsarenko * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| *Coelastrum proboscideum* Bohlin * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| *Coelastrum sphaericum* Nägeli, citado como *Coelastrum verrucosum* (Reinsch) Reinsch * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| *Desmodesmus armatus* var. *bicaudatus* (Guglielmetti) E. Hegewald * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| *Desmodesmus communis* (E. Hegewald) E. Hegewald * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| *Desmodesmus opoliensis* (P.G. Richter) E. Hegewald * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E4, E5 |
| *Dimorphococcus lunatus* A. Braun * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| *Pectinodesmus javanensis* (Chodat) E. Hegewald, C. Bock & Krienitz * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| *Scenedesmus obtusus* Meyen * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| *Westella botryoides* (West) De Wildeman * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| **Selenastraceae** | | |
| *Ankistrodesmus arcuatus* Korshikov * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| *Messastrum gracile* (Reinsch) T.S.Garcia, citado como *Ankistrodesmus gracilis* (Reinsch) Korshikov * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| *Monoraphidium contortum* (Thuret) Komárková-Legnerová * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E8, E9, E10 |
| *Monoraphidium intermedium* Hindák * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E6, E7, E8, E9, E10 |
| **Sphaerocystidaceae** | | |
| *Sphaerocystis planctonica* (Korshikov) Bourrelly * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| **Chlorophyta/Trebouxiophyceae** | | |
| **Chlorellaceae** | | |
| *Mucidosphaerium pulchellum* (H.C.Wood) C.Bock, Proschold & Krienitz * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| **Oocystaceae** | | |
| *Oocystis borgei* J. W. Snow * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| **Trebouxiophyceae Família *incertae sedis*** | | |
| *Lemmermannia komarekii* (Hindák) C.Bock & Krienitz * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| *Lemmermannia triangularis* (Chodat) C. Bock & Krienitz * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |

**Continued Table 2.**

| Division/Class/Family/Species | References | Occurrence |
|---|---|---|
| **Chlorophyta/Ulvophyceae** | | |
| **Ulotrichaceae** | | |
| *Ulothrix bipyrenoidosa* F. E. Fritsch & M. F. Rich | S.F. Sousa, 2004, unpublished data | -- |
| *Ulothrix implexa* (Kützing) Kützing | S.F. Sousa, 2004, unpublished data | -- |
| *Ulothrix limnetica* Lemmermann | S.F. Sousa, 2004, unpublished data | -- |
| *Ulothrix tenerrima* (Kützing) Kützing, citado como *Ulothrix variabilis* Kützing | S.F. Sousa, 2004, unpublished data | -- |
| *Ulothrix zonata* (F. Weber &amp; Mohr) Kützing | S.F. Sousa, 2004, unpublished data | -- |
| **Charophyta/Conjugatophyceae** | | |
| **Closteriaceae** | | |
| *Closterium acutum* var. *variabile* (Lemmermann) Willi Krieger * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1 |
| *Closterium cornu* Ehrenberg ex Ralfs | Fonseca et al. (2014) | -- |
| *Closterium costatum* var. *borgei* (Willi Krieger) Ruzicka * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E5 |
| *Closterium ehrenbergii* Meneghini ex Ralfs | Fonseca et al. (2014) | -- |
| *Closterium gracile* Brébisson ex Ralfs | Borge (1903a) | -- |
| *Closterium intermedium* Ralfs | S.F. Sousa, 2004, unpublished data | -- |
| *Closterium jenneri* var. *cynthia* (De Notaris) Petlovany, citado como *Closterium cynthia* De Notaris | Fonseca et al. (2014) | -- |
| *Closterium juncidum* Ralfs | S.F. Sousa, 2004, unpublished data | -- |
| *Closterium moniliferum* var. *moniliferum* f. gracile Kurt Förster * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E5 |
| *Closterium navicula* (Brébisson) Lütkemüller * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1, E3 |
| *Closterium tumidum* L. N. Johnson | Borge (1903a) | -- |
| *Closterium venus* Kützing ex Ralfs | S.F. Sousa, 2004, unpublished data | -- |
| **Desmidiaceae** | | |
| *Actinotaenium cruciferum* var. *cruciferum* (De Bary) Teiling * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1, E5 |
| *Actinotaenium globosum* (Bulnheim) Kurt Förster ex Compère * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E2, E5 |
| *Actinotaenium silvae-nigrae* (Rabanus) Kouwets & Coesel, citado como *Penium silvae-nigrae* Rabanus | S.F. Sousa, 2004, unpublished data | -- |
| *Actinotaenium wollei* (West & G. S. West) Teiling | Fonseca et al. (2014) | -- |
| *Bambusina borreri* (Ralfs) Cleve, cited in (1) as *Bambusina brebissonii* Kützing ex Kützing[1] | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014), [1]Sophia & Silva (1989) | E1 |
| *Cosmarium circulare* Reinsch, citado em freitas como *C. candianum* * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E4 |
| *Cosmarium connatum* Brébisson ex Ralfs | Fonseca et al. (2014) | -- |
| *Cosmarium contractum* O. Kirchner | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014); Fonseca et al. (2014) | E1, E2, E3, E4, E5 |
| *Cosmarium furcatospermum* West & G. S. West | Fonseca et al. (2014) | -- |
| *Cosmarium obsoletum* (Hantzsch) Reinsch | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014); Fonseca et al. (2014) | E3 |

**Continued Table 2.**

| Division/Class/Family/Species | References | Occurrence |
|---|---|---|
| *Cosmarium pseudoconnatum* Nordstedt | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014); Fonseca et al. (2014) | E9 |
| *Cosmarium pyramidatum* var. *stephanii* (Irénée-Marie) Willi Krieger & Gerloff * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1, E5 |
| *Cosmarium quadratum* Ralfs ex Ralfs * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1 |
| *Cosmarium quadrum* P. Lundell | Fonseca et al. (2014) | -- |
| *Desmidium grevillei* (Kützing ex Ralfs) De Bary, citado como *Desmidium cylindricum* Greville | Sophia & Silva (1989) Fonseca et al. (2014) | -- |
| *Desmidium swartzii* C. Agardh ex Ralfs * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E3, E4 |
| *Euastrum brasiliense* Borge | Fonseca et al. (2014) | -- |
| *Euastrum sinuosum* var. *sinuosum* Archerk * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1, E2, E4, E5 |
| *Hyalotheca dissiliens* Brébisson ex Ralfs | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014); Fonseca et al. (2014) | E1, E2 |
| *Hyalotheca dissiliens* (Smith) Bréb. var. hians Wolle | Sophia & Silva (1989) | -- |
| *Micrasterias decemdentata* (Nägeli) W. Archer | Fonseca et al. (2014) | -- |
| *Micrasterias denticulata* Brébisson ex Ralfs * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E4 |
| *Micrasterias laticeps* var. *acuminata* Willi Krieger * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1, E2 |
| *Micrasterias papillifera* Brébisson ex Ralfs | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014); Fonseca et al. (2014) | E1, E3, E4 |
| *Micrasterias rotata* Ralfs * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1, E3 |
| *Micrasterias torreyi* var. *nordstedtiana* (Hyeronimus) Schmidle * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E3 |
| *Micrasterias truncata* Brébisson ex Ralfs * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1, E5 |
| *Pleurotaenium maximum* (Reinsch) P. Lundell | Borge (1903a) | -- |
| *Sphaerozosma desmidiiforme* Borge citado como *Spondylosium desmidiiforme* (Borge) G.S.West | Sophia & Silva (1989) | -- |
| *Spondylosium pulchrum* (Bail.) Archer var. *pulchrum*, in Pritch | Sophia & Silva (1989) | -- |
| *Staurastrum margaritaceum* Meneghini ex Ralfs | Fonseca et al. (2014) | -- |
| *Staurastrum excavatum* West & G. S. West * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| *Staurodesmus convergens* (Ehrenberb g ex Ralfs) S. Lillieroth * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1 |
| *Staurodesmus validus* (West & G. S. West) Thomasson | Fonseca et al. (2014) | -- |
| *Teilingia granulata* (J.Roy & Bisset) Bourrelly | Sophia & Silva (1989) | -- |
| **Mesotaeniaceae** | | |
| *Netrium digitus* (Brébisson ex Ralfs) Itzigsohn & Rothe | Fonseca et al. (2014) | -- |
| *Netrium parvum* (Borge) Petlovany * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1, E3, E5 |

**Continued Table 2.**

| Division/Class/Family/Species | References | Occurrence |
|---|---|---|
| **Zygnemataceae** | | |
| *Spirogyra irregularis* Nägeli ex Kützing | Dias (1986) | -- |
| *Spirogyra macrospora* (C. B. Rao) Krieger | Dias (1986) | -- |
| *Spirogyra neglecta* (Hassall) Kützing | Dias (1986) | -- |
| *Zygogonium ericetorum* Kützing | Dias (1986) | -- |
| **Cryptophyta/Cryptophyceae** | | |
| **Cryptomonadaceae** | | |
| *Cryptomonas marssonii* Skuja * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E8, E9 |
| **Cyanobacteria/Cyanophyceae** | | |
| **Aphanizomenonaceae** | | |
| *Cylindrospermopsis raciborskii* (Woloszynska) Seenayya & Subba Raju * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| **Chroococcaceae** | | |
| *Asterocapsa submersa* Azevedo, Sant'Anna, Senna, Komárek & Komárková * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1 |
| *Chroococcus dispersus* (Keissler) Lemmermann * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1 |
| *Chroococcus minor* (Kützing) Nägeli * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| **Coelosphaeriaceae** | | |
| *Snowella lacustris* (Chodat) Komárek & Hindák * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| **Gomontiellaceae** | | |
| *Komvophoron crassum* (Vozzhennikova) Anagnostidis & Komárek * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1, E3 |
| *Komvophoron schmidlei* (Jaag) Anagnostidis & Komárek * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1, E4, E10 |
| **Merismopediaceae** | | |
| *Merismopedia tenuissima* Lemmermann * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| **Microcoleaceae** | | |
| *Planktothrix agardhii* (Gomont) Anagnostidis & Komárek * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1, E3, E6, E8, E9, E10 |
| **Microcystaceae** | | |
| *Microcystis aeruginosa* (Kützing) Kützing * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1, E5 |
| *Sphaerocavum brasiliense* De Azevedo & C.L.Sant' Anna * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| **Oscillatoriaceae** | | |
| *Lyngbya major* Meneghini ex Gomont * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1, E2 |
| *Oscillatoria proteus* Skuja | S.I. Bazanella, 2003, unpublished data | -- |
| **Pseudanabaenaceae** | | |
| *Pseudanabaena galeata* Böcher * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E8, E9, E10 |
| *Pseudanabaena limnetica* (Lemmermann) Komárek, citado como *Oscillatoria limnetica* Lemmermann | S.I. Bazanella, 2003, unpublished data | -- |

**Continued Table 2.**

| Division/Class/Family/Species | References | Occurrence |
|---|---|---|
| **Euglenophyta/Euglenophyceae** | | |
| **Euglenaceae** | | |
| *Trachelomonas volvocina* (Ehrenberg) Ehrenberg * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E6, E7, E8, E9 |
| *Trachelomonas volvocinopsis* Svirenko * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E9 |
| **Phacaceae** | | |
| *Lepocinclis globulus* Perty, citado como *Lepocinclis ovum* (Ehrenberg) Lemmermann var. *globula* (Perty) Lemmermann | Menezes (1986) | -- |
| *Lepocinclis ovum* var. *dimidio-minor* (Deflandre) Conrad. | Menezes (1986) | -- |
| *Lepocinclis ovum* (Ehrenberg) Lemmermann, citado como *Lepocinclis ovum* (Ehrenberg) Lemmermann var. ovum | Menezes (1986) | -- |
| *Phacus anomalus* F. E. Fritsch & M. F. Rich | Menezes (1986) | -- |
| *Phacus hamatus* Pochmann | Menezes (1986) | -- |
| *Phacus hamelii* P.Allorge & M.Lefèvre | Menezes (1986) | -- |
| *Phacus longicauda* (Ehrenberg) Dujardin * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E1, E2, E3, E4, E5 |
| *Phacus orbicularis* K. Hübner | Menezes (1986) | 0 |
| *Phacus pleuronectes* (O. F. Müller) Nitzsch ex Dujardin * | Taxonomic inventory of Parque Nacional Chapada dos Guimarães-MT (2013-2014) | E3, E5, E9 |
| *Phacus pusillus* Lemmermann | Menezes (1986) | -- |
| *Phacus raciborskii* Drezepolski | Menezes (1986) | -- |
| **Miozoa/Dinophyceae** | | |
| **Peridiniopsidaceae** | | |
| *Parvodinium umbonatum* (Stein) S. Carty, citado como *Peridinium umbonatum* Stein var. *umbonatum*. | Menezes & Fernandes (1990) | -- |

*Microcystis aeruginosa*, although records of the occurrence the toxic species were not expected. These species are successful in shallow eutrophic ecosystems (Bittencourt-Oliveira et al. 2014), different from the region in question, which has environments considered as oligotrophic and slightly acidic (Teixeira-Oliveira & Hardoim 2010). The occurrence of these species may be associated with the presence of mammalian waste from the region, or even the existence of small farms and the very intense tourism that occurs in the studied rivers. This was a concern previously reported by Dias in 1986, and needs to be monitored, including in areas associated with effluents from the urban area of Chapada dos Guimarães, located upstream of the CGNP.

The high concentration of these species in aquatic ecosystems can trigger the production of toxins such as cylindrospermopsin and microcystin, resulting in health problems such as diarrhea, vomiting and weakness, and reaching organs such as the kidneys and the liver. Costa et al. (2017) reports the existence of these potentially toxic species in fishponds in the state of Mato Grosso. Currently in Brazil, microcystins were included as a monitoring parameter in *Portaria 1469* legislation (Brasil 2000) and have been used in water quality control ever since (Guerra et al. 2015).

The CGNP is of vital importance to the maintenance of aquatic biodiversity of the region, and understanding this community is becoming increasingly important for management measures. National parks are required to undertake inventories of their biodiversity, which serve as sources of reference data (Moresco & Rodrigues 2013). The Cerrado network and the Pró Centro-Oeste-REMISA network have developed projects for the diagnosis, analysis and synthesis of biodiversity data concerning CGNP. The studies of these projects have supported the exchange of technical information, as well as decision-making by the central manager of CGNP for the management and conservation of the aquatic ecosystems of the park.

The results from this work demonstrate an important increase of 80 species in the list of taxa existing in the region, an important advance for the knowledge of the ficology in the Center-West region of Brazil in recent years. However, 93 previously recorded taxa in the region were not sampled again. We believe that part of this loss in our studies is due to the exclusive collect made in the plankton and that other works that cover a greater number of habitats are important to evidence if there was loss of diversity.

Reducing the time interval between species inventories in watercourses is important to monitor the effect of land occupation and the impact of tourism on local biodiversity. For this, the monitoring of species in the region becomes a tool that is closely related to the integrity of the aquatic ecosystems existing in the park and its surroundings. We emphasize the importance of specialized taxonomist professionals for a better understanding of these microorganisms. Due to the great extension of water drainage of the CGNP, we conclude with the certainty that there are still gaps to be filled regarding studies of cyanobacteria and microalgae for the region studied.

## Acknowledgements

We thank Conselho Nacional de Desenvolvimento Científico e Tecnológico- CNPq and the Fundação de Amparo à Pesquisa do Estado de Mato Grosso - FAPEMAT for financial support through the projects: Rede Pró Centro-Oeste-REMISA (Projeto CNPq nº 564617/2010-5 and Projeto FAPEMAT nº 232949/2011), coordinated by Eliana Freire Gaspar de Carvalho Dores, and Rede ComCerrado/Núcleo UFMT, processo nº 563134/2010. Lívia Franco da Costa aided in the identification of diatoms, and Denise de Campos Bicudo graciously provided assistance in the production of the their permanent slides.

We thank Coordenação de Aperfeiçoamento de Pessoal de Nível Superior-CAPES for granting a PNPD grant to Daniela Maimoni de Figueiredo of the Programa de Pós-Graduação em Recursos Hídricos.

## Author Contributions

Gisele Fernanda Pereira Assis: Substantial contribution in the concept and design of the study; Contribution to data collection; Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intelectual content.

Samiris Pereira da Silva: Contribution to data collection; Contribution to data analysis and interpretation; Contribution to manuscript preparation.

Ludmylla Fernanda de Siqueira Silva: Contribution to data collection; Contribution to data analysis and interpretation.

Regiane Luiza da Costa: Contribution to data collection; Contribution to data analysis and interpretation.

Luany Weiler da Fonseca: Contribution to data collection.

Ermelinda Maria De-Lamonica-Freire: Contribution to data collection; Contribution to critical revision, adding intelectual content.

Daniela Maimoni de Figueireido: Contribution to data collection; Contribution to critical revision, adding intelectual content.

Márcia Teixeira de Oliveira: Substantial contribution in the concept and design of the study; Contribution to data collection; Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intelectual content.

## Conflicts of interest

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

## References

BAZANELLA, S.I. 2003. Diversidade de Bacillariophyceae em rios encachoeirados do Parna, Chapada dos Guimarães - Mato Grosso. Trabalho de conclusão de curso, Universidade Federal de Mato Grosso, Cuiabá.

BELLINGER, E.G. & SIGEE, D.C. 2010. Freshwater algae: identification and use as Bioindicators. Edição Wiley-Blackwell, West Sussex. 285p. ISBN 978-0-470-05814-5

BICUDO, C.E.M & MENEZES, M.A. 2006. Gêneros de algas continentais do Brasil: chave para identificação e descrições. 2 ed. Rima, São Carlos.

BICUDO, C.E.M. & MENEZES, M. 2010. Introdução: as algas do Brasil. In Catálogo de plantas e fungos do Brasil (R.C. Forzza et al., eds). Andrea Jakobsson Estúdio/Instituto de Pesquisa Jardim Botânico do Rio de Janeiro, Rio de Janeiro, v.1, p.49-60.

BITTENCOURT-OLIVEIRA, M.C., PICCIN-SANTOS, V., MOURA, A.N., ARAGÃO-TAVARES, N.K.C. & CORDEIRO-ARAÚJO, M.K. 2014. Cyanobacteria, microcystins and cylindrospermopsin in public drinking supply reservoirs of Brazil. Ann. Acad. Bras. Cienc. 86(1):297–310. doi:10.1590/0001-3765201302512

BORGES, O. 1903. Die algen der ersten Regnellschen Expedition: II.: Desmidiaceen. Arkiv För Botanik, n. 1: p. 277-285.

BRASIL. Portaria nº 1469, de 29 de Dezembro de 2000. Estabelece os procedimentos e responsabilidades relativos ao controle e vigilância da qualidade da água para consumo humano e seu padrão de potabilidade. Diário Oficial [da] República Federativa do Brasil, Brasília, DF, 22.02.01, Seção I.

CAVALCANTE, K.P., TREMARIN, P.I., CASTRO, E.C., TIBIRICÁ, C.E.J.A., WOJCIECHOWSKI, J., LUDWIG, T.A.V. Epiphytic Eunotia (Bacillariophyceae) on Podostemum from Santa Catarina, southern Brazil, including new observations on morphology and taxonomy of some rare recorded species. Biota Neotropica. 14(3): 000–000. http://dx.doi.org/10.1590/1676-06032014003 (last access in 02/03/2018)

COSTA, R.L., TODESCHINI, T., RIBEIRO, M.J.P. & TEIXEIRA-OLIVEIRA, M. 2017. Florações de cianobactérias potencialmente tóxicas em tanques de pisciculturas da região centro sul do estado de mato grosso. Biodiversidade. 16 (1): 33-45.

DE-LAMONICA-FREIRE, E.M. 1989. Catálogo das algas referidas para o Estado de Mato Grosso, Brasil, 2. Rev. Brasil., Biol. 49 (3): 679-689.

DIAS, I.C.A. 1986. Zygnemaceae (Zygnemaphyceae) da Chapada dos Guimarães e arredores, Mato Grosso, Brasil: uma contribuição ao seu conhecimento. Rickia 13: 69-75.

FONSECA, L.W., ALVES, M.A.S., SILVA, L.C.M., RODRIGUES, N.S. & PINILLOS, A.C.M. 2014. Zygnemaphyceae do Córrego Quinera – Parque Nacional de Chapada dos Guimarães/MT: estudo qualitativo e quantitativo. Enciclopédia Biosfera, Centro Científico Conhecer 10 (18): 3107-3117.

FREITAS, L.C & LOVERDE-OLIVEIRA, S.M. 2013. Checklist of green algae (Chlorophyta) for the state of Mato Grosso, Central Brazil. Check List 9 (6): 1471-1483.

GOMES-SILVA, P.A.J. 2015. Limnologia e qualidade da água da bacia do rio Coxipó (MT): subsídios à gestão dos recursos hídricos. Dissertação de Mestrado, Universidade Federal de Mato Grosso, Cuiabá.

GUERRA, A.B., TONUCCI, M.C., CEBALLOS, B.S.O., GUIMARÃES, H.R.C., LOPES, W.S., AQUINO, S.F. & LIBÂNIO, M. 2015. Remoção de microcistina-LR de águas eutrofizadas por clarificação e filtração seguidas de adsorção em carvão ativado granular. Eng Sanit Ambient. 20 (4): 603-612.

KOMÁREK, J. 2014. Modern classification of cyanobacteria. In Cyanobacteria: An Economic Perspective (eds N. K. Sharma, A. K. Rai and L. J. Stal), John Wiley & Sons, Ltd, Chichester, UK. p. 21-39. doi: 10.1002/9781118402238.ch2

LIMA, E.B.N.R. & LIMA, J.B. 2009. Qualidade da água das principais sub-bacias urbanas do município de Cuiabá. In Bacia do rio Cuiabá: uma abordagem socioambiental (D.M. Figueiredo & F.X.T. Salomão, orgs.). Entrelinhas: EdUFMT, Cuiabá, p. 140-154.

LOPES, L.E., PINHO, J.B., BERNARDON, B., OLIVEIRA, F.F., BERNARDON, G., FERREIRA, L.P., VASCONCELOS, M.P., NOBREGA, P.F.A. & RUBIO, T.C. 2009. Aves da Chapada dos Guimarães, Mato Grosso, Brasil: uma síntese histórica do conhecimento. Papéis Avulsos de Zoologia, Museu de Zoologia da Universidade de São Paulo 49(2): 9-47.

MARÇAL, S.F. & LOVERDE-OLIVEIRA, S.M. 2015. Phytoplankton in Coqueiro lake (Pantanal de Poconé, Mato Grosso, Brazil). Revista Biotemas, 28 (2): 9-25.

MENEZES, M. 1986. Ficoflórula da Chapada dos Guimarães e arredores, Mato Grosso, Brasil: Euglenaceae pigmentadas (Euglenophyceae). Rickia 13: 87-95.

MENEZES, M. & FERNANDES, V. 1990. Dinophyceae do Estado de Mato Grosso, MT, Brasil: Municípios de Barra do Bugres, Cáceres, Chapada dos Guimarães, Porto Esperidião e Quatro Marcos. Acta bot. bras. 4 (2): 21-30.

MENEZES, V.C., BUENO, N.C., BORTOLINI, J.C., BIOLO, S. & SIQUEIRA, N.S. 2011. O gênero Cosmarium Corda ex Ralfs (Desmidiaceae) no Reservatório de Itaipu, PR, Brasil. Hoehnea 38 (3): 483-493.

MENEZES, M. et al. 2015. Update of the Brazilian floristic list of Algae and Cyanobacteria. Rodriguésia. 66 (4): p. 1047-1062.

MORESCO, C. & RODRIGUES, L. 2013. O perifíton como bioindicador em rios. In Ecologia do Perífiton (A. Schwarzbold, A.L. Burliga, L.C. Torgan, orgs.). Rima, São Carlos, v.1, p.147-156.

NISHIMURA, P.Y.; MOSCHINI-CARLOS, V., POMPÊO, M. 2015. O estudo fitoplâncton com base nos grupos funcionais: origens e um vislumbre sobre seu futuro. In Ecologia de reservatórios e interfaces (M. Pompêo, V. Moschini-Carlos, P. Yuri Nishimura, S. Cardoso da Silva, J. Cesar López-Doval, orgs.). Instituto de Biociências da Universidade de São Paulo, São Paulo, p.120-131.

PADILHA JUNIOR, A.G & NUNES, J.R.S. 2014. As Variações da Qualidade da Água na Bacia do Rio Coxipó, Cuiabá-MT. Uniciências, Cuiabá 18 (1): 57-66.

REYNOLDS, C. S. 2006. Ecology of phytoplankton. Cambrigde: Cambrigde University Press.

ROUND, F.E.; CRAWFORD, R.M. & MANN, D.G. 1990. The diatoms: biology and morphology of genera. Cambridge, Cambridge University Press.

RUGGIERO, M.A.; GORDON, D.P.; ORRELL, T.M.; BAILLY, N.; BOURGOIN, T.; BRUSCA, R.C.; CAVALIER-SMITH, T.; GUIRY, M.D.; KIRK. P.M. 2015. A Higher Level Classification of All Living Organisms. PLoS ONE, 10(4): e0119248. 60 pp. doi:10.1371/journal.pone.0119248.

SOPHIA, M.G. & SILVA, L.H.S. 1989. Considerações sobre a flora de Desmídias filamentosas (Zygnematophyceae) do Noroeste de Mato Grosso e Sudeste de Rondônia, Brasil. Revista Brasileira de Biologia 49 (4): 943-956.

SOUSA, S.F. 2004. Ocorrência de microalgas e cianobactérias em ambientes fitotélmicos bromelícolas do Parque Nacional de Chapada dos Guimarães – MT. Trabalho de Conclusão de Curso. Universidade Federal de Mato Grosso, Cuiabá.

STEVENSON, R.J. 1996. Na Introduction to algal ecology in freshwater benthic habitats. In Algal ecology: freshwater bentic ecosystems. (R.J, Stevenson, M.L, Bothwell, R.L, Lowe, eds) San Diego: Academic Press, cap.1, p.3-30.

TEIXEIRA DE OLIVEIRA, M. & HARDOIM, E.L. 2010. Study of testacean assemblages (Protozoa: Rhizopoda) in touristic waterfall regions of Chapada dos Guimarães National Park, Mato Grosso State, Brazil. Acta Scientiarum. Biological Sciences. 32 (4): 387-395.

*Received: 29/06/2017*
*Revised: 14/03/2018*
*Accepted: 26/03/2018*
*Published online: 23/04/2018*

Biota Neotropica 18(2): e20170346, 2018
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
inventory

# Climbing plants of Porto Ferreira State Park, southeastern Brazil

*Betânia da Cunha Vargas*[*1;2]; *Ana Paula Caldeira Oliveira*[1]; *Renata Giassi Udulutsch*[3];
*Gabriel Mendes Marcusso*[1]; *Gabriel Pavan Sabino*[1]; *Pablo Hendrigo Alves de Melo*[1];
*Roberta Marotti Martelletti Grillo*[1]; *Vitor de Andrade Kamimura*[1]; *Marco Antonio Assis*[1]

[1]*Universidade Estadual Paulista, Instituto de Biociências de Rio Claro, Departamento de Botânica, Rio Claro, SP, Brasil*
[2]*Universidade Estadual Paulista, Instituto de Biociências de Rio Claro, Departamento de Botânica,*
*Laboratório de Fenologia, Rio Claro, SP, Brasil*
[3]*Universidade Estadual Paulista, Faculdade de Ciências e Letras, Departamento de Ciências Biológicas, Assis, SP, Brasil*
**Corresponding author: Betânia da Cunha Vargas, e-mail: betaniadacunhavargas@gmail.com*

VARGAS, B. C.; OLIVEIRA, A. P. C.; UDULUTSCH, R. G.; MARCUSSO, G. M.; SABINO, G. P.; MELO, P. H. A.; GRILLO, R. M. M.; KAMIMURA, V. A.; ASSIS, M. A. **Climbing plants of Porto Ferreira State Park, southeastern Brazil**. Biota Neotropica. 18(2): e20170346. http://dx.doi.org/10.1590/1676-0611-BN-2017-0346

**Abstract:** A floristic survey of climbing plants was carried out in an ecotone area of seasonal semideciduous forest (SSF) and forested savanna (CER), in Porto Ferreira State Park (PFSP), Southeastern Brazil. We sampled the reproductive specimens every month during two periods, March 2010 to September 2011 and April and July 2015. The surveys were performed by the walking method, and the sampled individuals were classified by habit, climbing mechanism and dispersal mode. Overall, 109 species, belonging to 67 genera and 29 families, were recorded; 49 species occurred in both, 29 and 31 were exclusive to SSF and CER, respectively. Bignoniaceae and Malpighiaceae were the richest families, with 17 species, followed by Sapindaceae (12 species), Asteraceae and Apocynaceae (8 species each) and Fabaceae (6). The majority of climbers were lianas, twining and anemochoric species, corresponding to 70%, 47% and 66% of all samples, respectively. In this work, we added one new family and 14 species to the Cerrado's list of climbing plants from São Paulo state, and 10 species to the Brazilian seasonal semideciduous forest's list. Therefore, we contributed to the understanding of diversity of climbing plants in vegetation types poorly studied for this plant group, mainly in the Cerradão, wherein we found new records for several species.

**Key words:** *Cerrado; Seasonal Semideciduous Forest; ecotone; climbing plants.*

## Trepadeiras do Parque Estadual de Porto Ferreira, Brasil

**Resumo:** O levantamento florístico das trepadeiras foi realizado em um ecótono de Floresta Estacional Semidecidual (FES) e Cerradão (CER), no Parque Estadual de Porto Ferreira, Sudeste do Brasil. Realizamos coletas mensais dos espécimes reprodutivos ao longo de dois períodos, março 2010 a setembro 2011, abril e julho 2015. Os levantamentos foram realizados por meio do método de caminhada e os indivíduos amostrados foram classificados quanto ao hábito, mecanismo de ascensão e síndrome de dispersão. No geral, foram registradas 109 espécies, pertencentes a 67 gêneros e 29 famílias. Dentre essas, 49 espécies ocorrem nos dois tipos de vegetação, sendo que 29 e 31 espécies são exclusivas de FES e CER, respectivamente. Bignoniaceae e Malpighiaceae foram as famílias mais ricas com 17 espécies, seguidas por Sapindaceae (12 espécies), Asteraceae e Apocynaceae (8 espécies cada) e Fabaceae (6). A maioria das espécies de trepadeiras são lianas, volúveis e anemocóricas, correspondendo a 70%, 47% e 66% de toda a amostra, respectivamente. Neste trabalho, acrescentamos uma nova família e 14 espécies para a lista de trepadeiras do Cerrado paulista e 10 espécies para a lista brasileira de trepadeiras em Floresta Estacional Semidecidual. Portanto, contribuímos para o conhecimento da diversidade de trepadeiras em tipos vegetacionais pouco estudados para este grupo de planta, destacando o Cerradão, no qual encontramos novos registros para um grande número de espécies.

**Palavras-chave:** *Cerrado, Floresta Estacional Semidecidual; ecótono; trepadeiras.*

## Introduction

Climbing plants germinate and remain on the ground, requiring external mechanical sustentation provided by others plants for access to light in the forest canopy (Darwin 1867; Putz & Windsor 1987; Gerwing et al. 2006; Lawdig & Meiners 2010; van der Heijden et al. 2013). These plants occur in many climates and vegetation types, representing up to 25% of plant diversity in some tropical forests (Gentry 1991; Engel et al. 1998; Pérez Salicrup et al. 2001). Besides climbing plants playing an important role in biodiversity maintenance, they establish competition for resources with the host tree (phorophyte), and can change dynamic and natural regeneration in different biomes (Laurence et al. 2001; Schnitzer & Bongers 2002).

Although floristic and structural surveys of climbing plants have increased over the past decades (e.g. Durigon & Waechter 2011; Yorke et al. 2013; Vargas et al. 2014; Ibarra-Marínquez et al. 2015), climbing plants receive less attention in contrast to studies carried out with tree communities (Phillips et al. 2002; Letcher & Chazdon 2009; Carvalho et al. 2013). In Southeastern Brazil, climbing plant studies have been conducted by floristic and phytosociological surveys, mostly in semideciduous seasonal forest (e.g. Morellato & Leitão-Filho 1998; Hora & Soares 2002; Udulutsch et al. 2004; Rezende & Ranga 2005; Tibiriçá et al. 2006; Rezende et al. 2007; Santos et al. 2009; Udulutsch et al. 2010). Nevertheless, studies on vegetation types of the Cerrado are still incipient (Weiser 2002; 2007; Carvalho et al. 2013).

Porto Ferreira State Park has been the subject of numerous floristic surveys (Bertoni & Martins 1987; Bertoni et al. 2001; Colli et al. 2003; Oliveira 2012; Osaco 2012; Sabino 2013; Marcusso et al. 2016); however, studies on climbing plants have not been performed in this area. The main objective of this study was to survey the climbing flora of an ecotone area, between seasonal semideciduous forest and forested savanna (Cerradão), in Porto Ferreira State Park, São Paulo, Southeastern Brazil.

## Materials and methods

### *1. Study site*

Porto Ferreira State Park (PFSP) is located in the municipality of Porto Ferreira, in São Paulo state, Southeastern Brazil (Figure 1). The study area is 611.55 hectares, and has altitudinal variation between 540 and 608 m.a.s.l. (São Paulo 2003). PFSP is located in a geomorphological region of peripheral depression, in the central region of the watershed of Mogi-Guaçu River (São Paulo 2003).

The climate of the region is classified as Aw, according to Köeppen's classification (Bertoni & Martins 1987). The annual mean temperature is 22.3 °C and the annual mean precipitation is 1.497 mm, presenting variation between the rainy (247.9 mm) and dry seasons (26.6 mm) (CEPAGRI 2016).

PFSP has distinct vegetation types according to IBGE (2012), presenting forested savanna (Cerradão) and seasonal semideciduous forest. They are mainly differentiated in the field by their physiognomy (small average height and high density in the Cerradão), and greater average height and lower density in Semideciduous forests), ecological aspects (soil types, deciduousness) and typical and exclusive species of each vegetation type (Durigan et al. 2012). Furthermore, there are ecotonal areas among these vegetation types (Osaco 2012; Sabino 2013), in which a floristic mixture and phytophysiognomic indistinguishability occurs (IBGE 2012).

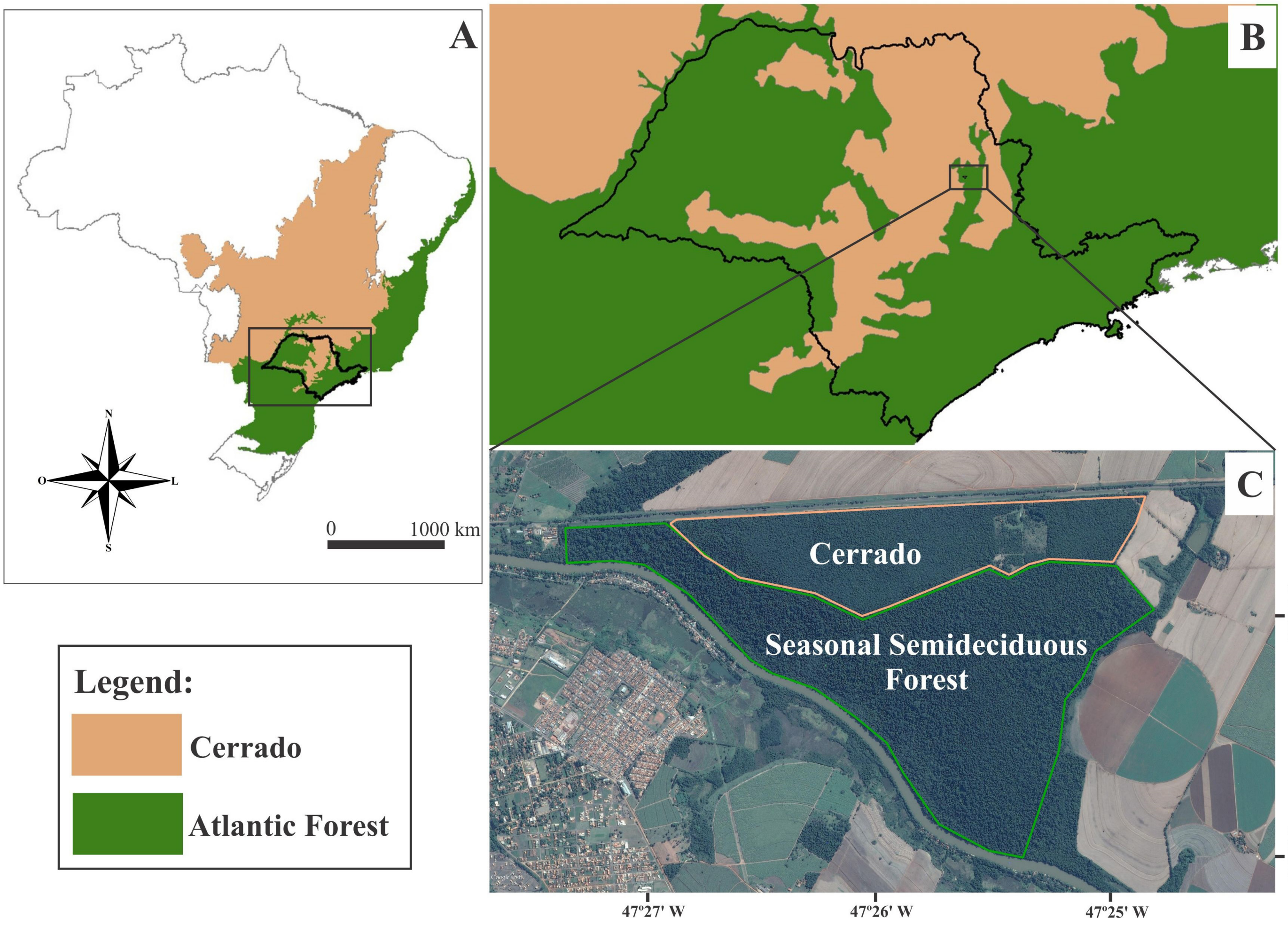

**Figure 1.** A. Brazilian Atlantic Forest and the Cerrado and the location of São Paulo state; B. location of Porto Ferreira State Park; C. Porto Ferreira State Park and the main vegetation types studied.

### *1.2 Data collection*

Climbing plants sampling was performed by the walking method (Filgueiras et al. 1994), every month between March 2010 and September 2011. According to Morellato et al. (1996), transitional and final periods between climatic seasons can be related to the flowering and fruiting peaks of climbing plants, especially of the families most abundant in species. In this way, aiming to improve the sample, we performed additional floristic surveys in April and July 2015. The reproductive specimens collected in the field were processed and herborized following the protocols of Fidalgo & Bononi (1984). The vouchers were incorporated in the Herbarium Rioclarense (HRCB). Taxonomic identity was determined through specialized literature, direct comparison with identified specimens in HRCB's collection and by expert taxonomists (cited in the acknowledgements). Synonyms were verified by BFG (2015), and we adopted APG IV (2016) to classify the botanical families.

Identified plants were classified into two different habits: woody (lianas – plants with a secondary growth stem) or herbaceous (plants without a secondary growth stem) climbing plants, following the protocols of Gentry (1991) and of Villagra & Romaniuc Neto (2014). Climbing mechanisms were categorized as twining, tendril climbing or scandent (Hergaty 1991; Villagra & Romaniuc Neto 2014). Additionally, we classified climbing plants according to their dispersal modes: anemochory, autochory or zoochory (van der Pijl 1982; Barroso et al. 1999; Peres 2016). We compared the species sampled here with the list of climbing plants for seasonal semideciduous forest (Santos et al. 2009), savanna (Weiser & Martins 2014) and Brazilian flora (BFG 2015).

## Results

We recorded 109 species, distributed in 67 genera and 29 families (Table 1). We found 78 and 80 species in Seasonal Semideciduous Forest and Cerradão, respectively, of which 49 (45%) occurred in both, and 29 (26.6%) and 31 (28.4%) were exclusive for the specific vegetation types. The richest families were Bignoniaceae and Malpighiaceae (17 species each), followed by Sapindaceae (12), Asteraceae and Apocynaceae (8 species each) and Fabaceae (6), corresponding to 46.7% of overall richness (Figure 2). In contrast, 11 families (38% of total families) had only one species recorded.

Among the habits, 76 species (70%) were lianas (woody climbers). The three richest families were entirely composed by woody plants (Table 1). The twining climbing mode was the most representative strategy (51 species; 47%), followed by tendril climbing (37 species, 37%) and scandent (18 species, 16%).

Anemochory was the most representative dispersal mechanism among the climbing plants species surveyed (72 species; 66%), followed by zoochory (23 species, 21%) and autochory (14 species, 13%). Among lianas, anemochory was the main dispersal mode (63 species, 83%), followed by zoochory (8 species, 10.5%) and autochory (5 species, 6.5%), while among herbaceous species, zoochory was the most frequent dispersal mode (15 species, 45.4%), followed by autochory and anemochory (9 species each, 27.3%).

In this study, we have registered one new family and 14 species for the Cerrado list, and 10 species for the seasonal semideciduous forest list (Table 1).

**Table 1.** Climbing plants sampled in Porto Ferreira State Park, Porto Ferreira, Southeastern Brazil. CER: forested savanna (Cerradão); SSF: seasonal semideciduous forest. Habit: Herb: herbaceous climbing plants; Wood: woody climbing plants (liana). Climbing mode: scandent; tendril; twining. Dispersion: Ane: anemochory; Aut: autochory; Zoo: zoochory. Voucher: APO: Ana Paula Caldeira Oliveira; HRCB: Herbário de Rio Claro; JAL: Júlio Antonio Lombardi. * First family and/or species record for FES; ● first record of the family and/or species for the Cerrado (Santos et al. 2009; Weiser & Martins 2014; Brazilian Flora Group 2015).

| Family/species | Vegetation type | Habit | Climbing mode | Dispersion | Voucher |
|---|---|---|---|---|---|
| **Acanthaceae** | | | | | |
| *Mendoncia puberula* Mart. | SSF | Herb. | Twining | Zoo. | JAL 7712 |
| **Amaranthaceae** | | | | | |
| *Alternanthera brasiliana* (L.) Kuntze | SSF* | Herb. | Scandent | Ane. | JAL 7710 |
| *Chamissoa acuminata* Mart. | SSF* | Herb. | Scandent | Ane. | HRCB 68052 |
| **Apocynaceae** | | | | | |
| *Condylocarpon isthmicum* (Vell.) A.DC. | CER●, SSF | Wood | Twining | Ane. | JAL 7763 |
| *Forsteronia australis* Müll.Arg. | CER | Wood | Twining | Ane. | HRCB 67992 |
| *Forsteronia pubescens* A.DC. | CER, SSF | Wood | Twining | Ane. | HRCB 67993 |
| *Odontadenia lutea* (Vell.) Markgr. | CER | Wood | Twining | Ane. | HRCB 68001 |
| *Oxypetalum appendiculatum* Mart. | CER | Herb. | Twining | Ane. | HRCB 67994 |
| *Prestonia coalita* (Vell.) Woodson | CER, SSF | Wood | Twining | Ane. | HRCB 67995 |
| *Secondatia densiflora* A.DC. | CER, SSF | Wood | Twining | Ane. | HRCB 67996 |
| *Temnadenia* violacea (Vell.) Miers | CER, SSF | Wood | Twining | Ane. | HRCB 68066 |
| **Aristolochiaceae** | | | | | |
| *Aristolochia labiata* Willd. | CER, SSF | Wood | Twining | Aut. | HRCB 67998 |
| **Asteraceae** | | | | | |
| *Bidens segetum* Mart. ex Colla | CER, SSF | Wood | Scandent | Ane. | HRCB 67999 |
| *Cyrtocymura scorpioides* (Lam.) H.Rob. | SSF | Herb. | Scandent | Ane. | APO 116 |
| *Dasyphyllum brasiliense* (Spreng.) Cabrera | SSF | Wood | Scandent | Ane. | HRCB 68000 |
| *Mikania cordifolia* (L. f.) Willd. | CER | Herb. | Twining | Ane. | APO 7 |
| *Mikania laevigata* Sch.Bip. ex Baker | CER | Wood | Scandent | Ane. | APO 110 |
| *Mikania* sp. 1 | SSF | Wood | Twining | Ane. | APO 117 |
| *Mikania* sp. 2 | SSF | Wood | Twining | Ane. | APO 104 |
| *Mikania triangularis* Baker | SSF | Herb. | Twining | Ane. | APO 103 |

**Table 1.** Continued...

| Family/species | Vegetation type | Habit | Climbing mode | Dispersion | Voucher |
|---|---|---|---|---|---|
| **Bignoniaceae** | | | | | |
| *Adenocalymma bracteatum* (Cham.) DC. | CER, SSF | Wood | Tendril | Ane. | JAL 7730 |
| *Adenocalymma marginatum* (Cham.) DC. | CER•, SSF | Wood | Tendril | Ane. | JAL 7784 |
| *Amphilophium crucigerum* (L.) L.G.Lohmann | CER, SSF | Wood | Tendril | Ane. | HRCB 68002 |
| *Amphilophium elongatum* (Vahl) L.G. Lohmann | CER, SSF | Wood | Tendril | Ane. | HRCB 68003 |
| *Anemopaegma chamberlaynii* (Sims) Bureau & K. Schum. | CER, SSF | Wood | Tendril | Ane. | JAL 7745 |
| *Bignonia campanulata* Cham. | CER•, SSF | Wood | Tendril | Ane. | HRCB 68006 |
| *Cuspidaria convoluta* (Vell.) A.H.Gentry | CER, SSF | Wood | Tendril | Ane. | HRCB 68007 |
| *Cuspidaria pulchra* (Cham.) L.G.Lohmann | CER, SSF | Wood | Tendril | Ane. | JAL 7765 |
| *Dolichandra unguis-cati* (L.) L.G. Lohmann | SSF | Wood | Tendril | Ane. | HRCB 68009 |
| *Fridericia craterophora* (DC.) L.G.Lohmann | CER | Wood | Tendril | Ane. | HRCB 68005 |
| *Fridericia florida* (DC.) L.G.Lohmann | CER | Wood | Tendril | Ane. | HRCB 68004 |
| *Fridericia formosa* (Bureau) L.G. Lohmann | CER, SSF | Wood | Tendril | Ane. | HRCB 68010 |
| *Fridericia speciosa* Mart. | CER, SSF | Wood | Tendril | Ane. | HRCB 68061 |
| *Lundia obliqua* Sond. | CER•, SSF | Wood | Tendril | Ane. | APO 62 |
| *Pyrostegia venusta* (Ker-Gawl.) Miers | CER, SSF | Wood | Tendril | Ane. | HRCB 68060 |
| *Tanaecium selloi* (Spreng.) L.G. Lohmann | CER, SSF | Wood | Tendril | Ane. | APO 40 |
| *Stizophyllum perforatum* (Cham.) Miers | CER, SSF | Wood | Tendril | Ane. | HRCB 68012 |
| **Boraginaceae** | | | | | |
| *Myriopus rubicundus* (Salzm. ex DC.) Luebert | CER• | Wood | Scandent | Zoo. | HRCB 68013 |
| *Varronia urticifolia* (Cham.) J.S.Mill. | CER• | Wood | Scandent | Zoo. | HRCB 68014 |
| **Cactaceae** | | | | | |
| *Pereskia aculeata* Mill. | SSF | Wood | Scandent | Zoo. | JAL 8087 |
| **Cannabaceae** | | | | | |
| *Celtis iguanaea* (Jacq.) Sarg. | SSF | Wood | Scandent | Zoo. | JAL 8532 |
| **Celastraceae** | | | | | |
| *Semialarium paniculatum* (Mart. ex Schult.) N.Hallé | SSF | Wood | Scandent | Ane. | JAL 8534 |
| **Commelinaceae** | | | | | |
| *Dichorisandra hexandra* (Aubl.) C.B.Clarke | SSF | Herb. | Scandent | Zoo. | JAL 7671 |
| **Convolvulaceae** | | | | | |
| *Ipomoea chondrosepala* Hallier f. | CER, SSF* | Herb. | Twining | Aut. | JAL 7743 |
| *Ipomoea saopaulista* O'Donell | CER, SSF | Herb. | Twining | Aut. | JAL 7744 |
| *Merremia macrocalyx* (Ruiz & Pav.) O'Donell | CER, SSF | Herb. | Twining | Aut. | HRCB 68015 |
| *Merremia umbellata* (L.) Hallier f. | CER, SSF* | Herb. | Twining | Aut. | APO 60 |
| **Cucurbitaceae** | | | | | |
| *Gurania* sp. | CER•, SSF* | Herb. | Tendril | Zoo. | APO 55 |
| *Psiguria ternata* (M.Roem.) C.Jeffrey | CER | Herb. | Tendril | Zoo. | HRCB 68016 |
| **Cyperaceae** | | | | | |
| *Scleria latifolia* Sw. | SSF | Herb. | Scandent/thorn | Zoo. | HRCB 68059 |
| **Dilleniaceae** | | | | | |
| *Davilla elliptica* A.St.-Hil. | SSF* | Wood | Twining | Zoo. | HRCB 68017 |
| *Davilla rugosa* Poir. | CER, SSF | Wood | Twining | Zoo. | APO 46 |
| *Doliocarpus dentatus* (Aubl.) Standl. | CER, SSF | Wood | Twining | Zoo. | APO 21 |
| **Dioscoreaceae** | | | | | |
| *Dioscorea dodecaneura* Vell. | CER, SSF | Herb. | Twining | Ane. | JAL 7736 |
| *Dioscorea olfersiana* Klotzsch ex Griseb. | CER, SSF | Herb. | Twining | Ane. | JAL 7741 |
| **Euphorbiaceae** | | | | | |
| *Dalechampia pentaphylla* Lam. | CER•, SSF | Herb. | Twining | Aut. | JAL 7777 |
| *Dalechampia stipulacea* Müll.Arg. | SSF | Herb. | Twining | Aut. | JAL 7709 |
| *Dalechampia triphylla* Lam. | SSF | Herb. | Twining | Aut. | HRCB 68019 |
| **Fabaceae** | | | | | |
| *Canavalia picta* Mart. ex Benth. | CER | Wood | Twining | Aut. | APO 92 |
| *Centrosema sagittatum* (Humb. & Bonpl. ex Willd.) Brandegee | SSF | Herb. | Twining | Aut. | HRCB 68020 |
| *Dioclea violacea* Mart. ex Benth. | SSF | Wood | Twining | Aut. | HRCB 68021 |
| *Rhynchosia minima* (L.) DC. | CER• SSF | Herb. | Twining | Aut. | JAL 7752 |
| *Rhynchosia phaseoloides* (Sw.) DC. | SSF | Wood | Twining | Aut. | HRCB 68022 |
| *Senegalia polyphylla* (DC.) Britton & Rose | CER | Wood | Scandent/thorn | Aut. | JAL 8531 |

**Table 1.** Continued...

| Family/species | Vegetation type | Habit | Climbing mode | Dispersion | Voucher |
|---|---|---|---|---|---|
| **Lygodiaceae** | | | | | |
| *Lygodium volubile* Sw. | CER, SSF | Herb. | Twining | Ane. | HRCB 68050 |
| **Malpighiaceae** | | | | | |
| *Banisteriopsis adenopoda* (A.Juss.) B.Gates | CER• | Wood | Twining | Ane. | APO 91 |
| *Banisteriopsis argyrophylla* (A.Juss.) B.Gates | CER, SSF | Wood | Twining | Ane. | JAL 7755 |
| *Banisteriopsis latifolia* (A.Juss.) B.Gates | CER | Wood | Twining | Ane. | HRCB 68025 |
| *Banisteriopsis malifolia* (Nees & Mart.) B.Gates var. malifolia | CER, SSF* | Wood | Twining | Ane. | HRCB 68026 |
| *Banisteriopsis* cf. *muricata* (Cav.) Cuatrec. | CER, SSF | Wood | Twining | Ane. | HRCB 68031 |
| *Banisteriopsis oxyclada* (A.Juss.) B.Gates | CER, SSF | Wood | Twining | Ane. | HRCB 68027 |
| *Banisteriopsis stellaris* (Griseb.) B.Gates | CER | Wood | Twining | Ane. | HRCB 68028 |
| *Banisteriopsis variabilis* B.Gates | CER | Wood | Scandent | Ane. | HRCB 68029 |
| *Diplopterys pubipetala* (A.Juss.) W.R.Anderson & C.C.Davis | CER | Wood | Twining | Ane. | APO 114 |
| *Heteropterys umbellata* A.Juss. | SSF* | Wood | Twining | Ane. | JAL 8089 |
| *Heteropterys* sp. | CER | Wood | Twining | Ane. | HRCB 68030 |
| *Mascagnia cordifolia* (A.Juss.) Griseb. | CER | Wood | Twining | Ane. | APO 115 |
| *Mascagnia sepium* (A.Juss.) Griseb. | CER, SSF | Wood | Twining | Ane. | JAL 7732 |
| *Niedenzuella lucida* (A.Juss.) W.R.Anderson | SSF* | Wood | Twining | Ane. | HRCB 68034 |
| *Niedenzuella multiglandulosa* (A.Juss.) W.R.Anderson | CER, SSF | Wood | Twining | Ane. | HRCB 68032 |
| *Stigmaphyllon lalandianum* A.Juss. | SSF | Wood | Twining | Ane. | HRCB 68033 |
| *Tetrapterys* sp. | SSF | Wood | Twining | Ane. | HRCB 68049 |
| **Menispermaceae** | | | | | |
| *Cissampelos pareira* L. | CER | Wood | Twining | Zoo. | JAL 8536 |
| **Passifloraceae** | | | | | |
| *Passiflora alata* Curtis | SSF* | Herb. | Tendril | Zoo. | JAL 7767 |
| *Passiflora miersii* Mast. | CER | Herb. | Tendril | Zoo. | APO 95 |
| *Passiflora suberosa* L. | CER | Herb. | Tendril | Zoo. | APO 2 |
| **Polygalaceae** | | | | | |
| *Bredemeyera floribunda* Willd. | CER, SSF | Wood | Scandent | Ane. | HRCB 68035 |
| *Securidaca tomentosa* A.St.Hil. & Moq. | CER• | Wood | Scandent | Ane. | HRCB 68065 |
| **Ranunculaceae•** | | | | | |
| *Clematis dioica* L. | CER• | Wood | Twining | Ane. | JAL 8530 |
| **Rhamnaceae** | | | | | |
| *Gouania virgata* Reissek | CER, SSF | Wood | Tendril | Ane. | HRCB 68037 |
| **Rubiaceae** | | | | | |
| *Galianthe laxa* (Cham. & Schltdl.) E.L.Cabral | CER, SSF | Herb. | Scandent | Zoo. | JAL 7738 |
| *Manettia cordifolia* Mart. | CER, SSF | Herb. | Twining | Zoo. | HRCB 68038 |
| **Sapindaceae** | | | | | |
| *Cardiospermum grandiflorum* Sw. | SSF | Wood | Tendril | Ane. | HRCB 68039 |
| *Paullinia rhomboidea* Radlk. | CER, SSF | Wood | Tendril | Ane. | APO 102 |
| *Serjania* cf. *acoma* Radlk. | CER | Wood | Tendril | Ane. | HRCB 68040 |
| *Serjania communis* Cambess. | CER• | Wood | Tendril | Ane. | APO 3 |
| *Serjania fuscifolia* Radlk. | CER•, SSF | Wood | Tendril | Ane. | APO 44 |
| *Serjania laruotteana* Cambess. | CER | Wood | Tendril | Ane. | HRCB 68041 |
| *Serjania lethalis* A.St.-Hil. | CER | Wood | Tendril | Ane. | APO 107 |
| *Serjania meridionalis* Cambess. | SSF | Wood | Tendril | Ane. | JAL 7715 |
| *Serjania paradoxa* Radlk. | CER | Wood | Tendril | Ane. | APO 120 |
| *Serjania pinnatifolia* Radlk. | CER, SSF | Wood | Tendril | Ane. | HRCB 68055 |
| *Serjania reticulata* Cambess. | CER, SSF | Wood | Tendril | Ane. | APO 48 |
| *Urvillea laevis* Radlk. | CER, SSF | Wood | Tendril | Ane. | APO 63 |
| **Smilaceae** | | | | | |
| *Smilax elastica* Griseb. | CER | Herb. | Tendril | Zoo. | HRCB 68043 |
| *Smilax fluminensis* Steud. | CER | Herb. | Tendril | Zoo. | HRCB 68058 |
| **Vitaceae** | | | | | |
| *Cissus erosa* Rich. | CER, SSF | Herb. | Tendril | Zoo. | HRCB 68045 |
| *Cissus tinctoria* Mart. | SSF | Herb. | Tendril | Zoo. | HRCB 68046 |
| *Cissus verticillata* (L.) Nicolson & C.E.Jarvis | SSF | Herb. | Tendril | Zoo. | HRCB 68047 |

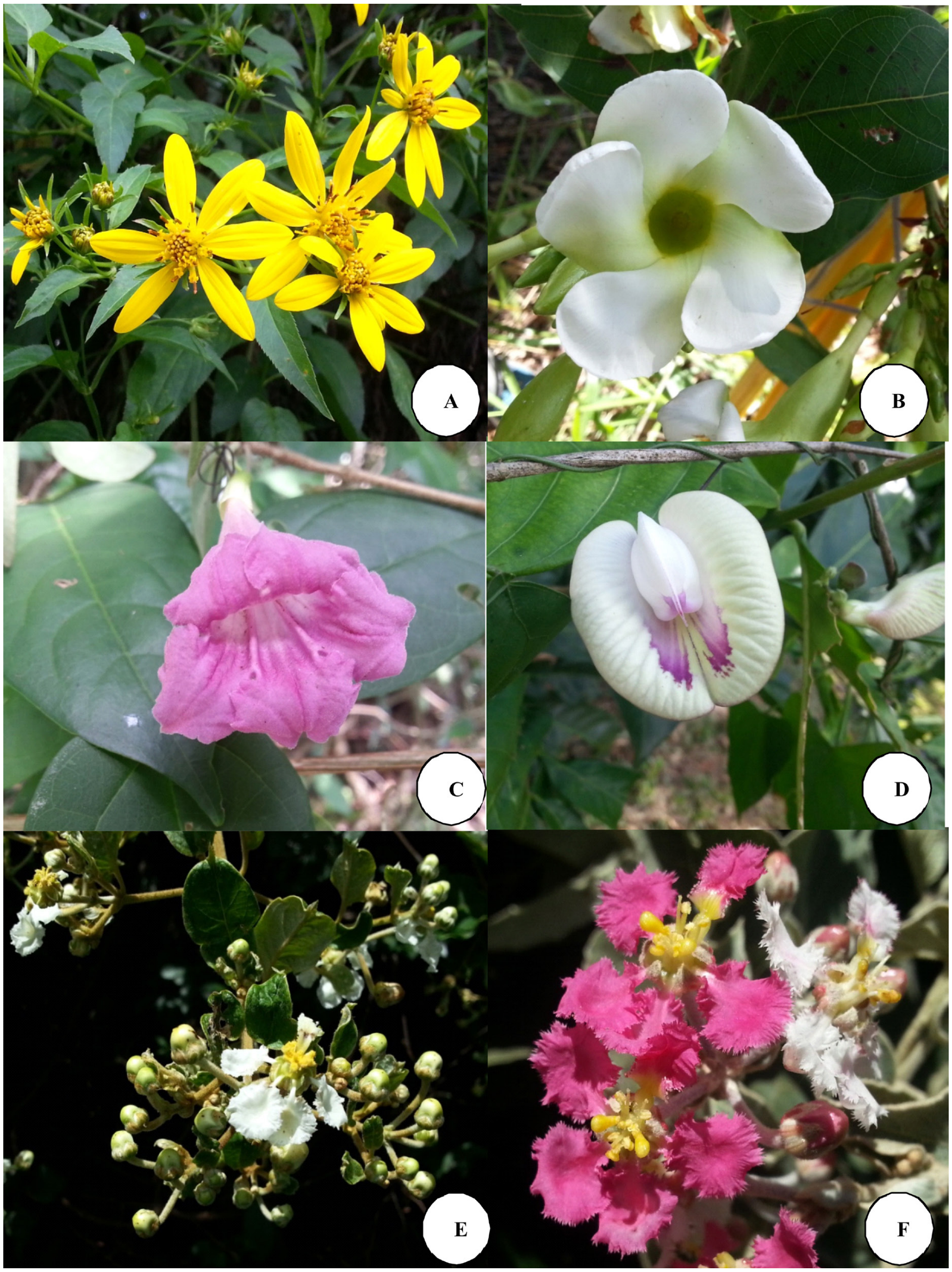

**Figure 2.** A. *Bidens segetum*; B. *Odontadenia lutea*; C. *Fridericia craterophora*; D. *Centrosema sagittatum*; E. *Banisteriopsis argyrophylla*; F. *Banisteriopsis adenopoda*. By: Marcusso, G., Sabino, G. and Udulutsch, R.G.

## Discussion

The present study showed elevated richness of climbing plants in Cerradão, compared to other studies carried out in Cerrado *sensu stricto* in São Paulo state, where 41 (Mantovani & Martins 1993) and 15 species (Weiser & Godoy 2001) were recorded. On the other hand, in a Cerradão in Bauru, 52 species of climbers were recorded (Weiser 2007), corroborating our results that the Cerradão is richer in climbing plants than Cerrado *sensu stricto*. Although these studies had different sample time spans, the richness recorded in the present study can be considered high by the fact that the studies carried out in Cerrado *sensu stricto* had very similar sample times to ours (16 to 22 months, Mantovani & Martins 1993; Weiser & Godoy 2001, respectively), while the study in Cerradão considered a much larger sample time (51 months, Weiser 2007). However, the last considered a smaller area than the present study (1 versus 169 hectares, respectively). In this way, it is likely that other Cerradão areas are as rich in this vegetation type as that recorded in the present study.

Otherwise, the number of species found in Seasonal Semideciduous Forest can be considered low compared to the average for this vegetation type (e.g. Morellato & Leitão-Filho 1998; Udulutsch et al. 2004; Rezende & Ranga 2005; Tibiriçá et al. 2006; Carneiro & Vieira 2012). However, we did not sample months with the same frequency, as we collected one more time during transitional months and those at the end of the climatic season (rainy and dry season), and these reproductive periods are considered the peak of flowering and fruiting for climbing plants (Morellato & Leitão-Filho 1996). This was also the case in the study of Udulutsch et al. (2010), so much that these surveys showed a similar number of species (74 species) to the present study (78 species). Furthermore, floristic surveys are usually carried out for different time spans and in areas with different sizes, which compromises comparisons of diversity and the relationships between flora of different sites (e.g. Forzza et al. 2014). In this way, we suggest that floristic studies are made considering equal sample frequency during the year, considering the reproductive stages of the plants. Therefore, it may be that the Seasonal Semideciduous Forest of PFSP is so rich as those in other studies which have reported high values for richness (e.g. Morellato & Leitão- Filho 1998; Udulutsch et al. 2004; Tibiriçá et al. 2006).

In general, the reasonably substantial number of climbing plant species recorded in this study is perhaps associated with the ecotonal condition of this area, where the floristic elements of both vegetation types (seasonal semideciduous forest and Cerradão) contribute to the richness. Although for climbing plants this aspect is poorly known, this has already been documented for vascular epiphytes (e.g. Kersten 2010; Bonnet et al. 2011; Marcusso & Monteiro 2016) and trees (e.g. Pinheiro & Monteiro 2008). This elevated richness and abundance of species in an ecotone is related to the meeting of adjacent areas, and thus encompasses the diversity of the community around it (Odum 1969; Kent et al. 1997; Kark 2012). This transitional area shares environmental conditions but also establishes the particular conditions of an ecotone, allowing coexistence of species from the surrounding vegetation, as well as rare and endemic species (Kark & Rensburg 2006; Kark 2012).

The majority of climbing plants species registered belong to few families, corroborating the hypothesis described by Gentry (1991) in which the majority of species (70% in the present study) are concentrated in only 13 families. Among the richest families, Bignoniaceae, Malpighiaceae and Sapindaceae stand out (e.g. Lombardi et al. 1999; Nabe-Nielsen 2001; Hora & Soares 2002; Tibiriçá et al. 2006). These families have a widespread geographical distribution, occurring among different vegetation types (Lohmann 2015; Mamede et al. 2015; Somner et al. 2015), and certain genera are predominantly (e.g. Bignoniaceae: *Fridericia*; Sapindaceae: *Serjania*; Malpighiaceae: *Banisteriopsis*) or exclusively (e.g. Bignoniaceae: *Lundia*, *Pyrostegia*, *Tanaecium*, *Stizophyllum*; Sapindaceae: *Urvillea*; Malpighiaceae: *Mascagnia*, *Niedenzuella*) composed by climbing species (Gentry 1991; BFG 2015).

We found a prevalence of lianas in the study area. Although an equal proportion of lianas and herbaceous climbing plants is expected in tropical forests (Gentry & Dodson 1987; Gentry 1991; Durigon et al. 2009), studies of climbing plants realized in semideciduous forest found 64% (Udulutsch et al. 2004) and 60% (Vargas et al. 2013) lianas, contradicting this estimation. On the other hand, herbaceous vines can represent almost 85% of the richness in subtropical and temperate forests (Durigon et al. 2014).

The pattern of climbing mechanism registered for tropical forests was corroborated in this study, wherein twining was the predominant mechanism, followed by tendril climbing (e.g. Gentry 1991; Araujo & Alves 2010; Vivek & Parthasarathy 2015). Despite some species having specialized structures to assist in colonization of the phorophyte, such as tendrils modified with adhesive pads and hooks, improving their colonization success (Gentry 1979; Lohmann 2006), this climbing mechanism has not been the most encountered in tropical forests (Gentry 1991). In this study, we recorded *Scleria latifolia* and *Senegalia polyphylla* with a twining habit. In general, these species are not included in climbing plant floristic surveys, but in PFSP these species were observed with this growth mode; perhaps they use scabrous and thorn features to ascend in the phorophyte.

In general, anemochory (72 species) was the most commonly found dispersal mode among climbing plants (lianas + herbaceous vines) (Durigon & Waechter 2011; Gallagher et al. 2011; Vargas et al. 2013), which is associated with environments with pronounced climatic seasonality (Dewalt et al. 2010; Schnitzer & Bongers 2011). According to Morellato & Leitão-Filho (1996), the pattern of dispersion can be considered complementary in forest phenology, wherein in periods with a smaller amount of annual precipitation, the tree community totally or partially loses its leaves (Montovani & Martins 1998), and climbing plants can use wind currents to disperse their seeds (Morellato & Leitão-Filho 1998). Although, when considering only herbaceous vines, this relation can be altered by the predominance of zoochory, thus their fruits mature during the rainy season (Morellato & Leitão-Filho 1996).

Despite floristic inventories of climbing plants increasing, they are concentrated in semideciduous forest (e.g. Hora & Soares 2002; Tibiriçá et al. 2006; Rezende et al. 2007; Udulutsch et al. 2010; Vargas et al. 2013), to the detriment of those realized in the Cerrado (Weiser & Godoy 2001; Weiser 2007; Oliveira et al. 2014). However, this study included new registers of species for both vegetation types. This is because climbing plants comprise a very diverse group, so much so that they are considered key to innovation throughout evolution, increasing angiosperm diversity (Gianoli 2015; Gianoli et al. 2016). For this reason, we highlight the importance of including climbing plants in community research (Durigon et al. 2014; Schnitzer et al. 2015), and realizing floristic inventories that include or integrate climbing plants.

The present study reveals the considerable richness of this sinusia in Porto Ferreira State Park, with a similar number of species between the vegetation types. The mainly contribution is relation to diversity, recorded species, like *Scleria latifolia* and *Senegalia polyphylla*, as climbing plants. Both to vegetation types showed new records to the climbing plants checklist. Thus, we encourage the initiatives of floristic surveys with climbing plants, with similar frequency of sample, in these vegetation types, mainly in the Cerradão, in view of the importance of its floristic richness and to filling out the remaining gaps.

## Acknowledgements

We would like to thank the following experts, followed by their respective linked herbaria, for help with some identifications: Maria Cândida Henrique Mamede (SP), Rosângela Simão Bianchini (SP), Lidyanne Y. Saleme Aona (UFRB), Luiza Sumiko Kinoshita (UEC), Rubens Teixeira Queiroz (UEC), Ana Maria Goulart de Azevedo Tozzi (UEC), Ana Paula Fortuna-Perez (BOTU), Marcelo Monge Egea (UEC), João Semir (UEC) and Rafael Felipe de Almeida (HUEFS); the employees of PFSP; Capes and CNPq for the fellowship grant;; and São Paulo Research Foundation (FAPESP) for fellowship grant 2015/13112-7 to P.H.A. Melo. We like to thank to J.A. Lombardi contributions with data collection.

## Author Contributions

Marco Antonio Assis and Renata Giassi Udulutsch: Contribution in the concept and design of the study

Betânia da Cunha Vargas, Renata Giassi Udulutsch, Gabriel Mendes Marcusso, Gabriel Pavan Sabino, Pablo Hendrigo Alves de Melo, Roberta Marotti Martelletti Grillo, Vitor de Andrade Kamimura, Marco Antonio Assis: Contribution to data collection

Betânia da Cunha Vargas, Gabriel Mendes Marcusso, Gabriel Pavan Sabino, Pablo Hendrigo Alves de Melo, Vitor de Andrade Kamimura: Contribution to data analysis and interpretion

Betânia da Cunha Vargas, Gabriel Mendes Marcusso, Gabriel Pavan Sabino, Roberta Marotti Martelletti Grillo, Vitor de Andrade Kamimura: Contribution to manuscript preparation

Betânia da Cunha Vargas, Renata Giassi Udulutsch, Gabriel Mendes Marcusso, Gabriel Pavan Sabino, Vitor de Andrade Kamimura, Marco Antônio Assis: Contribution to critical revision, adding intellectual content

## Conflicts of interest

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

## References

ARAUJO, D. & ALVES, M. 2010. Climbing plants of a fragmented area of lowland Atlantic Forest, Igarassu, Pernambuco (Northeastern Brazil). Phytotaxa 8: 1-24.

APG. 2016. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. Botanical Journal of the Linnean Society 181 (1): 1-20.

BARROS, A.A.M.; RIBAS, L.A. & ARAUJO, D.S.D. 2009. Trepadeiras do Parque Estadual da Serra da Tiririca, Rio de Janeiro, Brasil. Rodriguesia 60 (3): 681-694.

BARROSO, G.M.; MORIM, M.P.; PEIXOTO, A.L. & ICHASO, C.L.F. 1999. Frutos e sementes - morfologia aplicada à sistemática de dicotiledôneas. Viçosa: Editora UFV. 444 pp.

BERTONI, J.E.A. & MARTINS, F.R. 1987. Composição florística de uma floresta ripária na Reserva Estadual de Porto Ferreira, SP. Acta Botanica Brasilica 1 (1): 17-26.

BERTONI, J.E.A.; TOLEDO FILHO, D.V.; LEITÃO FILHO, H.F.; FRANCO, G.A.D.C. & AGUIAR, O.T. 2001. Flora arbórea e arbustiva do cerrado do Parque Estadual de Porto Ferreira (SP). Revista do Instituto Florestal 13 (2): 169-188.

BFG. 2015. Growing knowledge: an overview of Seed Plant diversity in Brazil. Rodriguésia 66 (4): 1085-1113.

BONNET, A.; CURCIO, G.R.; LAVORANTI, O.J. & GALVÃO, F. 2011. Flora epifítica vascular em três unidades vegetacionais do Rio Tibagi, Paraná, Brasil. Rodriguésia 62: 491-498.

CARNEIRO, J.S. & VIEIRA, A.O.S. 2012. Trepadeiras: florística da Estação Ecológica do Caiuá e chave de identificação vegetativa para espécies do Norte do Estado do Paraná. Acta Scientiarum Biological Sciences 34 (2): 217-223.

CARVALHO, P.G.; MELIS J.V.; MORELLATO, L.P. & GROMBONE- GUARATINI, M.T. 2013. Critérios para a amostragem de lianas: comparação e estimativa da abundância e biomassa de lianas no cerrado. Revista Árvore 37 (6): 1037-1043.

CEPAGRI. Clima dos municípios paulistas. Disponível em: <http://www.cpa.unicamp.br/outras-informacoes/clima_muni_457.html>. Acesso em: 31 de janeiro de 2016.

COLLI, A.M.T.; SOUZA, S.A. & SILVA, R.T. 2003. Pteridófitas do Parque Estadual de Porto Ferreira (SP), Brasil. Revista do Instituto Florestal 15 (1): 29-35.

DARWIN, C. 1867. On the moviments and habits of climbing plants. Journal of the Linnean Society, ser. Botany, 9: 1-118.

DEWALT, S.J.; SCHINITZER, S.A.; CHAVE, J.; BONGER, F.; BURNHAM, R.J.; CAI, Z.; CHUYONG, G.; CLARCK, D.B.; EWAANGO, C.E.N.; GERWING, J.J.; GORTAIRE, E.; HART, T.; IBARRA-MANRÍQUES, G.; ICKES, K.; KENFACK, D.; MACÍA, M.J.; MAKANA, J.; MARTÍNEZ-RAMOS, M.; MASCARO, J.; MOSES, S.; MULLER-LANDAU, H.C.; PARREN, M.P.E.; PARTHASARATHY, N.; PÉREZ-SALICRUP, D.R.; PUTZ, F.E.; ROMERO-SALTOS, H. & THOMAS, D. 2010. Annual rainfall and seasonality predict pan-tropical patterns of liana density and basal area. Biotropica 42 (3): 309-317.

DURIGAN, G.; RAMOS, V.S.; IVANAUSKAS, N. M.; FRANCO, G.A.D.C. 2012. Espécies indicadoras de fitofisionomias na transição Cerrado-Mata Atlântica no Estado de São Paulo. São Paulo: Secretaria do Meio Ambiente, 145p.

DURIGON, J.; CANTO-DOROW, T.S. & EISINGER, S.M. 2009. Composição florística de trepadeiras ocorrentes em bordas de fragmentos de floresta estacional, Santa Maria, Rio Grande do Sul, Brasil. Rodriguesia 60 (2): 415-422.

DURIGON, J. & WAECHTER, J.L. 2011. Floristic composition and biogeographic relations of a subtropical assemblage of climbing plants. Biodiversity Conservation 20 (5): 1027-1044.

DURIGON, J., MIOTTO, S.T.S. & GIANOLI, E. 2014. Distribution and traits of climbing plants in subtropical and temperate South America. Journal of Vegetation Science 25: 1484-1492.

ENGEL, V.L.; FONSECA, R.C.B. & OLIVEIRA, R.E. 1998. Ecologia de lianas e o manejo de fragmentos florestais. Série Técnica IPEF 12 (32): 43-64.

FIDALGO, O. & BONONI, V.L.R. 1984. Técnicas de coleta, preservação e herborização de material botânico. Instituto de Botânica, São Paulo. 62 p.

FILGUEIRAS, T.S.; NOGUEIRA, P.E.; BROCHADO, A.L. & GUALALL, G.F. 1994. Caminhamento: um método expedito para levantamentos florísticos qualitativos. Cadernos de Geociências 12: 39- 347.

FORZZA, R.C.; PIFANO, D.S.; OLIVEIRA-FILHO, A.R.; MEIRELES, L.D.; FARIA, P.L.; SALIMENA, F.R.; MYNSSEN, C.M. & PRADO, J. 2014. Flora vascular da Reserva Biológica da Represa do Grama, Minas Gerais, e sua relação florística com outras florestas do sudeste brasileiro. Rodriguésia 65 (2): 275-292.

GALLAGHER, R. V.; LEISHMAM, M. R. & MOLES, A. T. 2011. Traits and ecological strategies of Australian tropical and temperate climbing plants. Jounal of Biogegraphy 38 (5): 828-839.

GENTRY, A. H. 1979. Additional generic mergers in Bignoniaceae. Annals of the Missouri Botanical Garden 66: 778–787.

GENTRY, A.H. & DODSON, C. 1987. Contribution of Nontrees to Species Richness of a Tropical Rain Forest. Biotropica 19 (2): 149-156.

GENTRY, A.H. 1991. The distribution and evolution of climbing plants, pp. 3-49, in: Putz, F.E. and Mooney, H.A. (ed.). The biology of vines. Cambridge, Cambridge University Press.

GERWING, J.J.; SCHNITZER, S.A.; BURNHAM, R.J.; BONGERS, F.; CHAVE, J.; DEWALT, S.; EWANGO, C.E.N.; FOSTER, R.; KENFACK, D.; MARTÍNEZ-RAMOS, M.; PARREN, M.; PARTHASARATHY, N.; PÉREZ-SALICRUP, D.; PUTZ, F.E. & THOMAS, D.W. 2006. A Standard Protocol for Liana Censuses. Biotropica 38 (2): 256–261.

GIANOLI, E. Evolutionary implications of the climbing habit in plants. 2015. In: Schnitzer, S.A.; Bongers, F.; Burnham, R.J. & Putz, F.E. Ecology of lianas, Wiley Blackwell, Oxford. P.p. 239-250.

GIANOLI, E.; TORRES-DIAZ, C.; RUIZ, E., SALGADO-LUARTE, C.; MOLINA-MONTENEGRO, M.A.; SALDAÑA, A. & RIOS, R.S. 2016. Woody climbers show greater population genetic differentiation than trees: Insights into the link between ecological traits and diversification. Evolution 70 (12): 2736-2745.

HERGATY, E.E. 1991. Vine-host interactions, pp. 357-375, in: Putz, F.E. and Mooney, H.A. (ed.). The biology of vines. Cambridge, Cambridge University Press.

HORA, R.C. & SOARES, J.J. 2002. Estrutura fitossociológica da comunidade de lianas em uma floresta estacional na Fazenda Cachim, São Carlos, SP. Revista Brasileira de Botânica 25 (3): 323-329.

IBARRA-MANRÍQUEZ, G.; RENDÓN-SANDOVAL, F.J.; CORNEJO-TENORIO, G. & CARRILLO-REYES, P.2013. Lianas of Mexico. Botanical Sciences 9 (3): 365-417.

IBGE. Instituto Brasileiro de Geografia e Estatística. 2012. Manual técnico da vegetação brasileira. Instituto Brasileiro de Geografia e Estatística. Rio de Janeiro. 276 p.

KARK, S. & VAN RENSBURG, B.J. 2006. Ecotones: marginal or central areas of transition? Israel Journal of Ecology and Evolution 52 (1): 29-53.

KARK, S. 2012. Ecotones and Ecological Gradients, pp. 147-160, in: Meyers, R.A (ed.). Encyclopedia of Sustainability Science and Technology. New York: Springer Science + Business Media.

KENT, M.; GILL, W.J.; WEAVER; R.E. & ARMITAGE, R.P. 1997. Landscape and plant community boundaries in biogeography. Progress in Physical Geopgraphy 21 (3): 315-353.

KERSTEN, R.A. 2010. Epífitas vasculares - histórico, participação taxonômica e aspectos relevantes, com ênfase na Mata Atlântica. Hoehnea 37: 9-38.

LADWIG, L. & MEINERS, S. 2010. Spatiotemporal dynamics of lianas during 50 years of succession to temperate forest, Ecology 91 (3): 671–680.

LETCHER, S.G. & CHAZDON, R.L. 200. Lianas and self-supporting plants during tropical forest succession. Forest Ecology and Management 257 (10): 2150-2156.

LOHMANN, L. 2006. Untangling the phylogeny of Neotropical lianas (Bignonieae, Bignoniaceae). American Journal of Botany 93 (4): 304-318.

LOHMANN, L.G. 2015. Bignoniaceae in Lista de Espécies da Flora do Brasil. Jardim Botânico do Rio de Janeiro. Disponível em: http://floradobrasil.jbrj.gov.br/jabot/floradobrasil/FB112305. Acesso em: 31 de janeiro de 2017.

LOMBARDI, J.A.; TEMPONI, L.G. & LEITE C.A. 1999. Mortality and diameter growth of lianas in a semideciduos forest fragmente in southeastern Brazil. Acta Botanica Brasilica 13 (2): 159-165.

MAMEDE, M.C.H.; SEBASTIANI, R.; ALMEIDA, R.F.; FRANCENER, A. & AMORIM, A.M.A. 2015. Malpighiaceae in Lista de Espécies da Flora do Brasil. Jardim Botânico do Rio de Janeiro. Disponível em: http://floradobrasil.jbrj.gov.br/jabot/floradobrasil/FB155. Acesso em: 31 de janeiro de 2017.

MANTOVANI, W. & MARTINS, F.R. 1993. Florística do cerrado na Reserva Biológica de Moji Guaçu, estado de São Paulo. Acta Botânica Brasílica 7 (1): 33-60.

MARCUSSO, G.M.; DICKFELDT, E.P.; BERTONI, J.E.A. & MONTEIRO, R. 2016. Epífitas vasculares do Parque Estadual de Porto Ferreira, São Paulo, Brasil. Revista do Instituto Florestal 28 (2): 119-133.

MARCUSSO, G.M. & MONTEIRO, R. 2016. Composição florística das epífitas vasculares em duas fisionomias vegetais no município de Botucatu, estado de São Paulo, Brasil. Rodriguésia, 67 (3): 553-569.

MORELLATO, P.C. & LEITÃO FILHO, H.F. 1996. Reproductive phenology of climbers is Southeastern Brazilian forest. Biotropica 28 (2): 180-191.

MORELLATO, P.C. & LEITÃO FILHO, H.F. 1998. Levantamento florístico da comunidade de trepadeiras de uma floresta semidecídua no Sudeste do Brasil. Boletim do Museu Nacional, Nova Série Botânica 103: 1-15.

NABE-NIELSEN, J. 2001. Diversity and distribution of lianas in a Neotropical rain forest, Yasuní National Park, Ecuador. Journal of Tropical Ecology 17: 1-19.

ODUM, E.P. 1969. Ecologia. Interamericana, México. 412p.

OLIVEIRA, A.P.C. 2012. Flora vascular não-arbórea do Parque Estadual de Porto Ferreira, SP, Brasil. Dissertação de Mestrado. Universidade Estadual Paulista “Júlio Mesquita Filho”, Rio Claro.

OLIVEIRA, E.A.; MARIMON, B.S.; FELDPAUSCH, T.R.; COLLIF, G.R.; MARIMON-JUNIOR, B.H.; LLOYD, J.; LENZA, E.; MARACAHIPES, L.; OLIVEIRA-SANTOS, C. & PHILLIPS, O.L. 2014. Diversity, abundance and distribution of lianas of the Cerrado–Amazonian forest transition, Brazil. Plant Ecology and Diversity 7 (1-2): 231-240.

OSACO, M. 2012. Florística e fitossociologia do estrato arbustivo de área de transição savana-floresta no Parque Estadual de Porto Ferreira. Dissertação de Mestrado. Universidade Estadual Paulista “Júlio de Mesquita Filho”, Rio Claro.

PERES, M.K. 2016. Estratégias de dispersão de sementes no Bioma Cerrado: considerações ecológicas e filogenéticas. Tese de Doutorado, Brasília, Universidade de Brasília.

PÉREZ-SALICRUP, D.R.; SORK, V.L. & PUTZ, F.E. 2001. Lianas and trees in a Lianas Forest of Amazonian Bolivia. Biotropica 33 (1): 34-47.

PHILLIPS, O.L.; VÁSQUEZ, M.R.; ARROYO, L.; BAKER, T.; KILLEEN, T.; LEWIS, S.L.; YANDVINDER, M.; MENDONZA, A.M.; NEIL, D.; VARGAS, P.C.; ALEXIADES, M.; CERÓN, C.; DI FIORE, A.; ERWIN, T.; JARDIM, A.; PALACIOS, W.; SALDIAS, M. & VINCETI, B. 2002. Increasing dominance of large lianas in Amazonian forests. Nature 418: 770–774.

PINHEIRO, M.H.O. & MONTEIRO, R. 2008. Florística de uma Floresta Estacional Semidecidual, localizada em ecótono savânico-florestal, no município de Bauru, SP, Brasil. Acta Botanica Brasilica, 22 (4): 1085-1094.

PUTZ, F.E. & CHAI, P. 1987. Ecological studies of lianas in Lambir National Park, Sarawak. Journal of Ecology 75 (2): 523-531.

REZENDE, A.A. & RANGA, N.T. 2005. Lianas da Estação Ecológica do Noroeste Paulista, São José do Rio Preto/Mirassol, SP, Brasil. Acta Botânica Brasílica 19 (2): 273-279.

REZENDE, A.A.; RANGA, N.T. & PEREIRA, R.A.S. 2007. Lianas de uma floresta estacional semidecidual, município de Paulo de Faria, norte do estado de São Paulo, Brasil. Revista Brasileira de Botânica 30 (3): 451-461.

São Paulo. 2003. Instituto Florestal. Plano de Manejo do Parque Estadual de Porto Ferreira.

SANTOS, K.; KINOSHITA, L.S. & REZENDE, A.A. 2009. Species composition of climbers in seasonal semideciduous forest fragments of Southeastern Brazil. Biota Neotropica 9: 175-188.

SABINO, G.P. 2013. Florística e Fitossociologia de uma comunidade arbórea em contato savana-floresta no Parque Estadual de Porto Ferreira, Porto Ferreira, São Paulo. Trabalho de Conclusão de Curso (Graduação em Ciências Biológicas) -Universidade Estadual Paulista “Júlio Mesquita Filhos”, Rio Claro.

SCHNITZER, S.A. & BONGERS, F. 2002. The ecology of lianas and their role in forest. Trends in Ecology & Evolution 17 (5): 223-230.

SCHNITZER, S.A. & BONGERS, F. 2011. Increasing liana abundance and biomass in tropical forests: emerging patterns and putative mechanisms. Ecology Letters 14 (4): 397-402.

SCHNITZER, S.A.; VAN DER HEIJDEN, G.M.F. & POWERS, J.S. 2016. Addressing the challenges of including lianas in global vegetation models. Proceedings of the National Academy of Sciences of the United States of America 113 (1): 5-6.

SOMNER, G.V.; FERRUCCI, M.S.; ACEVEDO-RODRÍGUEZ, P.; PERDIZ, R.O.; COELHO, R.L.G. & MEDEIROS, H. 2015. Sapindaceae in Lista de Espécies da Flora do Brasil. Jardim Botânico do Rio de Janeiro. Disponível em: http://floradobrasil.jbrj.gov.br/jabot/floradobrasil/FB216. Acesso em: 31 de janeiro de 2017.

TIBIRIÇÁ, Y.J.A.: COELHO, L.F.M. & MOURA, L.C. 2006. Florística de lianas em um fragmento de floresta estacional semidecidual, Parque Estadual de Vassununga, Santa Rita do Passa Quatro, SP, Brasil. Acta Botanica Brasilica 20 (2): 339-346.

UDULUTSCH, R.G.; ASSIS, M.A. & PICCHI, D.G. 2004. Florística de trepadeiras numa floresta estacional semidecídua, Rio Claro–Araras, estado de São Paulo, Brasil. Revista Brasileira de Botânica 27 (1): 125-134.

UDULUTSCH, R.G.; SOUZA, V.C.; RODRIGUES, R.R. & DIAS, P. 2010. Composição florística e chaves de identificação para as lianas da Estação Ecológica dos Caetetus, estado de São Paulo, Brasil. Rodriguésia 61 (4): 715-730.

VAN DER HEIDJEN, G.M.; SCHNITZER, S.A.; POWERS, J.S. & PHILLIPS, O.L. 2013. Liana Impacts on Carbon Cycling, Storage and Sequestration in Tropical Forests. Biotropica 45(6): 682-692.

VAN DER PIJL, L. 1982. Principles of dispersal in higher plants. 3rd ed. Springer Verlag, New York. 139p.

VARGAS, B.C.; ARAÚJO, G.M.; SCHIAVINI, I.; ROSA, P.O. & HATTORI, E.K.O. 2013. Florística de trepadeiras em floresta semidecidual e em Mata ciliar no vale do Rio Araguari, MG. Bioscience Journal 29 (1): 185-197.

VARGAS, B.C. & ARAÚJO, G.M. 2014. Florística de trepadeiras em fragmentos de florestas semideciduais em Uberlândia, Minas Gerais, Brasil. Rodriguésia 65 (1): 49-59.

VILLAGRA, B.L.P. & ROMANIUC NETO, S.R. 2010. Florística de trepadeiras no Parque Estadual das Fontes do Ipiranga, São Paulo, SP, Brasil. Revista Brasileira de Biociências 8 (2): 186-200.

VILLAGRA, B.L.P. & ROMANIUC NETO, S.R. 2014. Nomenclatura das plantas de hábito trepador, pp. 1-12, in: B.L.P., Villagra, M.M.R.F., Melo, S., Romaniuc-Neto, L.M. & Barbosa, L.M. (eds). Diversidade e conservação de trepadeiras: contribuição para a restauração de ecossistemas brasileiros. São Paulo: Instituto de Botânica.

VIVEK, P. & N. PARTHASARATHY. 2015. Liana community and functional trait analysis in tropical dry evergreen forest of India. Journal of Plant Ecology 8 (5): 501-512.

YORKE, S.R.; SCHNITZER, S.A.; MASCARO, J.; LECHTER, S.G. & CARSON, W.P. 2013. Increasing liana abundance and basal area in a tropical forest: the contribution of long-distance clonal colonization. Biotropica 45 (3): 317-324.

WEISER, V. de L. & GODOY, S.A.P. 2001. Florística em um hectare de cerrado sensu stricto na ARIE – Cerrado Pé de Gigante, Santa Rita do Passa Quatro, SP. Acta Botanica Brasilica 15 (2): 201-212.

WEISER, V. de L. 2002. Ecologia e sistemática de lianas em um hectare de cerrado *stricto sensu* da ARIE- Cerrado Pé-de Gigante, Santa Rita do Passa Quatro, SP. Dissertação de Mestrado, Ribeirão Preto, Universidade de São Paulo.

WEISER, V. de L. 2007. Árvores, arbustos e trepadeiras do cerradão do Jardim Botânico Municipal de Bauru, SP. Tese de Doutorado, Campinas, Universidade de Campinas.

WEISER, V. de L. & MARTINS, F.R. 2014. Trepadeiras do cerrado paulista, pp. 58-71, in: B.L.P., Villagra, M.M.R.F., Melo, S., Romaniuc-Neto, L.M. & Barbosa, L.M. (eds). Diversidade e conservação de trepadeiras: contribuição para a restauração de ecossistemas brasileiros. São Paulo: Instituto de Botânica.

*Received: 28/03/2017*
*Revised: 17/07/2017*
*Accepted: 24/01/2018*
*Published online: 12/03/2018*

Biota Neotropica 18(2): e20170451, 2018
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
article

# Lobation and bronchopulmonary segmentation of *Callithrix jacchus* (Linnaeus, 1758)

*Brunna Muniz Rodrigues Falcão*[1], *Ana Karoline Rocha Vieira*[1], *Joyce Galvão de Souza*[1],
*Artur da Nóbrega Carreiro*[1], *Débora Vitória Fernandes de Araújo*[1], *José Rômulo Soares dos Santos*[2],
*Danilo José Ayres de Menezes*[3] *& Gildenor Xavier Medeiros*[1*]

[1]*Universidade Federal de Campina Grande - UAMV, Avenida Universitária, Patos, PB 58708-110, Brasil*
[2]*Universidade Federal da Paraíba, Areia, PB, Brasil*
[3]*Universidade Federal do Rio Grande do Norte, Natal, RN, Brasil*
**Corresponding author: Gildenor Xavier Medeiros, e-mail: gildenorxavier@gmail.com*

FALCÃO, B. M. R., VIEIRA, A. K. R., SOUZA, J. G., CARREIRO, A. N., ARAÚJO, D. V. F., SANTOS, J. R. S., MENEZES, D. J. A., MEDEIROS, G. X. **Lobation and bronchopulmonary segmentation of *Callithrix jacchus* (Linnaeus, 1758).** Biota Neotropica. 18(2): e20170451. http://dx.doi.org/ 10.1590/1676-0611-BN-2017-0451

***Abstract:*** The common marmoset (*Callithrix jacchus*) are small primates belonging to the family *Cebidae*, subfamily *Callitrichinae* and are the most well-known and common in adaptation to captivity. The scarcity of data in the literature on the anatomy of these marmosets and wild animals hinders the application of appropriate anesthetic and surgical procedures and therapeutics. In order to understand the anatomic variations in the lobation and bronchopulmonary segmentation the lungs were dissected from nine adult common marmoset (*Callithrix jacchus*) corpses, five males and four females. In the marmosets, the right lung presented cranial lobe, middle lobe, caudal lobe and accessory lobe while the left lung presented cranial and caudal lobes. The fissures were very pro-eminent in both the lungs. The main right bronchus emitted independent branches, one for each lobe, and it followed in a straight line in the caudal lobe as a continuation of this bronchus and the same was observed in the main left bronchus. The bronchopulmonary segmentation in the right lung ranged from one to five branches in the cranial lobe; the middle lobe had a single branch; the caudal lobe had three to five branches and the accessory lobe had three branches. In the left lung the cranial lobe bronchopulmonary segmentation ranged from one to five branches while in the caudal lobe it was three to four branches.

***Keywords:*** *Anatomy; bronchial tree; common marmoset; primates*

## Lobação e segmentação broncopulmonar de *Callithrix jacchus* (Linnaeus, 1758)

*Resumo:* Os saguis-de-tufos-brancos (*Callithrix jacchus*) são pequenos primatas que pertencem à família *Cebidae*, subfamília *Callitrichinae* e são os mais conhecidos e comuns na adaptação ao cativeiro. A escassez de dados disponíveis na literatura sobre a anatomia desses saguis e de animais silvestres dificulta a aplicação de procedimentos anestésicos, cirúrgicos e terapêuticos apropriados. Visando conhecer as variações anatômicas da lobação e segmentação broncopulmonar foram dissecados os pulmões de nove cadáveres de saguis-de-tufos-brancos (*Callithrix jacchus*) adultos, sendo cinco machos e quatro fêmeas. Nos saguis, o pulmão direito apresentou lobo cranial; lobo médio; lobo caudal e lobo acessório; e o pulmão esquerdo os lobos cranial e caudal. As fissuras são bem proeminentes em ambos os pulmões. O brônquio principal direito emitiu ramos independentes, um para cada lobo, sendo que no lobo caudal seguiu em linha reta como a continuação deste brônquio e o mesmo foi observado no brônquio principal esquerdo. Em relação à segmentação broncopulmonar, o pulmão direito apresentou no lobo cranial variando de um a cinco ramos; lobo médio com um único ramo; o lobo caudal com três a cinco ramos e o acessório com três ramos. No pulmão esquerdo o lobo cranial teve uma variação de um a cinco e no caudal foi de três a quatro ramos.

***Palavras-chave:*** *Anatomia, árvore bronquial, sagui-de-tufos-brancos, primatas.*

## Introduction

The small anthropoid primates known as the common marmoset (*Callithrix jacchus*) (Linnaeus 1758) belong to the family *Cebidae*, subfamília *Callitrichinae* (Groves et al. 2005) and according to Rylands (2012) the marmosets belong to the order *Primates* and the family *Callitrichidae*, and are the most known and common in adaptation to captivity. They are small sized animals with striped fur on the ears, a white spot on the frontal region of the head and general pale gray body coloring. The body is smaller than the tail that serves to ensure the animal´s balance. They normally feed on fruit, flowers, seeds, gum tree exudates, insects and spiders, and can also feed on bird eggs and small vertebrates, such as fledglings (Coimbra-Filho et al. 1980).

According to Groves et al. (2005), the common marmoset is native to the north-east of Brazil, but is also found in the south-east and south of the country. The marmosets that occur in the Atlantic rainforest were all considered as subspecies of *Callithrix jacchus*. However, all these taxa, according to Coimbra-Filho (1984) and Ruiz-Miranda et al. (2000), came to be considered as separate species, with *Callithrix jacchus* referring only to the populations that occur in the Brazilian North East and Caatinga (tropical thorn forest), and that are native to the states of Alagoas, Pernambuco, Sergipe, Paraíba, Rio Grande do Norte, Ceará, Maranhão, Bahia and Tocantins, to the south of the river São Francisco. This species has been introduced to various regions of the country, for example the state of Rio de Janeiro and south-eastern Brazil.

The common marmoset has a non-prehensile tail, longer than its body length, to guarantee balance. They are arboreal, can inhabit various plant physiognomies and are highly adapted to the jumping life. They occur in the Caatinga and the the north-eastern Atlantic rainforest, and have now been dispersed through a vast area as far as the south of the country by anthropic introduction (Stevenson & Rylands 1988, Pissinatti et al. 2010).

According to Machin (2007), wild animals in a captivity situation for research or rearing purposes should have adequate management so that they are maintained without pain, anxiety or suffering, because animals suffer deleterious effects if pain is not treated, that can result in behavioral changes, weight loss, muscle lesions, depression of the respiratory function, increase in blood pressure, self-mutilation and potential to develop states of chronic pain.

Pissinatti et al. (2010) emphasized that although the marmoset is a good model, its use for scientific purposes in Brazil is restricted. However, in other countries the use of this species, especially for molecular and cytogenetic studies, has favored problem solution and modified the primate systematics, always fitting their classification closer to genetics (Tardif et al. 2008).

According to Renctas (2001), wild animal trafficking, which includes flora, fauna and their products and byproducts, is considered the third biggest illegal activity in the world, following armaments and drugs. Nobody knows the exact size of this trade, but is estimated that the annual turnover is $10-$20 billion throughout the world. Rocha (1995) and Lopes (2000) estimated that 5% to 15% of this total occurs in Brazil and 95% of the animals commercialized in the New World are species that occur in Brazil.

Renctas (2001) stated that wild animal trafficking is one of the factors responsible for the introduction of exotic species in Brazil and the world, and in Brazil most of the animals commercialized illegally are from the Northern, North Eastern and Central Western regions. They are transported to the Southern and South-eastern regions on the federal highways.

König & Liebich (2016) described the respiratory apparatus as essential for gas exchange between air and blood. Thus respiration consists of gas transport to the cells. The respiratory apparatus can be divided into respiratory pathways and gas exchange locations, and the respiratory pathways consist of the following organs: external nose, nasal cavity, nasal portion of the pharynges, larynges, trachea, bronchi and lungs. The gas exchange locations are the respiratory bronchioles, aveolar ducts and alveoli that are inside the lungs.

The respiratory apparatus places the animals in direct relation with the environment and together with the circulatory system adapts to carry out gas exchanges quickly, due to increase in the animal body mass, especially the vertebrates. Thus, the respiratory apparatus is one of the most commonly described in publications that report diseases, pathological lesions and/or clinical treatment in nonhuman primates throughout the world (Lowenstine & Osborn 2012). The respiratory apparatus has great physiological importance, and its parameters can change, mainly when the animal develops flight activities because of predatory action (Romer & Pearson 1986); but it is important also in the heat regulation process, endogenous substance metabolism and in protecting the animal against dust, gases and inhaled infectious agents (Cunningham 2014).

The lung anatomy of domestic animals has been well described in all its aspects (Hare 1986, Dyce et al. 2010, König & Liebich 2016). In wild mammals there are detailed descriptions of the lung anatomy of some species such as: the Paraguayan hairy dwarf porcupine (*Sphiggurus villosus*) (Guimarães et al. 2012), coati (*Nasua nasua*) (Oliveira et al. 2012), agouti (*Dasyprocta sp*) (Peno et al. 2005), jaguarundi (*Herpailurus yagouaroundi)* (Santos et al. 2011), fox (*Cerdocyon thous*) (Dantas et al. 2014), Arctic fox (*Alopex lagopus*) (Voyevoda et al. 1992), lion (*Panthera leo*) (Nakakuki 1985) and baboon (*Papio anubis*) (Maina 1987).

The objective of the present study is to know the anatomic variations in the lobation and bronchopulmonary segmentation of the common marmoset (*Callithrix jacchus*), providing a database for new research, improved surgical techniques and as an aid in preventive medicine.

## Material and Methods

The study was carried out in the Veterinary Anatomy Laboratory (LAV), of the Veterinary Medicine Academic Unit at the Rural Health and Technology Center (CSTR), at the Federal University of Campina Grande (UFCG), Campus de Patos, PB, Brazil.

Lungs were used to carry out this study collected from nine common marmoset corpses used in another study authorized by the SISBIO/ICMbio, protocol Nº 44489-1. All the animals were adult, four females and five males, and were donated to the Wild Animals Screening Center (CETAS) and the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA) located in the municipality of Cabedelo, Paraíba, for the CSTR LAV at the UFCG. The project of this study was submitted to the Committee of Ethics in Research on use of Animals (CEUA) do CSTR/UFCG, protocol certificate number Nº CEUA 277/2015.

The lungs were fixed and preserved in 10% formaldehyde solution. After making a detailed description of the external anatomy, each lung was sectioned and the pulmonary parenchyma was removed carefully, using dissection tweezers and a circular cold light magnifying glass. After this, the heart was carefully removed and the trachea and the lungs were preserved. The lungs were washed externally and internally with water inserted through the trachea. Shortly afterwards a needle was placed in the trachea lumen and tied with string in the attachment location to guarantee the firmness of the needle.

The preparation of the vinyl acetate, following methodology proposed by Rodrigues et al. (1999), began by weighing 13 g powdered vinyl acetate and five g oil paint; 100 mL 100% acetone was measured in a test tube. Next the mixture was homogenized in an Erlenmeyer-type recipient with a glass stick, and then carefully sealed and kept in a refrigerator to be used the next day. When the vinyl acetate was ready, it was shaken well and stained with synthetic red varnish and mixed until it presented a certain viscosity. After preparing the solution, it was inserted into the lung via the trachea with a 3 mL syringe until the lung lobe were completely filled; the needle was removed and the opening in the trachea was closed by tying the string. Afterwards, the lungs were kept submerged in water for 24hours to help the solution to solidify.

After this proves process, one lung was separated and placed in a glass recipient where it was submersed in 30% chloridric acid for eight hours. The lung was washed to remove any tissue remains and thus all the bronchial tree was shown. This was preserved in an individual recipient for long term maintenance of the structure, due to the increased protection.

The other eight lungs were dissected using dissection pincers, with 14 cm Castroviejo curved scissors and a stereoscopic magnifying glass that was also used to identify each segment of the bronchial system. The results obtained were documented with a digital photographic camera (NIKON® D5100 16.2 megapixel and NIKON® AF-S DX NIKKOR 18-55 mm f/3.5-5.6 G VR lenses). The nomenclature used in the present research followed the *Nomina Anatomica Veterinaria* (I.C.V.G.A.N & W.A.V.A 2012).

## Results

The lungs of the common marmoset are semi-conical in shape, with an oblique surface and apex, base, lateral surface (costal), medial surface (mediastinum), caudal surface (diaphragmatic), dorsal border, ventral border and basal border that are similar to other mammals. The pulmonary hilum was identified on the mediastinum surface, which penetrates the lung root formed by the main bronchi, blood and lymphatic vessels and nerves.

The pulmonary lobation is also similar to that of mammals, the right lung has cranial lobe, middle lobe, caudal lobe and accessory lobe, while the left lung consists of the cranial and caudal lobes (Table 1). However, there was no division in the cranial lobe.

Regarding the fissures, the cranial interlobar fissure was identified in the right lung, that separated the cranial and middle lobes; the caudal inter-lobar fissures that divided the caudal lobe of the cranial and middle lobes and the parasagittal fissure separating the caudal and accessory lobes. In the left lung a single interlobar fissure was observed that divided the caudal lobe from the cranial lobe. These fissures extended from the dorsal margin to the ventral margin completely dividing the lobe in both the lungs (Figure 1).

There was anatomic variation in the lungs of one of the marmosets studied in which the pulmonary fissures were not completely separated in the right and left lungs. In addition, this animal presented an accessory lobe in the left lung.

In the marmoset, the trachea divides into the main right and left dorsal bronchi at the base of the heart. The main right bronchus emitted three independent lobar branches for the cranial, middle and accessory lobes, respectively. For the caudal lobe, the main bronchus followed in a straight line in the interior of the lung, where it becomes known as the caudal lobar bronchus. Two lobar branches emerged from the main left bronchus, one to the cranial lobe and the other to the caudal lobe. As described for the right caudal lobe, the main left bronchus followed a straight line to form the left lobe bronchus.

The right cranial lobar bronchus emitted three to five segmentary bronchi, the middle lobar bronchus emitted only one segmentary bronchus and the caudal lobar bronchus emitted three to four branches, except in one marmoset that presented five segments. A variation of one to three segments was observed in the accessory lobe bronchus, in which one segment predominated in 55.5% of the cases. The left cranial lobar bronchus of the marmoset presented mostly three to four segments in 66.6% of the cases, but three lungs presented one, four and five segments. The left caudal lobar bronchus of the marmoset emitted three to four branches, with a higher incidence of four segments, totaling 66.6% of the cases (Figure 2).

**Table 1.** Lobation of lungs the domestics and wild animals.

| ESPECIE | LOBATION | | REFERENCE |
|---|---|---|---|
| | RIGHT LUNG | LEFT LUNG | |
| Common marmoset (*Callithrix jacchus*) | Cranial lobe, middle lobe, caudal lobe and accessory lobe | Cranial lobe and caudal lobe | |
| Crab-eating raccoon (*Procyon cancrivorus*) | Cranial lobe, middle lobe, caudal lobe and accessory lobe | Cranial lobe and caudal lobe | Sestari et al., 2011;<br>Santos et al., 2013. |
| Hairy dwarf porcupine (*Sphiggurus villosus*) | Cranial lobe, middle lobe, caudal lobe and accessory lobe | Cranial lobe (cranial part and caudal part) and caudal lobe | Guimarães et al., 2012 |
| Fox (*Cerdocyon thous*) | Cranial lobe, middle lobe, caudal lobe and accessory lobe | Cranial lobe (cranial part and caudal part) and caudal lobe | Dantas et al., 2014 |
| Dogs, cats and suines | Cranial lobe, middle lobe, caudal lobe and accessory lobe | Cranial lobe (cranial part and caudal part) and caudal lobe | Dyce; Sack; Wensing, 2010 |
| Ruminants | Cranial lobe (cranial part and caudal part), middle lobe, caudal lobe and accessory lobe | Cranial lobe (cranial part and caudal part) and caudal lobe | Dyce; Sack; Wensing, 2010 |
| Equines | Cranial lobe, caudal lobe and accessory lobe | Cranial lobe and caudal lobe | Dyce; Sack; Wensing, 2010 |

**Figure 1.** A - Lateral view of the right lung of common marmoset. 1 Cranial lobe, 2 Middle lobe, 3 Caudal lobe, 4 Heart incisura, 5 Dorsal margin, 6 Ventral margin, 7 Basal margin, 8 Cranial interlobar fissure, 9 Caudal interlobar fissure. B – Lateral view of left lung of common marmoset. 1 Cranial lobe, 2 Caudal lobe, 3 Heart incisura, 4 Interlobar fissure. C – Caudal view of lung of marmoset. 1 Dorsal margin, 2 Basal margin, 3 Ventral margin, 4 Left caudal lobe, 5 Right caudal lobe, 6 Accessory lobe, 7 Middle lobe, 8 Heart, 9 Parassagital fissure.

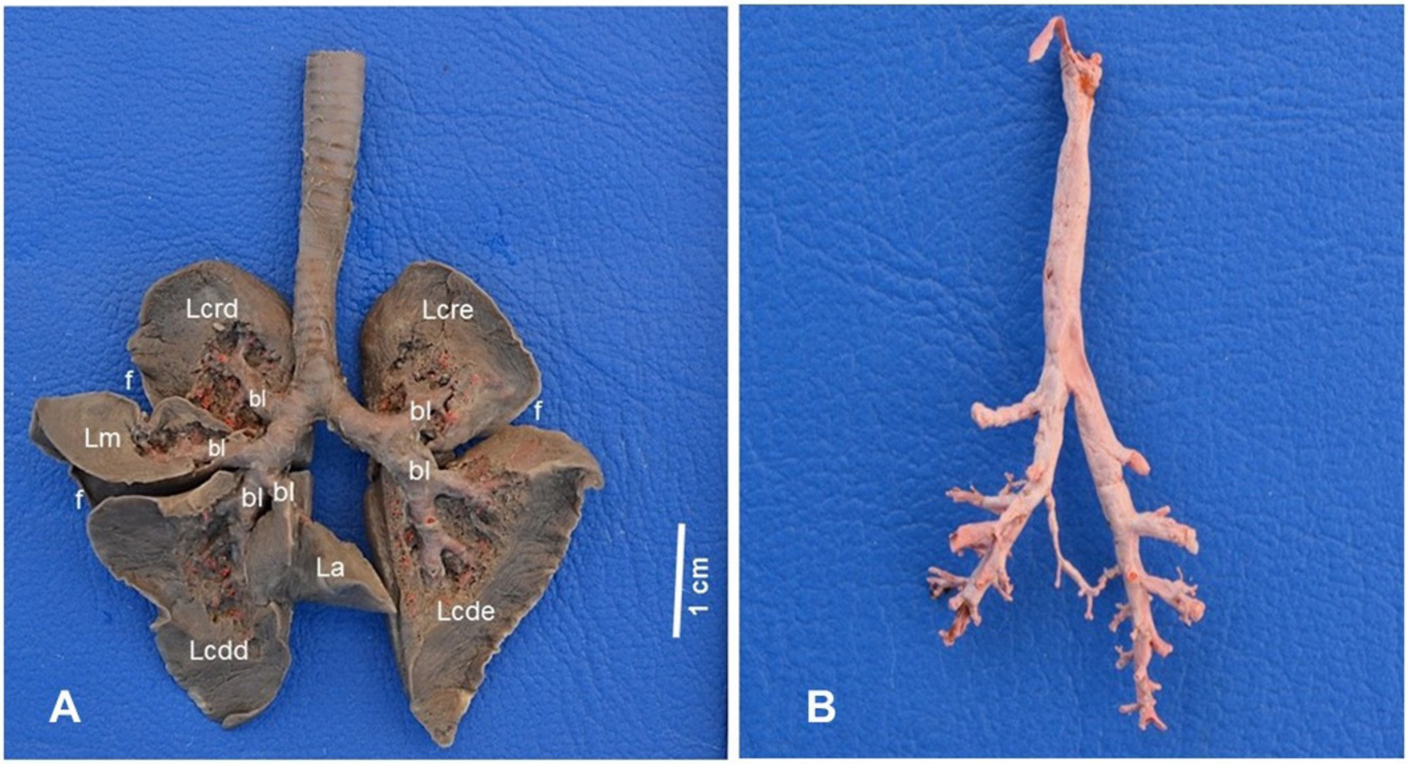

**Figure 2.** Ventral view of lung of common marmoset. A - lobes separate per fissure (f); right cranial lobe (Lcrd), middle lobe (Lm), right caudal lobe (Lcdd) and accessory lobe (La); left cranial lobe (Lcre), left caudal lobe (Lcde) and lobular bronchi (bl). B – The tracheobronchial tree witch lobular and segmental bronchis

## Discussion

The non-existence of division in the cranial lobe of the common marmoset in the present study differed from findings for other domestic animals such as dogs, sheep, cattle and pigs (Dyce et al. 2010) and wild animals such as the fox (*Cerdocyon thous*) (Dantas et al. 2014), lion (*Panthera leo)* (Nakakuki 1985), Artic Fox (*Alopex lagopus*) (Voyevoda et al. 1992) and Paraguayan hairy dwarf porcupine (*Sphiggurus villosus*) (Guimarães et al. 2012). Similalrity was observed in the common marmoset and the crab-eating raccoon (*Procyon cancrivorus,* Cuvier, 1798) (Sestari et al. 2011) and domestic equine species (Dyce et al. 2010) that also do not have the cranial lobe divided into cranial and caudal portions.

The fissures observed in the right and left lobes of the specimens were similar to those described in the lungs of the Paraguayan hairy dwarf porcupine (*Sphiggurus villosus*) (Guimarães et al. 2012), domestic carnivores (Hare 1986), crab-eating raccoon (*Procyon cancrivorus*, Cuvier 1798) (Sestari et al. 2011) and agouti (*Dasyprocta sp*.) (Penno et al. 2005). The lung of the marmoset presented a concavity, the heart incisura, similar to other mammals.

The presence of an accessory lobe in the left lung in the specimen differed from the others was similar to that described by Rehder et al. (2008) in lungs of pacas (*Agouti paca*). The ramification of the right cranial lobar bronchus is similar to that described by Voyevoda et al. (1992) in the dog and the Artic fox (*Alopex lagopus*) and by Liebich (1974) and Nakakuki (1983) in rats *(Rattus norvegicus)*. Dantas et al. (2014) demonstrated that the fox (*Cerdocyon thous*) has eight to 10 segments, the lion (*Panthera leo)* (Nakakuki 1985) has six segments and in the lung of the Paraguayan hairy dwarf porcupine (*Sphiggurus villosus*) there were five segments for the cranial part and three for the caudal part (Guimarães et al. 2012). In all the mammal species studied there was little variation in the quantity of segmentary bronchi emitted from the right cranial lobar bronchus except in the agouti (*Dasyprocta sp*.), that has from two to 12 segmentary bronchi (Penno et al. 2005).

The middle lobar bronchus was similar to that observed by Voyevoda et al. (1992) in the dog and arctic fox (*Alopex lagopus*). But the marmoset differs from the fox (*Cerdocyon thous*) (Dantas et al. 2014) and the lion (*Panthera leo)* (Nakakuki 1985) that have an average of 10 segments, as does the rat *(Rattus norvegicus)* (Liebich 1974, Nakakuki 1983) that presented a variation of eight to 10 segments, the Paraguayan hairy dwarf porcupine (*Sphiggurus villosus*) (Guimarães et al. 2012) has four segments and the agouti (*Dasyprocta sp*.) (Penno et al. 2005) has six to 10 segments.

The presence of three to four branches from the caudal lobar bronchus is similar to the fox (*Cerdocyon thous*) (Dantas et al. 2014) and the dog (*Canis lupus f. familiars)* (Voyevoda et al. 1992). The other mammals were shown to be different from the marmoset studied here, in which the rat lung (*Rattus norvegicus*) (Liebich 1974, Nakakuki 1983) and the lion lung (*Panthera leo)* (Nakakuki 1985) had 13 segments; that of the Paraguayan hairy dwarf porcupine (*Sphiggurus villosus*) (Guimarães et al. 2012), had 11 segmentary bronchi and that of the Arctic foxes (*Alopex lagopus*) (Voyevoda et al. 1992), had seven segments and that of the jaguarandi (*Herpailurus yagouaroundi*- Severtzow, 1848) (Santos et al. 2011) had six segments.

The branching of this accessory lobe bronchus with predominantly one segment is similar to that of the lion (*Panthera leo)*, described by Nakakuki (1985) and the agouti (*Dasyprocta sp*.) (Penno et al. 2005, Santos et al. 2011) and the jaguarandi (Voyevoda et al. 1992). Dantas et al. (2014) described a variation of three to five segments, but most of the cases were had four segments. Liebich (1974) and Nakakuki (1983) found three branches in the rat *(Rattus norvegicus)*, a higher number than that of the marmoset.

When studying the segments of the left cranial lobar bronchus, it was observed that the marmoset differs from other species, regarding the external anatomic part because there is no division between the cranial and caudal parts, but is similar regarding the total number of segments to dogs and arctic foxes (*Alopex lagopus*) (Voyevoda et al. 1992), with four segments and also to the agouti (*Dasyprocta sp*.) (Penno et al. 2005) that emitted five to seven segments. However, the marmoset presented a much smaller number compared to the fox (*Cerdocyon thous*) (Dantas et al. 2014), that has a mean of 10 to 13 branches in the cranial part and seven to 13 branches in the caudal part. The marmoset lung also differed from that of the lion (*Panthera leo)* (Nakakuki 1985), where the cranial and caudal portions of the cranial lobe presented eight and seven segments, respectively Guimarães et al. (2012) described seven segments in the Paraguayan hairy dwarf porcupine (*Sphiggurus villosus*), five for the cranial part and two for the caudal part, showing significant differences in relation to the marmoset in the present study.

Comparison of the left caudal lobar bronchus branching with that of other species shows that the species closest to the marmoset were the jaguarandi (*Herpailurus yagouaroundi*- Severtzow, 1848) (Santos et al. 2011) and the dog (Voyevoda et al. 1992), both with five segments. The lion (*Panthera leo)* (Nakakuki 1985), the Paraguayan hairy dwarf porcupine (*Sphiggurus villosus*) (Guimarães et al. 2012) and the fox (*Cerdocyon thous*) (Dantas et al. 2014) showed a variation of between 10 and 13 segments. In rats *(Rattus norvegicus*), a large quantity of segmentary bronchi was observed (from 14 to 16) branching from the caudal lobar bronchus Nakakuki (1983) and Liebich (1974).

The results obtained showed that the bronchopulmonary lobation and segmentation of the common marmoset (*Callithrix jacchus*) consists of lobes and numbers of segmentary bronchi similar to other mammals, with small variations. The segmentation varied little among the specimens, but this knowledge is relevant for better diagnosis of lung lesions and for surgical and anesthetic procedures.

## Author Contributions

Brunna Muniz Rodrigues Falcão - Contribution to data collection, to data analysis and interpretation and to manuscript preparation;

Ana Karoline Rocha Vieira - Contribution to manuscript preparation;

Joyce Galvão de Souza - Contribution to data analysis and interpretation;

Artur da Nóbrega Carreiro - Contribution to data analysis and interpretation;

Débora Vitória Fernandes de Araújo - Contribution to data collection;

José Rômulo Soares dos Santos - Substantial contribution in the concept and design of the study;

Danilo José Ayres de Menezes - Contribution to critical revision, adding intelectual content;

Gildenor Xavier Medeiros - Substantial contribution in the concept, design of the study and to critical revision, adding intelectual content.

## Conflicts of Interest

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

## References

COIMBRA-FILHO, A.F., ROCHA, N.D.C.& PISSINATTI, A. 1980. Morfofisiologia do ceco e sua correlação com o tipo odontológico em *Callitrichidae* (*Platyrrhini, Primates*). Rev. Bras. Biol.,40, p.177.

COIMBRA-FILHO, A.F. 1984. Situação atual dos calitriquídeos que ocorrem no Brasil (*Callitrichidae – Primates*). In: Mello, M.T., A Primatologia no Brasil. Sociedade Brasileira de Primatologia, Brasília, p.15-33.

CUNNIGHAM, J.G. 2014. Tratado de Fisiologia Veterinária. 5 ed. Rio de Janeiro, Guanabara Koogan.

DANTAS, A.K.F.P., SILVA, E.F., NETO, R.B.S., SANTOS, J.R.S., CORDEIRO, J.F., OLIVEIRA, M.F., MEDEIROS, G.X. & MENEZES, D.J.A. 2014. Morfologia e Segmentação Pulmonar de Raposas (*Cedocyon thous*). Acta Vet. Bras., 8, p.31-37.

DYCE, K.M., SACK, W.O & WENSING, C.J.G. 2010. Tratado de Anatomia Veterinária. 4 ed. Rio de Janeiro, Elsevier.

GROVES, C. In: REEDER, D.M. & WILSON, D.E. 2005. Mammal Species of the World. A Taxonomic and Geographic Reference. 3 ed. Johns Hopkins University Press, p.2000.

GUIMARÃES, G.C., LOPES, G.C., ROSA, M.C.B., SESTARI, C.E.O. & OLIVEIRA, F.S. 2012. Lobação pulmonar e distribuição brônquica do ouriço-cacheiro (*Sphiggurus villosus*). Acta Sci. Vet., 40, 2, p.1037.

HARE, W.C.D. 1986. Sistema respiratório do carnívoro. In: Getty, R. Anatomia dos Animais Domésticos. 5 ed. Guanabara Koogan, Rio de Janeiro, 2, p.1465-1481.

I.C.V.G.A.N – International Committee on Veterinary Gross Anatomical Nomenclature; W.A.V.A. – World Association of Veterinary Anatomists. Nomina AnatomicaVeterinaria. 2012. Hannover, Columbia, MO, Ghent, Sapporo: Editorial Committee.

KÖNIG, H.E. & LIEBICH, H.G. 2016. Anatomia dos animais domésticos: texto e atlas colorido. Tradução: Régis Pizzato. 6 ed. Porto Alegre, Artmed, p.377-398.

LIEBICH, H.G. 1974. The Segmentation of the Lung of the white Rat (*Rattus norvegicus*). Anat. Histol. Embryol. Journal of the World Association of Veterinary Anatomists, 3, p.243-249.

LOPES, J.C. 2000. O Tráfico Ilegal de Animais Silvestres no Brasil.

LOWENSTINE, L.J. & OSBORN, K.G. 2012. Respiratory system diseases of nonhuman primates. 2 ed. In: ABEE, R.C., MANSFIELD, K., TARDIF, S. & MORRIS, T. Nonhuman Primates in Biomedical Research. London: Elsevier, 2, p.413-483.

MACHIN, K.L. 1984. Wildlife analgesia. In.: WEST, G., HEARD, D. & CAULKETT, n. 2007. Zoo animal & wildlife immobilization and anesthesia. Ames: Blackwell Publishing, p.43-60.

MAINA, J.N. 1987. The morphology and morphometry of the adult normal baboon lung (*Papio anubis*). J. Anat., 150, p.229-245.

NAKAKUKI, S. 1985. The bronchial tree, lobular division, and blood vessels of the lion lung. Anat. Anz., p.315-321.

NAKAKUKI, S. 1983. Bronchial ramification. In: the bronchial tree and blood vessels of the rat lung. Anat. Anz., p.306-307.

OLIVEIRA, V.C. 2012. Estudo morfológico do sistema respiratório de quati (*Nasuanasua*). Biotemas, p.81-92.

PENNO, A.K., CARVALHO, M.A.M., ASSIS-NETO, A.C., AZEVEDO, L.M. & MELLO, G.W.S. 2005. Lobação, ramificação brônquica e distribuição arterial no pulmão da cutia (*Dasyprocta sp., Mammalia - Rodentia*). Braz. J. Vet. Res. Anim. Sci. São Paulo, 42, 5, p.331-336.

PISSINATTI, A., GOLDSCHMIDT, B. & SOUZA, I.V. 2010. Taxonomia. In: ANDRADE, A. et al. Biologia, manejo e medicina de primatas não humanos na pesquisa biomédica. Rio de Janeiro, Fiocruz, 2, p.51.

RENCTAS (Rede Nacional de Combate ao Tráfico de Animais Silvestres). 2001. 1º Relatório Nacional sobre o Tráfico de Fauna Silvestre.

REHDER, A.M.A., CORTELLINI, L.M., OLIVEIRA, F.S. & MACHADO, M.R.F. 2008. Lobação, árvore brônquica e vascularização arterial do pulmão da paca (*Agouti paca*, LINNAEUS, 1766). Ciênc. Anim. Bras., 9, 2, p.442-448.

ROCHA, F.M. 1995. Tráfico de Animais Silvestres. WWF. Documento para discussão.

ROMER, A.S. & PEARSON, T.S. 1986. The Vertebrate Body. 6 ed. Philadelphia, W. B. Saunders, p.679.

RUIZ-MIRANDA, C.R., AFFONSO, A.G., MARTINS, A. & BECK, B. 2000. Distribuição do sagui (*Callithrix jacchus*) nas áreas de ocorrência do mico-leão-dourado (*Leontopithecus rosalia*) no estado do Rio de Janeiro. Neotrop. Primates, 8, 3, p.98-101.

RYLANDS, A.B. 2012. Taxonomy of the Neotropical Primates. International Union for Conservation of Nature (IUCN), Species Survival Commission (SSC), Primate Specialist Group, Gland.

SANTOS, A.L.Q., MORAES, F.M., CARVALHO, S.F.M., MENEZES, L.T., KAMINISHI, A.P.S., LEONARDO, T.G. & NASCIMENTO, L.R. 2011. Lobos pulmonares e formação dos brônquios do gato mourisco (*Herpailurus yagouaroundi*- Severtzow, 1848) (*Felidae*). PUBVET, Londrina, 5, p.13.

SESTARI, C.E.O., CORRÊA, A.F., MARTINS, L.L., GUIMARÃES, G.C. & OLIVEIRA, F.S. 2011. Lobação pulmonar e distribuição brônquica em mão-pelada (*Procyon cancrivorus*, Cuvier, 1798) - Relato de dois casos. Veterinária e Zootecnia. Arq. Bras. Med. Vet., 18, 3, p.374-378.

STEVENSON, M. & RYLANDS, A.B. 1988. The marmosets, genus *Callithrix*. In: MITTERMEIER, R.A., RYLANDS, A.B., COIMBRA-FILHO, A. & FONSECA, G.A.B. Ecology and behavior of Neotropical primates, W.W.F., Washington, p.131-222.

TARDIF, S.D., ARAÚJO, A., ARRUDA, M.F., FRENCH, J.A., SOUSA, M.B. & YAMAMOTO, M.E. 2008. Reproduction and aging in marmosets and tamarins. In: ATSALIS, S., MARGULIS, S.W. & HOF, P.R. Interdisciplinary Topics in Gerontology. Karger, 36, p.29-48.

VOYEVODA, T.V, SHISHKIN, G.S., VALITSKAYA, R.I. & UMANTSEVA, N.D. 1992. Macrostructure differences of polar fox and dog lungs. In: The Anatomical Record. American Association of Anatomists. 234, 1, p.89-92.

*Received: 18/09/2017*
*Revised: 05/02/2018*
*Accepted: 07/02/2018*

Biota Neotropica 18(2): e20170350, 2018
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
Inventory

# Update on the ichthyofauna of the Piquiri River basin, Paraná, Brazil: a conservation priority area

*Daiane Cavalli*[1]*, *Augusto Frota*[4,5], *Angelica Dorigon Lira*[2], *Éder André Gubiani*[1,2],

*Vladimir Pavan Margarido*[3] & *Weferson Júnio da Graça*[4,6]

*[1]Universidade Estadual do Oeste do Paraná, Curso de Engenharia de Pesca, Grupo de Pesquisas em Recursos Pesqueiros e Limnologia, Rua da Faculdade, 645, CEP 85903000, Toledo, PR, Brasil*
*[2]Universidade Estadual do Oeste do Paraná, Programa de Pós-Graduação em Recursos Pesqueiros e Engenharia de Pesca, Grupo de Pesquisas em Recursos Pesqueiros e Limnologia, Rua da Faculdade, 645, CEP 85903000, Toledo, PR, Brasil*
*[3]Universidade Estadual do Oeste do Paraná, Centro de Ciências Biológicas e da Saúde, Rua Universitária, 2069, CEP 85819110, Cascavel, PR, Brasil*
*[4]Universidade Estadual de Maringá, Coleção Ictiológica do Núcleo de Pesquisas em Limnologia, Ictiologia e Aquicultura, Av. Colombo, 5790, CEP 87020-900, Maringá, PR, Brasil*
*[5]Universidade Estadual de Maringá, Programa de Pós-Graduação em Ecologia de Ambientes Aquáticos Continentais, Av. Colombo, 5790, CEP 87020-900, Maringá, PR, Brasil*
*[6]Universidade Estadual de Maringá, Centro de Ciências Biológicas, Departamento de Biologia e Núcleo de Pesquisas em Limnologia, Ictiologia e Aquicultura, Av. Colombo, 5790, CEP 87020-900, Maringá, PR, Brasil*
**Corresponding author: Daiane Cavalli, e-mail: daia.cavalli@hotmail.com*

CAVALLI, D., FROTA, A., LIRA, A. D., GUBIANI, E. A., MARGARIDO, V. P., GRAÇA, W. J. **Update on the ichthyofauna of the Piquiri River basin, Paraná, Brazil: a conservation priority area**. Biota Neotropica. 18(2): e20170350. http://dx.doi.org/10.1590/1676-0611-BN-2017-0350

***Abstract:*** Knowledge of the fish species in river basins is among the minimum requirements for the management of water and fish resources. Therefore, the aim of this study was to update the fish species composition of the Piquiri River basin, upper Paraná River basin. Data were gathered from recent information published in specialized literature and records for ichthyology collections. This update reports the occurrence of 152 fish species distributed in 8 orders, 31 families, and 89 genera. Non-native species accounted for 20% of all species, and the construction of the Itaipu Power Plant and its fish ladder were the main vectors of introduction. Three percent of the species were endangered, and 11% were classified as migratory. The Piquiri River basin harbors a large number of species, some of which are rare, endangered, migratory, endemic, and even unknown by science. Because of this, maintaining the integrity of this river basin will support the persistence of regional biodiversity.

***Keywords:*** *Ichthyofaunal survey, species knowledge, preservation, upper Paraná River basin.*

# Atualização da ictiofauna da bacia do rio Piquiri, Paraná, Brasil: uma área prioritária para conservação

***Resumo:*** O conhecimento das espécies de peixes existentes em uma bacia hidrográfica é condição mínima necessária para a implantação de qualquer medida de manejo dos recursos hídricos e pesqueiros. Dessa forma, o objetivo deste estudo foi realizar uma atualização da composição das espécies de peixes da bacia do rio Piquiri, sistema do alto rio Paraná, proveniente de recentes informações contidas em estudos divulgados na literatura especializada e registros de espécies depositadas em coleções ictiológicas. A atualização do levantamento ictiofaunístico da bacia do rio Piquiri revelou a ocorrência de 152 espécies, as quais foram distribuídas em oito ordens, 31 famílias e 89 gêneros. Vinte por cento das espécies foram consideradas não nativas. O principal vetor de introdução foi a construção da barragem de Itaipu e seu sistema de transposição. Três por cento das espécies apresentaram alguma ameaça de extinção e 11% foram classificadas como migradoras. A bacia do rio Piquiri comporta grande número de espécies, algumas delas raras, ameaçadas de extinção, migradoras, endêmicas e até mesmo desconhecidas pela ciência. Dessa forma, a manutenção da integridade da bacia promoverá a persistência da biodiversidade regional.

***Palavras-chave:*** *Levantamento ictiofaunístico, conhecimento das espécies, preservação, bacia do alto rio Paraná.*

## Introduction

Knowing the fish species in a river basin is essential for any amount of water and fishery management (Oliveira et al. 2014, Agostinho et al. 2016). Spatial and temporal fish assemblage patterns can be understood by biotic, abiotic and spatial factors that determine fish assemblage biodiversity (Jackson et al. 2001), enabling the assessment of the environmental quality of a river system. Although much sampling has been carried out in basins to record existing ichthyofaunal compositions, several species are still unknown by science (Langeani et al. 2007, Galves et al. 2009, Frota et al. 2016a). Recent fish inventories in previously sampled areas have revealed new species (Pavanelli 2006, Frota et al. 2016a); consequently, the number of descriptions of new species has increased in recent years. It is thought that a full description of existing species is still far from being achieved (Ota et al. 2015).

In this regard, the upper Paraná River basin is no different; although recent studies have recorded 310 valid fish species and approximately 50 likely new fish species (Langeani et al. 2007), little is known about the fish fauna of the main tributaries of the upper Paraná River basin (Galves et al. 2009). Thus, information on fish assemblages, especially in the tributaries, is still scarce and most likely should be greater than currently known.

The Piquiri River is one of the main tributaries of the left bank of the upper Paraná River basin (Affonso et al. 2015), the third largest drainage area in the State of Paraná. It is highlighted as one of the last tributaries free of damming in the upper Paraná River basin (Agostinho et al. 2004, Gubiani et al. 2010, Affonso et al. 2015). This area is one of the last environments used by migratory fish during breeding displacement (Gogola et al. 2010, 2013, Gubiani et al. 2010). Despite its importance for fish assemblages, studies on its ichthyofauna composition are still scarce. Agostinho et al. (1997, 2004) registered 57 species. In Gubiani et al. (2006), the number increased to 62 species. Later, in Gubiani et al. (2010), 69 species were recorded. Additionally, recent studies have sampled small-order streams and larger tributaries of this river, increasing the specific richness of fish in the basin (Delariva & Silva 2013, Dei Tos et al. 2014).

In view of the abovementioned, this study aims to update the fish species composition of the Piquiri River, upper Paraná River basin, by scrutinizing the latest information in the literature and species records from ichthyology collections. In addition, the threat level, origin, biogeography, migratory behavior, and main current and future human impacts that may affect fish biodiversity in the basin are also discussed.

## Material and Methods

### *1. Study area*

The Piquiri River basin comprises a drainage area of approximately 25,000 km$^2$ (SEMA, 2010), the third largest in the State of Paraná (geographical coordinates 23°65' - 25°25' S and 51°59' - 54°07' W; Figure 1), which is approximately 12% of the Paraná state area (SEMA 2010). According to Maack (2012), its sources are located at an altitude of 1,237 m in the São João Mountains at the third plateau, south-central region of the state, and it runs 485 km before reaching the Paraná River on the border between the municipalities of Altônia and Terra Roxa. The river comprises several rapids, waterfalls, and narrow stretches, with a total fall of approximately 1,000 m from its headwaters to its mouth (Agostinho & Júlio Jr. 1999). The main tributaries of the Piquiri River are the Cantú, Tricolor, Goioerê, and Xambrê rivers on the right bank and the Sapucaia and Melissa rivers on the left bank (Paiva 1982).

Local land use is based on farming, fish farming and livestock, and soybeans, wheat, corn, sugarcane, and cassava are the primary crops. The industrial segment is related to livestock and includes industries such as dairy and cold stores. The region has undergone several changes, with few forest remnants near the municipalities of Guaraniaçu, Laranjal, and Altamira do Paraná. In the basin, there are key conservation units, such as the São Camilo Biological Reserve in Palotina, the Area of Relevant Ecological Interest of São Domingos between Roncador and Nova Cantú (Paraná 2010), and the Perobas Biological Reserve, which is located in the municipalities of Cianorte and Tuneiras do Oeste (Delariva & Silva 2013). The landscape is divided into intensive farming areas, artificial grasslands, and natural fields with small forest, urban, and industrial areas. The urban population living in the basin is approximately half a million inhabitants, of which 99% have a public water supply and only 28% have domestic effluent collection services (SEMA 2010).

### *2. Database*

The update of the fish species was performed by consulting fish collections with a vast amount of material such as the Londrina State University Museum in Londrina (MZUEL), the Museum of Zoology of the University of São Paulo in São Paulo (MZUSP), the Capão da Imbuia Natural History Museum in Curitiba (MHNCI), the PUCRS Museum of Science and Technology in Porto Alegre (MCP), the Nupélia Ichthyology Collection of the State University of Maringá in Maringá (NUP), and the Ichthyology Collection of GERPEL of the Western Paraná State University in Toledo (CIG). The species records of these collections came from online databases, e.g., Species Link, which is an information distribution network integrating live data from diverse scientific collections (CRIA 2016). In addition, to complement the information, in September 2016, bibliographical research was performed using articles in the Thomson Reuters (ISI Web of Knowledge, apps.isiknowledge.com), Elsevier – ScienceDirect (http://www.sciencedirect.com), and Scielo (http://www.scielo.org) databases that addressed the topic of "ichthyofauna of the Piquiri River basin." The search terms in the "Topic" field were "fish* OR ichthyo* OR check list AND Piquiri River", and the searched timespan included all years up to the date of the search. The search was then refined according to the following research areas: Environmental Sciences, Ecology, Zoology, Freshwater Biology, Biodiversity, Conservation, and Fisheries and Water Resources. In addition, all articles including lists of fish species of the Piquiri River basin that were published in the journal *Check List: Journal of Species Lists and Distributions*, which is not indexed in the aforementioned databases were also included in our review. For this, the search was carried out using the option "search for articles" at the journal website (http://www.checklist.org.br/search) and searching all categories and volumes.

For a study to be included in this bibliographical research it needed to show a list of fish species caught in the Piquiri River, upper Paraná River basin, Brazil. Non-related articles were excluded based on their title, abstract or, if necessary, after a careful reading of the entire text. The articles that met the required criteria were selected and tabulated in a spreadsheet to compose the final list of fish species. After the final

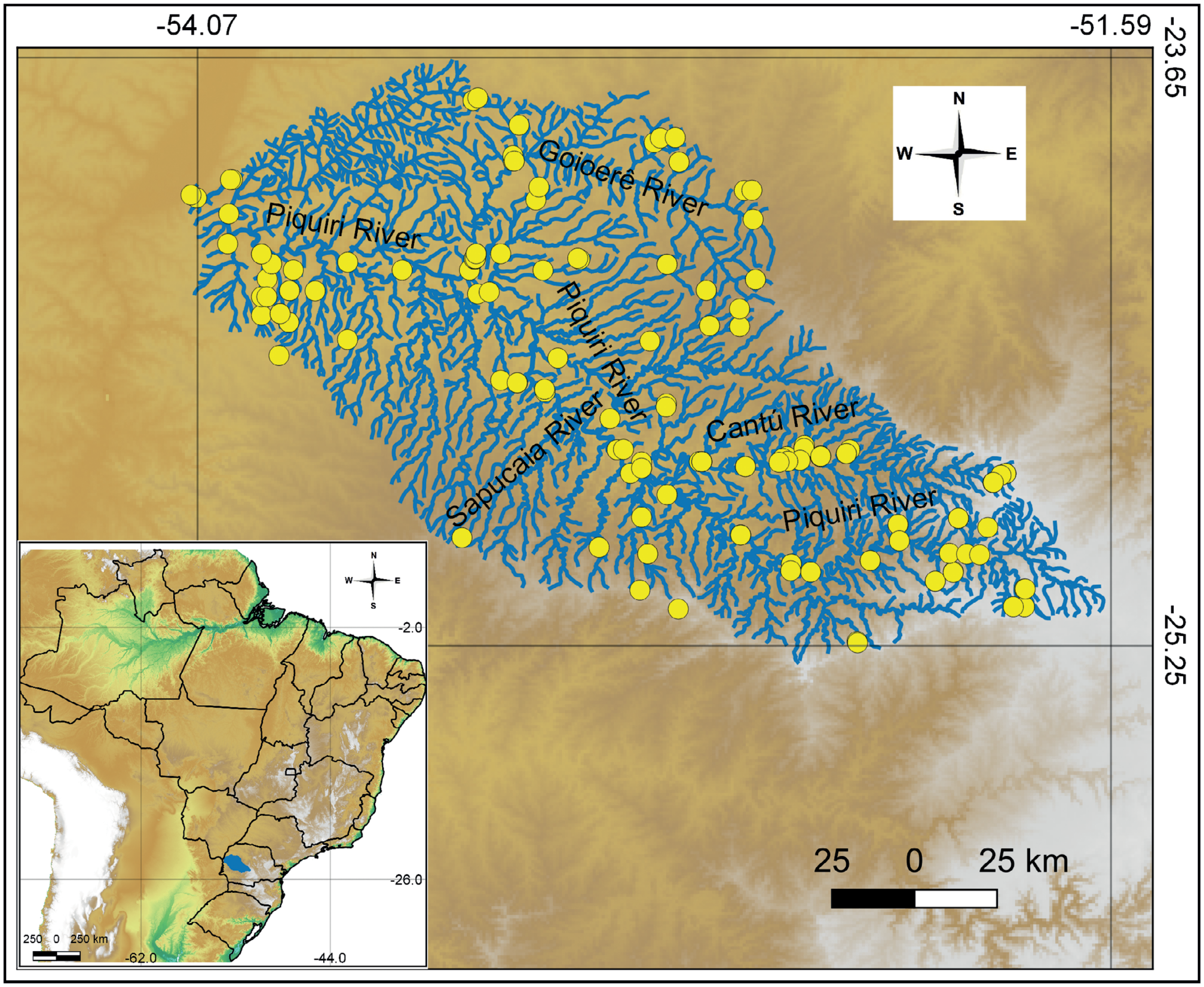

**Figure 1.** Map of the Piquiri River basin showing its location in Brazil and in the state of Paraná. Yellow dots indicate the sampling sites within the basin that were georeferenced and cataloged in the ichthyologic collections. Each point may correspond to more than one sampling site.

tabulation of the complete list of fish species recorded for the Piquiri River basin, the list was reviewed by experts to correct possible doubts about the occurrence or identification of fish species.

Fish species were classified based on Eschmeyer et al. (2016). However, the threat level for each species was set according to the Portaria do Ministério do Meio Ambiente, nº 445 (December 17 of 2014) (BRASIL 2014), which was amended by Decree nº 98 (April 28 of 2015) (BRASIL 2015). These regulations classify the endangered species of fish and aquatic invertebrates from the Brazilian fauna with the following categories: Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), and Vulnerable (VU). In addition, the species were categorized by origin based on the Langeani et al. (2007) method and grouped into autochthonous (native to the upper Paraná River basin), allochthonous (introduced species belonging to the Neotropical region), and exotic (from other continents) categories. If introduced, the introduction vectors were determined based on the species occurrence and distribution, as well as relevant literature, according to Reis et al. (2003), Langeani et al. (2007), Graça & Pavanelli (2007), Júlio Jr. et al. (2009) and Frota et al. (2016a). The possible causes of the occurrence of these species in the Piquiri River basin were grouped into seven categories: 1) Itaipu, species first recorded shortly after the construction of the Itaipu Dam with its native populations from the lower Paraná River basin; 2) Itaipu channel, species also coming from the lower Paraná River basin and introduced as a result of the construction and operation of the Itaipu Piracema Channel; 3) aquaculture, species widely used in the fish farms in the region; 4) baiting, species introduced by the use of natural baits for sport fishing; 5) mosquito control and aquarium purposes, species introduced for mosquito population control and species highly represented in fishkeeping; 6) sport-fishing, species introduced for sport fishing; 7) stocking, species introduced for fish stocks. In addition, species were classified according to their migratory status as proposed by Vazzoler (1996), Nakatani et al. (2001), and Agostinho et al. (2003), although only species with migratory behavior were evaluated in this way and shown in the results. Lastly, to discuss the main current and future human impacts on the region, predictions for the construction of small power plants (SPPs) and power plants (PPs) in the Piquiri River basin were mapped and computed by geographic maps of the Brazilian electric power sector (ANEEL 2016).

## Results

The update on ichthyofauna diversity for the Piquiri River basin revealed 152 species distributed in 8 orders, 31 families, and 89 genera (Table 1). The orders with the highest species richness were Siluriformes (69 species) and Characiformes (59 species), representing approximately 84% of all species recorded in the basin (Figure 2). The families showing the largest species richness were Loricariidae (26 species), Characidae (23 species), Pimelodidae (14 species), Anostomidae (12 species), and Heptapteridae (10 species), comprising nearly 56% of all species (Figure 2). Fifteen of the discovered species are believed to be new to science (Table 1), representing approximately 12% of the basin's total native species.

Of all the registered species, 80% (122) are autochthonous, 18% (28) are allochthonous, and 1% (2) is exotic. Allochthonous and exotic species are considered to be non-natives in the Piquiri River basin. Among the 30 non-native species, 23 (70%; Figure 3) allochthonous fish species originated from the ichthyofauna belonging to the lower Paraná River and were introduced to the upper Paraná River during the construction of the dam and the operation of the Itaipu Piracema channel (Table 1) and are now recorded in the Piquiri River basin. *Megaleporinus macrocephalus* (Garavello & Britski, 1988), considered an allochthonous fish species, was introduced by fish farming (Table 1). In addition, *Gymnotus pantanal* Fernandes, Albert, Daniel-Silva, Lopes, Crampton, & Almeida-Toledo, 2005, *Poecilia reticulata* Peters,

**Table 1.** Piquiri River basin ichthyofauna according to species, voucher specimens, the origin of each species, threat level, migratory behavior, and introduction vector. The asterisk (*) represents species with migratory behavior. VU = vulnerable; EN = endangered

| Species | Voucher | Origin/Threat level | Introduction Vector |
|---|---|---|---|
| **ELASMOBRANCHII** | | | |
| **Myliobatiformes** | | | |
| **Potamotrygonidae** | | | |
| 1 *Potamotrygon amandae* Loboda & Carvalho, 2013 | | Allochthonous | Itaipu |
| 2 *Potamotrygon falkneri* Castex & Maciel, 1963 | | Allochthonous | Itaipu |
| **ACTINOPTERYGII** | | | |
| **Cypriniformes** | | | |
| **Cyprinidae** | | | |
| 3 *Cyprinus carpio* Linnaeus, 1758 | CIG 2852 | Exotic | Fish farming |
| **Characiformes** | | | |
| **Parodontidae** | | | |
| 4 *Apareiodon affinis* (Steindachner, 1879) | NUP 4198 | Autochthonous | ––– |
| 5 *Apareiodon piracicabae* (Eigenmann, 1907) | NUP 7090 | Autochthonous | ––– |
| 6 *Apareiodon vladii* Pavanelli, 2006 | NUP 15731 | Autochthonous/VU | ––– |
| 7 *Parodon nasus* Kner, 1859 | NUP 14654 | Autochthonous | ––– |
| **Curimatidae** | | | |
| 8 *Cyphocharax modestus* (Fernández-Yépez, 1948) | NUP 16762 | Autochthonous | ––– |
| 9 *Cyphocharax nagelii* (Steindachner, 1881) | MZUSP 42963.0 | Autochthonous | ––– |
| 10 *Steindachnerina insculpta* (Fernández-Yépez, 1948) | NUP 16775 | Autochthonous | ––– |
| **Prochilodontidae** | | | |
| 11 *Prochilodus lineatus* (Valenciennes, 1836) | NUP 14606 | Autochthonous* | ––– |
| **Anostomidae** | | | |
| 12 *Leporellus vittatus* (Valenciennes, 1850) | NUP 4211 | Autochthonous | ––– |
| 13 *Leporinus amblyrhynchus* Garavello & Britski, 1987 | NUP 18154 | Autochthonous | ––– |
| 14 *Leporinus friderici* (Bloch, 1794) | NUP 18152 | Autochthonous | ––– |
| 15 *Leporinus lacustris* Campos, 1945 | | Autochthonous | ––– |
| 16 *Leporinus octofasciatus* Steindachner, 1915 | CIG 2165 | Autochthonous | ––– |
| 17 *Leporinus striatus* Kner, 1858 | MZUSP 43092 | Autochthonous | ––– |
| 18 *Megaleporinus macrocephalus* (Garavello & Britski, 1988) | | Allochthonous* | Fish farming |
| 19 *Megaleporinus obtusidens* (Valenciennes, 1836) | NUP 4206 | Autochthonous* | ––– |
| 20 *Megaleporinus piavussu* (Britski, Birindelli & Garavello, 2012) | NUP 1899 | Autochthonous* | ––– |
| 21 *Schizodon altoparanae* Garavello & Britski, 1990 | NUP 1690 | Autochthonous | ––– |
| 22 *Schizodon borellii* (Boulenger, 1900) | NUP 1768 | Autochthonous | ––– |

**Continued Table 1.**

| Species | Voucher | Origin/Threat level | Introduction Vector |
|---|---|---|---|
| 23 *Schizodon nasutus* Kner, 1858 | NUP 2481 | Autochthonous | --- |
| **Crenuchidae** | | | |
| 24 *Characidium* aff. *zebra* Eigenmann, 1909 | NUP 16048 | Autochthonous | --- |
| 25 *Characidium gomesi* Travassos, 1956 | NUP 17236 | Autochthonous | --- |
| **Characidae** | | | |
| 26 *Astyanax bockmanni* Vari & Castro, 2007 | NUP 16689 | Autochthonous | --- |
| 27 *Astyanax* aff. *fasciatus* (Cuvier, 1829) | NUP 15622 | Autochthonous | --- |
| 28 *Astyanax* aff. *paranae* Eigenmann, 1914 | NUP 16056 | Autochthonous | --- |
| 29 *Astyanax lacustris* (Lütken, 1875) | NUP 18271 | Autochthonous | --- |
| 30 *Astyanax schubarti* Britski, 1964 | NUP 39 | Autochthonous | --- |
| 31 *Oligosarcus paranensis* Menezes & Géry, 1983 | NUP 16052 | Autochthonous | --- |
| 32 *Oligosarcus pintoi* Campos, 1945 | NUP 16739 | Autochthonous | --- |
| 33 *Oligosarcus* sp. | NUP 18992 | Autochthonous | --- |
| 34 *Psellogrammus kennedyi* (Eigenmann, 1903) | NUP 18649 | Autochthonous | --- |
| **Pristellinae** | | | |
| 35 *Moenkhausia gracilima* Eigenmann 1908 | NUP 18648 | Autochthonous | --- |
| 36 *Moenkhausia* aff. *intermedia* Eigenmann, 1908 | | Autochthonous | --- |
| 37 *Moenkhausia forestii* Benine, Mariguela & Oliveira, 2009 | NUP 10680 | Autochthonous | --- |
| 38 *Moenkhausia sanctaefilomenae* (Steindachner, 1907) | NUP 10681 | Autochthonous | --- |
| **Characinae** | | | |
| 39 *Galeocharax knerii* (Steindachner, 1879) | NUP 257 | Autochthonous | --- |
| 40 *Roeboides descalvadensis* Fowler, 1932 | NUP 4192 | Allochthonous | Itaipu |
| **Cheirodontinae** | | | |
| 41 *Serrapinnus notomelas* (Eigenmann, 1915) | NUP 14596 | Autochthonous | --- |
| 42 *Odontostilbe* sp. | CIG 2156 | Autochthonous | --- |
| **Stevardiinae** | | | |
| 43 *Bryconamericus exodon* Eigenmann, 1907 | CIG 100 | Allochthonous | Itaipu channel |
| 44 *Bryconamericus* aff. *iheringii* (Boulenger, 1887) | NUP 18277 | Autochthonous | --- |
| 45 *Bryconamericus* sp. | NUP 7777 | Autochthonous | --- |
| 46 *Piabarchus stramineus* (Eigenmann, 1908) | NUP 16614 | Autochthonous | --- |
| 47 *Piabina argentea* Reinhardt, 1867 | NUP 4190 | Autochthonous | --- |
| 48 *Planaltina* sp. | NUP 52 | Autochthonous | --- |
| **Bryconidae** | | | |
| **Bryconinae** | | | |
| 49 *Brycon orbignyanus* (Valenciennes, 1850) | NUP 2031 | Autochthonous*/EN | --- |
| **Salmininae** | | | |
| 50 *Salminus brasiliensis* (Cuvier, 1816) | NUP 1880 | Autochthonous* | --- |
| 51 *Salminus hilarii* Valenciennes, 1850 | NUP 2475 | Autochthonous* | --- |
| **Serrasalmidae** | | | |
| 52 *Myloplus tiete* (Eigenmann & Norris, 1900) | NUP 2484 | Autochthonous/EN | --- |
| 53 *Piaractus mesopotamicus* (Holmberg, 1887) | | Autochthonous* | --- |
| 54 *Serrasalmus maculatus* Kner, 1858 | NUP 4208 | Autochthonous | --- |
| 55 *Serrasalmus marginatus* Valenciennes, 1837 | | Allochthonous | Itaipu |
| **Acestrorhynchidae** | | | |
| 56 *Acestrorhynchus lacustris* (Lütken, 1875) | NUP 18026 | Autochthonous | --- |

**Continued Table 1.**

| Species | Voucher | Origin/Threat level | Introduction Vector |
|---|---|---|---|
| **Hemiodontidae** | | | |
| 57 *Hemiodus orthonops* Eigenmann & Kennedy, 1903 | NUP 18153 | Allochthonous | Itaipu channel |
| **Cynodontidae** | | | |
| 58 *Rhaphiodon vulpinus* Spix & Agassiz, 1829 | | Autochthonous* | —— |
| **Erythrinidae** | | | |
| 59 *Hoplias intermedius* (Günther, 1864) | NUP 271 | Autochthonous | —— |
| 60 *Hoplias mbigua* Azpelicueta, Benítez, Aichino & Mendez, 2015 | NUP 4253 | Allochthonous | Itaipu |
| 61 *Hoplias* sp. 2 | NUP 18042 | Autochthonous | —— |
| 62 *Hoplias* sp. 3 | NUP 15792 | Autochthonous | —— |
| **Siluriformes** | | | |
| **Cetopsidae** | | | |
| 63 *Cetopsis gobioides* (Kner, 1858) | NUP 16777 | Autochthonous | —— |
| **Trichomycteridae** | | | |
| 64 *Trichomycterus* aff. *davisi* (Haseman, 1911) | NUP 16086 | Autochthonous | —— |
| 65 *Trichomycterus* cf. *stawiarski* (Miranda Ribeiro, 1968 | NUP 18858 | Autochthonous | —— |
| **Callichthyidae** | | | |
| **Callichthyinae** | | | |
| 66 *Callichthys callichthys* (Linnaeus, 1758) | NUP 16088 | Autochthonous | —— |
| 67 *Hoplosternum littorale* (Hancock, 1828) | | Autochthonous | —— |
| **Corydoradinae** | | | |
| 68 *Corydoras aeneus* (Gill, 1858) | NUP 16087 | Autochthonous | —— |
| **Loricariidae** | | | |
| **Hypoptopomatinae** | | | |
| 69 *Hisonotus* sp. | NUP 16050 | Autochthonous | —— |
| **Hypostominae** | | | |
| 70 *Ancistrus* sp. | NUP 15757 | Autochthonous | —— |
| 71 *Hypostomus albopunctatus* (Regan, 1908) | NUP 13532 | Autochthonous | —— |
| 72 *Hypostomus ancistroides* (Ihering, 1911) | NUP 17235 | Autochthonous | —— |
| 73 *Hypostomus cochliodon* Kner, 1854 | NUP 5604 | Allochthonous | Itaipu |
| 74 *Hypostomus commersoni* Valenciennes, 1836 | CIG 1514 | Allochthonous | Itaipu |
| 75 *Hypostomus hermanni* (Ihering, 1905) | NUP 9085 | Autochthonous | —— |
| 76 *Hypostomus iheringii* (Regan, 1908) | NUP 5594 | Autochthonous | —— |
| 77 *Hypostomus margaritifer* (Regan, 1908) | NUP 5602 | Autochthonous | —— |
| 78 *Hypostomus* aff. *paulinus* (Ihering, 1905) | NUP 5583 | Autochthonous | —— |
| 79 *Hypostomus regani* (Ihering, 1905) | NUP 13534 | Autochthonous | —— |
| 80 *Hypostomus strigaticeps* (Regan, 1908) | NUP 14441 | Autochthonous | —— |
| 81 *Hypostomus* cf. *topavae* (Godoy, 1969) | NUP 11430 | Autochthonous | —— |
| 82 *Hypostomus* cf. *tietensis* (Ihering, 1905) | NUP 18045 | Autochthonous | —— |
| 83 *Hypostomus* sp. 1 | NUP 5581 | Autochthonous | —— |
| 84 *Hypostomus* sp. 2 | NUP 9656 | Autochthonous | —— |
| 85 *Hypostomus* sp. 3 | NUP 9653 | Autochthonous | —— |
| 86 *Megalancistrus parananus* (Peters, 1881) | NUP 14680 | Autochthonous | —— |
| 87 *Pterygoplichthys ambrosettii* (Holmberg, 1893) | NUP 16708 | Allochthonous | Itaipu |
| 88 *Rhinelepis aspera* Spix & Agassiz, 1829 | | Autochthonous* | —— |

**Continued Table 1.**

| Species | Voucher | Origin/Threat level | Introduction Vector |
|---|---|---|---|
| **Loricariinae** | | | |
| 89 *Farlowella hahni* Meinken, 1937 | NUP 16781 | Autochthonous | ––– |
| 90 *Loricaria* sp. | | Autochthonous | ––– |
| 91 *Loricariichthys platymetopon* Isbrücker & Nijssen, 1979 | NUP 18725 | Allochthonous | Itaipu |
| 92 *Loricariichthys rostratus* Reis & Pereira, 2000 | NUP 18728 | Allochthonous | Itaipu |
| 93 *Rineloricaria* cf. *latirostris* (Boulenger, 1900) | NUP 8936 | Autochthonous | ––– |
| **Neoplecostominae** | | | |
| 94 *Neoplecostomus* sp. | NUP 15758 | Autochthonous | ––– |
| **Pseudopimelodidae** | | | |
| 95 *Pseudopimelodus mangurus* (Valenciennes, 1835) | NUP 2482 | Autochthonous | ––– |
| 96 *Pseudopimelodus pulcher* (Boulenger, 1887) | NUP 18030 | Autochthonous | ––– |
| **Heptapteridae** | | | |
| 97 *Cetopsorhamdia iheringi* Schubart & Gomes, 1959 | NUP 16727 | Autochthonous | ––– |
| 98 *Heptapterus mustelinus* (Vallenciennes, 1835) | CIG 1685 | Autochthonous | ––– |
| 99 *Imparfinis borodini* Mees & Cala, 1989 | NUP 14641 | Autochthonous | ––– |
| 100 *Imparfinis mirini* Haseman, 1911 | NUP 14592 | Autochthonous | ––– |
| 101 *Imparfinis schubarti* (Gomes, 1956) | NUP 16651 | Autochthonous | ––– |
| 102 *Phenacorhamdia tenebrosa* (Schubart, 1964) | NUP 16726 | Autochthonous | ––– |
| 103 *Pimelodella avanhandavae* Eigenmann, 1917 | NUP 16692 | Autochthonous | ––– |
| 104 *Pimelodella gracilis* (Valenciennes, 1835) | NUP 14590 | Autochthonous | ––– |
| 105 *Pimelodella taenioptera* Miranda-Ribeiro, 1914 | CIG 82 | Allochthonous | Itaipu channel |
| 106 *Rhamdia quelen* (Quoy & Gaimard, 1824) | NUP 15759 | Autochthonous | ––– |
| **Pimelodidae** | | | |
| 107 *Hemisorubim platyrhynchos* (Valenciennes, 1840) | | Autochthonous* | ––– |
| 108 *Hypophthalmus oremaculatus* Nani & Fuster, 1947 | | Autochthonous | ––– |
| 109 *Iheringichthys labrosus* (Lütken, 1874) | NUP 18726 | Autochthonous | ––– |
| 110 *Iheringichthys* sp. | NUP 14937 | Autochthonous | ––– |
| 111 *Megalonema platanum* (Gunther, 1880) | NUP 4209 | Autochthonous | ––– |
| 112 *Pimelodus microstoma* Steindachner, 1877 | NUP 18158 | Autochthonous | ––– |
| 113 *Pimelodus mysteriosus* Azpelicueta, 1998 | NUP 17275 | Allochthonous | Itaipu |
| 114 *Pimelodus ornatus* Kner, 1858 | NUP 4212 | Allochthonous | Itaipu |
| 115 *Pimelodus paranaensis* Britski & Langeani, 1988 | NUP 14936 | Autochthonous | ––– |
| 116 *Pinirampus pirinampu* (Spix & Agassiz 1829) | | Autochthonous* | ––– |
| 117 *Pseudoplatystoma corruscans* (Spix & Agassiz, 1829) | CIG 89 | Autochthonous* | ––– |
| 118 *Sorubim lima* (Bloch & Shneider, 1801) | NUP 2480 | Autochthonous* | ––– |
| 119 *Steindachneridion scriptum* (Miranda-Ribeiro, 1918) | CIG 1675 | Autochthonous*/EN | ––– |
| 120 *Zungaro jahu* (Ihering, 1898) | | Autochthonous* | ––– |
| **Doradidae** | | | |
| 121 *Ossancora eigenmanni* (Boulenger, 1895) | NUP 1706 | Allochthonous | Itaipu |
| 122 *Pterodoras granulosus* (Valenciennes, 1821) | | Allochthonous* | Itaipu |
| 123 *Rhinodoras dorbignyi* (Kner, 1855) | NUP 1701 | Autochthonous | ––– |
| 124 *Trachydoras paraguayensis* (Eigenmann & Ward, 1907) | NUP 1696 | Allochthonous | Itaipu |
| **Auchenipteridae** | | | |
| **Auchenipterinae** | | | |
| 125 *Ageneiosus inermis* (Linnaeus, 1766) | NUP 2010 | Allochthonous | Itaipu |

**Continued Table 1.**

| Species | Voucher | Origin/Threat level | Introduction Vector |
|---|---|---|---|
| 126 *Ageneiosus militaris* Valenciennes, 1836 | NUP 1935 | Autochthonous | ––– |
| 127 *Ageneiosus ucayalensis* Castelnau, 1855 | | Allochthonous | Itaipu |
| 128 *Auchenipterus osteomystax* (Miranda-Ribeiro, 1918) | | Autochthonous | ––– |
| 129 *Trachelyopterus galeatus* (Linnaeus, 1766) | NUP 1702 | Allochthonous | Itaipu |
| **Centromochlinae** | | | |
| 130 *Glanidium cesarpintoi* Ihering, 1928 | NUP 5455 | Autochthonous | ––– |
| 131 *Tatia neivai* (Ihering, 1930) | NUP 18031 | Autochthonous | ––– |
| **Gymnotiformes** | | | |
| **Gymnotidae** | | | |
| 132 *Gymnotus inaequilabiatus* (Valenciennes, 1839) | NUP 18164 | Autochthonous | ––– |
| 133 *Gymnotus pantanal* Fernandes, Albert, Daniel-Silva, Lopes, Crampton, & Almeida-Toledo, 2005 | NUP 14628 | Allochthonous | Baiting |
| 134 *Gymnotus sylvius* Albert & Fernandes-Matioli, 1999 | NUP 14593 | Autochthonous | ––– |
| **Sternopygidae** | | | |
| 135 *Eigenmannia trilineata* López e Castello, 1966 | CIG 2184 | Autochthonous | ––– |
| 136 *Eigenmannia virescens* (Valenciennes, 1836) | CIG 103 | Autochthonous | ––– |
| 137 *Sternopygus macrurus* (Bloch & Shneider, 1801) | CIG 1649 | Autochthonous | ––– |
| **Rhamphichthydae** | | | |
| 138 *Rhamphichthys hahni* (Meinken, 1937) | NUP 1708 | Allochthonous | Itaipu |
| **Apteronotidae** | | | |
| 139 *Apteronotus* aff. *albifrons* (Linnaeus, 1766) | NUP 16760 | Allochthonous | Itaipu |
| 140 *Porotergus ellisi* Arámburu, 1957 | NUP 2092 | Autochthonous | ––– |
| **Cyprinodontiformes** | | | |
| **Poeciliidae** | | | |
| 141 *Phalloceros harpagos* Lucinda, 2008 | NUP 15967 | Autochthonous | ––– |
| 142 *Poecilia reticulata* Peters, 1859 | NUP 3131 | Allochthonous | Mosquito control and aquarism |
| **Synbranchiformes** | | | |
| **Synbranchidae** | | | |
| 143 *Synbranchus marmoratus* Bloch, 1795 | NUP 11702 | Autochthonous | ––– |
| **Perciformes** | | | |
| **Cichlidae** | | | |
| 144 *Cichla piquiti* Kullander & Ferreira, 2006 | | Allochthonous | Sport-fishing |
| 145 *Cichlasoma paranaense* Kullander, 1983 | NUP 14597 | Autochthonous | ––– |
| 146 *Crenicichla britskii* Kullander, 1982 | NUP 16737 | Autochthonous | ––– |
| 147 *Crenicichla jaguarensis* Haseman, 1911 | NUP 18040 | Autochthonous | ––– |
| 148 *Crenicichla jupiaensis* Britski & Luengo, 1968 | NUP 14892 | Autochthonous/EN | ––– |
| 149 *Crenicichla* sp. | NUP 5446 | Autochthonous | ––– |
| 150 *Geophagus* aff. *brasiliensis* (Quoy & Gaimard, 1824) | NUP 15643 | Autochthonous | ––– |
| 151 *Oreochromis niloticus* (Linnaeus, 1758) | NUP 15918 | Exotic | Fish farming |
| **Sciaenidae** | | | |
| 152 *Plagioscion squamosissimus* (Heckel, 1840) | | Allochthonous | Stocking |

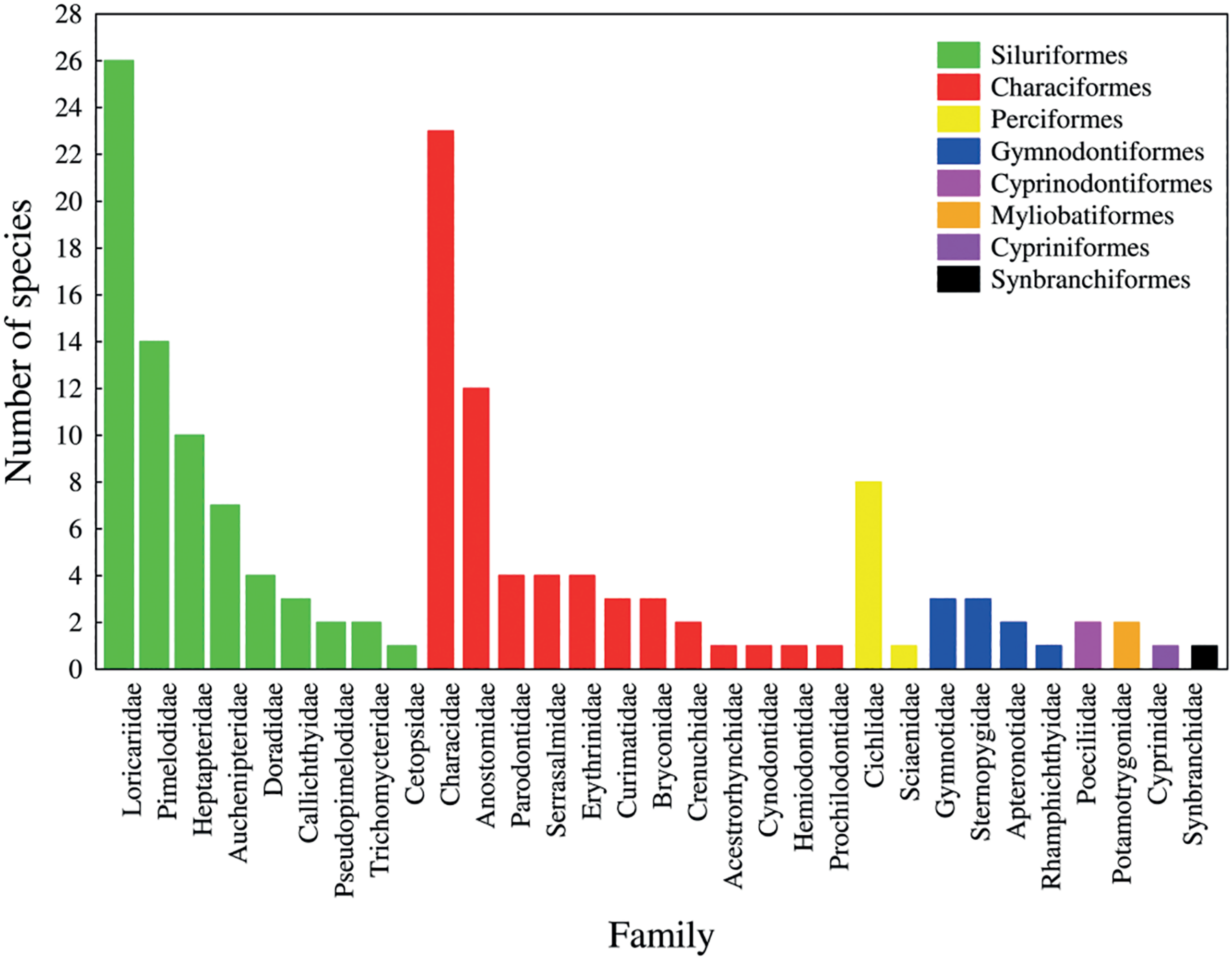

**Figure 2.** Number of species per family of the ichthyofauna recorded for the Piquiri River basin, upper Paraná River, Brazil. Colors indicate the orders, namely from the most to the less specific.

1859, *Cichla piquiti* Kullander & Ferreira, 2006 and *Plagioscion squamosissimus* (Heckel, 1840), also considered allochthonous fish species, were introduced by baiting, mosquito control and aquarism, sport fishing and stocking, respectively (Table 1). Two other exotic species, *Cyprinus carpio* Linnaeus, 1758 and *Oreochromis niloticus* (Linnaeus, 1758) were introduced by fish farming (Table 1). Thus, the main vectors of introduction of the fish species in the Piquiri River basin were Itaipu (67% of the fish species introduced), Itaipu channel (10%) and fish farming (10%) (Figure 3).

Of the 152 species recorded here, approximately 3% (5 species) were classified with a threat level (Table 1). *Apareiodon vladii* Pavanelli (2006) showed a vulnerable conservation status (VU) and is considered at high risk of extinction in the wild, while *Brycon orbignyanus* (Valenciennes 1850), *Myloplus tiete* (Eigenmann & Norris, 1900), *Steindachneridion scriptum* (Miranda-Ribeiro, 1918), and *Crenicichla jupiaensis* Britski & Luengo (1968) were designated as endangered conservation status (EN), i.e., they face a very high risk of extinction in the wild.

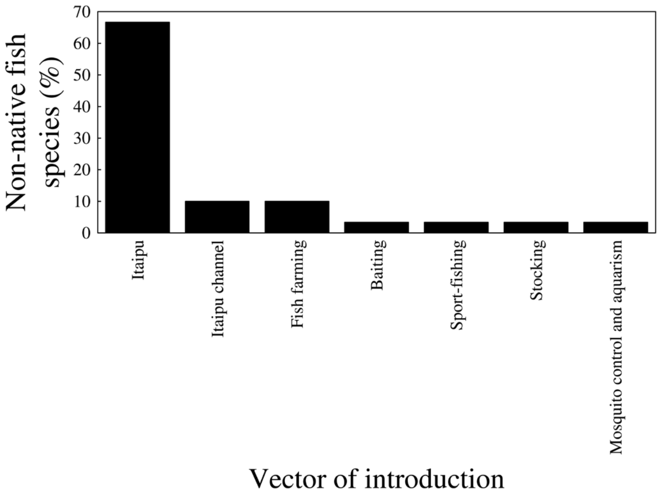

**Figure 3.** Non-native fish species according to their introduction vectors into the Piquiri River basin, upper Paraná River, Brazil.

Seventeen fish species recorded in the Piquiri River basin have migratory behavior – (11%, Table 1). In addition, *Brycon orbignyanus* (Valenciennes, 1850) and *Steindachneridion scriptum* (Miranda-Ribeiro, 1918) are listed as endangered in threat level status.

## Discussion

The outcomes of the update reveal 152 fish species, many which have already been reported by Graça & Pavanelli (2007), in the floodplain of the upper Paraná River and bordering areas. Although the Piquiri River drainage basin is partly within this floodplain, our results point to an intimate association between the basin and the maintenance of ichthyofauna biodiversity in this stretch of the upper Paraná River. This is because the studied river is one of the last refuge areas for a great proportion of the remaining native ichthyofauna (Baumgartner et al. 2004, Antonio et al. 2007, Gubiani et al. 2010, Affonso et al. 2015).

Ichthyofauna survey. The current survey discloses a much higher number of fish species than that recorded by Gubiani et al. (2006, 2010), who reported 62 and 69 species in 2006 and 2010, respectively. This new update represents a nearly 120% increase in the number of species recorded in the basin since the last list was released. When comparing the ichthyofauna found in the basins located in the State of Paraná, the Piquiri River basin has an absolute richness of fish species that is higher than the richness of the Pirapó basin (76 species, Pagotto et al. 2012), the Ivaí River basin (118 species, Frota et al. 2016a), the upper and lower Iguaçu River basin (41 and 106 species respectively, Ingenito et al. 2004, Baumgartner et al. 2012), and the Tibagi River basin (151 species, Raio & Bennemann 2010). Approximately 49% of the species listed here were coincident with those recorded for the upper Paraná River (see Langeani et al. 2007).

Introduced species. Most of the species introduced into the Piquiri River basin dispersed after the construction of the Itaipu Dam. After the dam was closed, the Sete Quedas, a natural geographic barrier separating two ichthyofauna provinces, was flooded. This area comprises the mid-lower and upper Paraná River within the city of Guaíra (Graça & Pavanelli 2007, Vitule et al. 2012). Consequently, many fish species previously isolated by this barrier were introduced into the upper Paraná River basin (Júlio Jr. et al. 2009, Vitule et al. 2012). Hence, after the closing of Itaipu Dam (see Júlio Jr. et al. 2009), 23 of the introduced species were recorded in the Piquiri River basin. Conversely, the occurrence of some species such as *Bryconamericus exodon*, *Hemiodus orthonops*, and *Pimelodella taenioptera*, is not related to the flooding of the Sete Quedas but is related to the functioning of the Itaipu Piracema channel, a passage for fish downstream and upstream of the Itaipu Dam (Graça & Pavanelli 2007, Júlio Jr. et al. 2009). This channel is envisaged as a continuous source of fish species introduced to the upper Paraná River basin (Agostinho et al. 2015).

Transposition systems that can be used as fish passages have been among the main strategies in an endeavor by the Brazilian authorities and electric power sector to reduce the damming effects on populations of migratory fish (Pompeu et al. 2012). Nonetheless, in addition to contributing to the rise of non-native fish, such systems have been identified as true ecological traps in some Brazilian dams, and their closure should be required (Pelicice & Agostinho 2008, Agostinho et al. 2012, Pompeu et al. 2012). These facts, which are related to the construction and functioning of the Itaipu Power Plant, are an indication that a biotic homogenization process is ongoing in the ichthyofauna of the upper Paraná River basin. These processes consequently lead to a decrease in taxonomic, genetic, and/or functional differences in the previously described biota (Olden 2006, Daga et al. 2015). Therefore, the construction of dams are a major form of global biodiversity loss and has been considered an unacceptable environmental alteration (Rockström et al. 2009, Stigall 2010, Vitule et al. 2012).

In addition, there are an alarming number of cases of species introduced by stocking, sport fishing, live bait use, control of mosquitoes, and fishkeeping (see Daga et al. 2015; Ribeiro et al. 2017). For instance, curvina (*Plagioscion squamosissimus*), a species introduced for stocking purposes, poses a threat to the other piscivorous species in the Piquiri River basin because it feeds on the same sources and is, most likely, a strong competitor (Pereira et al. 2015). The excellent visual predator, *Cichla piquiti*, has been illegally introduced throughout the country mainly for sport fishing and represents a threat to the diversity of native fish (Pelicice & Agostinho 2009; Pelicice et al. 2015) in the Piquiri River basin. All *Gymnotus* species are often used as live bait, which might cause releases between basins by ill-informed fishers. Although only *G. pantanal* is considered allochthonous, the other species of the genus have truly uncertain origins (Júlio Jr. et al. 2009). In addition, morphometric data show no differences among populations of *G. inaequilabiatus* from various sites of the upper Paraná River (Frota et al. 2014). *Poecilia reticulata* has been widespread worldwide as an ornamental animal and mosquito larvae control agent (Dussalt & Kramer 1981, Azevedo-Santos et al. 2016). This species is considered to be one of the most abundant in rural and urban streams at present (Oliveira & Bennemann 2005, Cunico et al. 2012, Pereira et al. 2014) likely because of its high resistance and resilience (Gomiero & Braga 2007, Daga et al. 2012) in addition to its high competitive efficiency against competition from invasive and native species (Pompeu & Alves 2003).

Another important vector of species introduction in aquatic environments is the escapes arising from fish farming. The Federal Law nº 5989 of 2009 intends to naturalize non-native fish species by decree in Brazil. Following this proposal, *Cyprinus carpio* and *Oreochromis niloticus*, which are non-native species, would end up being naturalized in the Piquiri River basin; therefore, they would be perceived as natural and can be used without legal restrictions in fish farming (Padial et al. 2017). Around the Piquiri River basin, innumerable fish farms are settled and breeding non-native species that show a high invasion risk (Lima Jr. et al. 2012, Pelicice et al. 2014, Forneck et al. 2016). Several authors have asserted the invading potential arising from fish farms and the negative effects of new introductions (Orsi & Agostinho 1999, Daga et al. 2015, Daga et al. 2016, Lima et al. 2016).

Endangered species. Environments with species listed in the vulnerable and endangered categories should be prioritized for conservation since the most likely evidence assigns them as highly and very highly endangered in the wild, respectively (IUCN 2017). The species of the Piquiri River basin listed in these categories are rare, so their population survival will depend narrowly on their tolerance to the biotic and abiotic changes occurring in the basin. Registered endangered species have rheophilic habits, are migratory (*Brycon orbignyanus* and *Steindachneridion scriptum*), and require allochthonous food sources (*Brycon orbignyanus* and *Myloplus tiete*) (Machado et al. 2008). The construction of dams, therefore, will lead to extreme changes in river habitats, turning rivers into semi-lentic systems, which exerts an intense negative effect on the fish species (Agostinho et al. 2016; Pelicice et al. 2017).

Migratory behavior and construction of electric power stations. Like other major tributaries of the floodplain of the upper Paraná River, the Piquiri River basin is used as a spawning ground for migratory fish (Baumgartner et al. 2004, Gubiani et al. 2010, Gogola et al. 2013). A vast majority of migratory species living in the basin are made up of large fish with relative ecological and economic importance to the region, such as pimelodida catfish, *Salminus* spp., *Leporinus* spp., *Brycon orbignyanus*, *Piaractus mesopotamicus*, and *Prochilodus lineatus* (Hoeinghaus et al. 2009). Recreational fishing of large migratory fish from the Piquiri River basin also poses a serious threat because it can alter the structure and production of the population stocks (Cooke & Cowx 2004).

In the coming years, the construction of 34 SPPs and 6 PPs, which must be installed within the main channel of the Piquiri River and its important tributaries, is expected (Figure 4). Some of these locations will continue to have no ichthyofaunal sampling prior to construction, particularly locations in Piquiri River tributaries such as the Sapucaia River (Figures 1 and 4). The electric power installations planned for the basin area would prevent fish access to ideal habitats, thus affecting fish distribution and reproduction and fishing in addition to influencing the basin landscape, causing serious ecosystemic effects (Affonso et al. 2015). The nature and intensity of the changes on aquatic biota are highly variable between reservoirs and should be studied on a case-by-case basis (Agostinho et al. 2016). However, overall, the dams cause extreme changes in the hydrological regime (Thomaz et al. 2004) as well as changes in the longitudinal distribution of fish species (Petry et al. 2011). Thus, electric power enterprises in the Piquiri River basin should be discussed in public hearings with joint initiatives undertaken by citizens, law specialists, and universities (Affonso et al. 2015).

New species and biogeography. The species recorded as new in this study account for a total percentage quite near that shown for the entire basin of the upper Paraná River (14% in Langeani et al. 2007). This shows that even with the increasing number of species descriptions over time, the knowledge of the actual number of animal species and respective geographical distributions in the area is far from complete (Ota et al. 2015). A great part of the new findings in the Piquiri River basin arose from an increased sampling effort for several scientific purposes. Therefore, the continuity of these samplings will undoubtedly reveal accurate data on new endangered populations. As such, similar efforts should be carefully extended to sites with no sampling efforts, and sites where the construction of PPs and SPPs are planned.

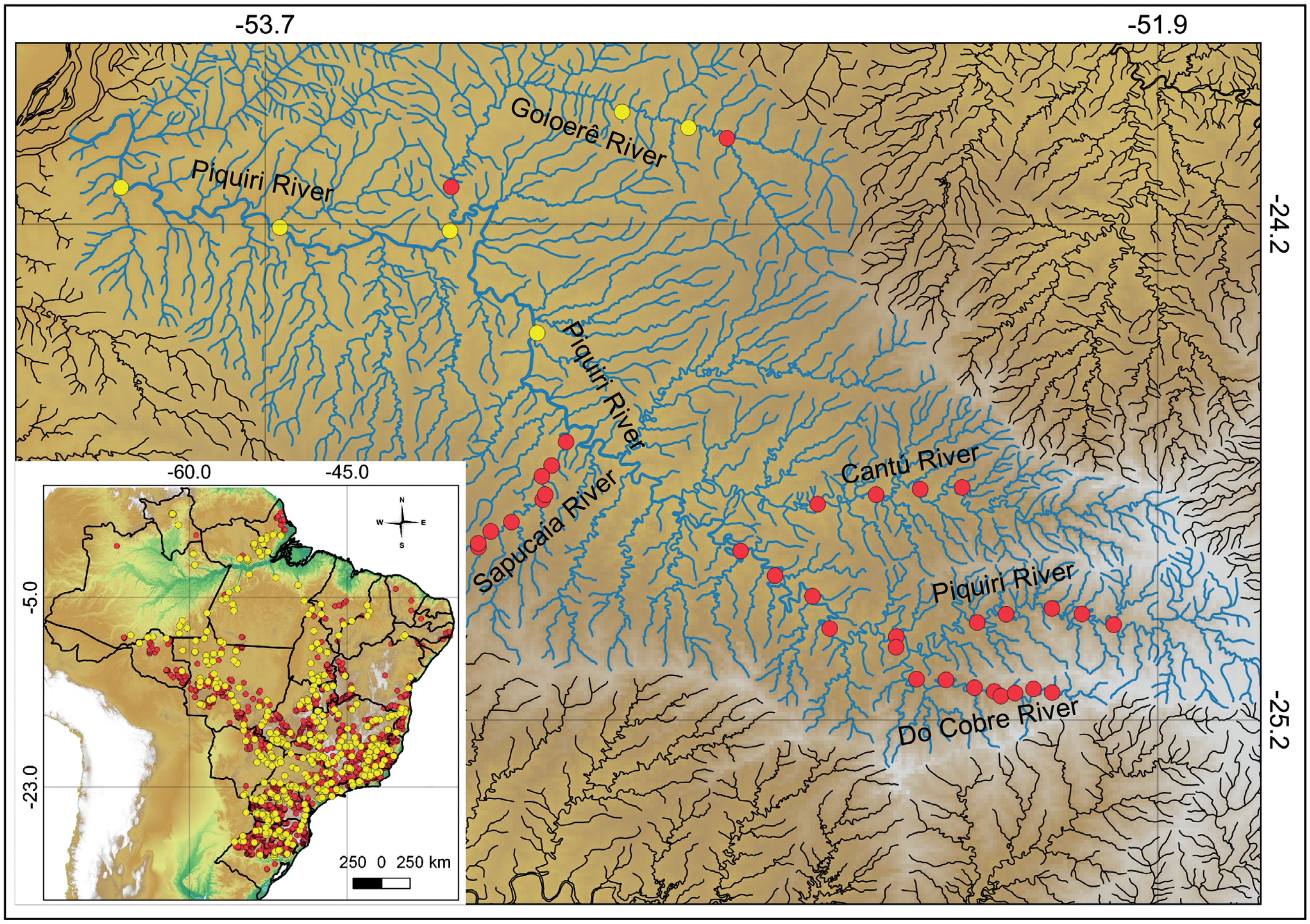

**Figure 4.** Map showing the locations of small power plants (SPPs, red dots) and power plants (PPs, yellow dots) predicted in Brazil, mainly within the Piquiri River basin (catchment area in blue). The number of localities within the Piquiri River basin represents 34 SPPs and 6 PPs.

From an ichthyofaunal standpoint, the upper Paraná River basin encompasses a unique historical area, which is complex and partly shared with neighboring drainage areas (Langeani et al. 2007). One likely area of endemism exists in the headwater streams, mainly in the upper section of the Piquiri River basin. In such high altitudes, *Trichomycterus* cf. *stawiarski* and *Planaltina* sp. are shared, respectively, with the basins of the Jordão (lower Iguaçu River) and Ivaí (upper Paraná River) Rivers. The former species is reported as endemic to the Iguaçu River basin (Baumgartner et al. 2012), while the latter is regarded as endemic to the upper Ivaí River basin (Frota et al. 2016a). Therefore, the presence of these species in the Piquiri River basin suggests past connections between the upper courses of those basins that might have occurred prior to the uplift of Serra da Esperança, which caused the isolation of the respective headwaters (Frota et al. 2016b). Thus, the identification of an endemic zone in the neighboring region between the Piquiri, Ivaí, and Jordão basins would allow an improved understanding of the local biota evolution (Morrone 1994) in addition to a prioritization of its value for biodiversity conservation purposes (Löwenberg-Neto & Carvalho 2004).

## Conclusions

In conclusion, the Piquiri River basin holds a large number of species, and some of these species are rare, endangered, migratory, endemic, and even unknown by science. This study and the various present and future threats to the fish biodiversity of the Piquiri River basin point to the potential disappearance of certain species before their actual distribution patterns are known or before they are known or formally described (e.g., *Wallacean* and *Linnean shortfalls*, Brown & Lomolino 1998). Therefore, this environment must be preserved so that the local and regional fish fauna biodiversity can be maintained, particularly since this area can be considered a high conservation area. Furthermore, ongoing studies on the systematics, biology, and ecology of fish species, as well as suitable strategies to mitigate potential ecological, sociological, and economic impacts on them, may help improve and accomplish the goals of conservationists.

## Acknowledgements

We are profoundly grateful to the *Fundação Araucária* (Seti-PR), Gerpel-Unioeste and Nupélia-UEM for financial support; to Francisco Alves Teixeira, Wladimir Marques Domingues, Rodrigo Júnio da Graça and Gerpel´s staff team for assistance in the field studies; to Claudimar Jean dos Santos for helping in fish cataloging; to Cláudio Zawadzki, Luiz Fernando Caserta Tencatt, Gabriel Deprá, Fagner de Souza, and Carlos Alexandre Miranda Oliveira for helping in fish identification. AF, WJG and VPM received grants from *Fundação Araucária*.

## Author Contributions

Daiane Cavalli and Éder André Gubiani: conceived, designed the samplings and wrote the paper.

Augusto Frota: contributed to data acquisition, analysis and interpretation of data, drafting of the manuscript and wrote the paper.

Weferson Júnio da Graça: contributed to the analysisand interpretation of data, and critical revision for adding substantive intellectual content.

Angelica Dorigon Lira: contributed to data acquisition, analysis of the data and wrote the paper

Vladimir Pavan Margarido: contributed to data acquisition and critical revision for adding substantive intellectual content.

## Conflicts of interest

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

## References

AFFONSO, I.P., AZEVEDO, R.F., SANTOS, N.L.C., DIAS, R.M., AGOSTINHO, A.A. & GOMES, L.C. 2015. Pulling the plug:strategies to preclude expansion of dams in Brazilian rivers with high-priority for conservation. Nat. Conservação 13(2):199-203.

AGOSTINHO, A.A., JÚLIO Jr., H.F., GOMES, L.C., BINI, L.M. & AGOSTINHO, C.S. 1997. Composição, abundância e distribuição espaço-temporal da ictiofauna. In: A Planície de Inundação do Alto Rio Paraná. A.E.A. de M. Vazzoler, A.A. Agostinho, N.S. Hahn (Eds.). EDUEM, Maringá, pp. 179-208.

AGOSTINHO, A.A. & JÚLIO Jr., H.F. 1999. Peixes da bacia do alto rio Paraná. In: Estudos ecológicos de comunidades de peixes tropicais. R.H. Lowe-McConnell (Ed.). EDUSP, São Paulo, pp. 375-399.

AGOSTINHO, A.A., GOMES, L.C., SUZUKI, H.I., JÚLIO Jr., H.F. 2003. Migratory fishes of the Upper Paraná River Basin, Brazil. In: Migratory fishes of South America: biology, social importance and conservation status. J. Carolsfeld, B. Harvey, C. Ross, A. Baer (Eds.). The World Bank and the International Development Research Centre, Victoria, pp. 19-99.

AGOSTINHO, A.A., BINI, L.M., GOMES, L.C., JÚLIO JÚNIOR, H.F., PAVANELLI, C.S. & AGOSTINHO C.S. 2004. Fish assemblages. In: The Upper Paraná River and its Floodplain: Physical Aspects, Ecology and Conservation. S.M. Thomaz, A.A. Agostinho, N.S. Hahn (Eds). The Netherlands Backhuys Publishers, Leiden, pp. 223-246.

AGOSTINHO, A.A., AGOSTINHO, C.S., PELICICE, F.M. & MARQUES, E.E. 2012. Fish ladders: safe fish passage or hotspot for predation? Neotrop. Ichthyol. 10(4):687-696.

AGOSTINHO, A.A., SUZUKI, H.I., FUGI, R., ALVES, D.C., TONELLA, L.H. & ESPINDOLA, L.A. 2015. Ecological and life history traits of *Hemiodus orthonops* in the invasion process: looking for clues at home. Hydrobiologia 746(1):415-430.

AGOSTINHO, A.A., GOMES, L.C., SANTOS, N.C.L., ORTEGA, J.C.G. & PELICICE, F.M. 2016. Fish assemblages in Neotropical reservoirs: colonization patterns, impacts and management. Fish. Res. 173:26-36.

ANEEL [Agência Nacional de Energia Elétrica]. 2016. Sistema de Informações Georreferenciadas do Setor Elétrico (SIGEL). https://sigel.aneel.gov.br/kmz.html (Access 08 Dec 2016).

ANTONIO, R.R., AGOSTINHO, A.A., PELICICE, F.M. BAILLY, D., OKADA, E.K. & DIAS, J.H.P. 2007. Blockage of migration routes by dam construction: can migratory fish find alternative routes? Neotrop. Ichthyol. 5(2):177-184.

AZEVEDO-SANTOS, V.M., VITULE, J.R.S., GARCÍA-BERTHOU, E., PELICICE, F.M. & SIMBERLOFF, D. 2016. Misguided strategy for mosquito control. Science 351(6274):675.

BAUMGARTNER, G., NAKATANI, K., GOMES, L.C., BIALETZKI, A. & SANCHES, P. 2004. Identification of spawning sites and natural nurseries of fishes in the upper Paraná River, Brazil. Environ. Biol. Fish. 71(2):115-125.

BAUMGARTNER, G., PAVANELLI, C.S., BAUMGARTNER, D., BIFI, A. G., DEBONA, T. & FRANA, V.A. 2012. Peixes do Baixo Rio Iguaçu. Eduem, Maringá.

BRASIL. Ministério do Meio Ambiente. 2014. Portaria MMA Nº 445, de 17 de Dezembro de 2014. http://www.pescamadora.com.br/pdf/Portaria-MMA-445_2014-Lista-Peixes-Ameacados-Extincao.pdf (Access 25 Nov 2016).

BRASIL. Ministério do Meio Ambiente. 2015. Portaria MMA Nº 98, de 28 de Abril de 2015.http://www.icmbio.gov.br/cepsul/images/stories/legislacao/Portaria/2015/p_mma_98_2015_altr_p_445_2014.pdf (Access 25 Nov 2016).

BROWN, J.H. & LOMOLINO, M.V. 1998. Biogeography. 2nd ed. SinauerPress, Sunderland.

COOKE, S.J. & COWX, I.G. 2004. The role of recreational fishing in global fish crises. BioScience 54(9):857-859.

CRIA [Centro de Referência em Informação Ambiental]. 2016. SpeciesLink. http://splink.cria.org.br (Acess 25 Nov 2016).

CUNICO, A.M., FERREIRA E.A., AGOSTINHO, A.A., BEAUMORD, A.C. & FERNANDES, R. 2012. The effects of local and regional environmental factors on the structure of fish assemblages in the Pirapó Basin, Southern Brazil. Landsc. Urban Plan. 105(3):336-344.

DAGA, V.S., GUBIANI, É.A., CUNICO, A.M. & BAUMGARTNER, G. 2012. Effects of abiotic variables on the distribution of fish assemblages in streams with different anthropogenic activities in southern Brazil. Neotrop. Ichthyol. 10(3):643-652.

DAGA, V.S., SKÓRA, F., PADIAL, A.A., ABILHOA, V., GUBIANI, É.A. & VITULE, J.R.S. 2015. Homogenization dynamics of the fish assemblages in Neotropical reservoirs: comparing the roles of introduced species and their vectors. Hydrobiologia 746:327-347.

DAGA, V.S., DEBONA, T., ABILHOA, V., GUBIANI, É.A. & VITULE, J.R.S. 2016. Non-native fish invasions of a Neotropical ecoregion with high endemism: a review of the Iguaçu River. Aquat. Invasions 11(2):209-223.

DEI TOS, C., GOMES, L.C. & RODRIGUES, M.A. 2014. Variation of the ichthyofauna along the Goioerê River: an important tributary of the Piquiri-Paraná basin. Iheringia, Ser. Zool. 104(1):104-112.

DELARIVA, R.L. & SILVA, J.C. 2013. Fish fauna of headwater streams of Perobas Biological Reserve, a conservation unit in the Atlantic Forest of the Northwestern Paraná State, Brazil. Check List 9(3):549-554.

DUSSALT, G.V. & KRAMER, D.L. 1981. Food and feeding behavior of the guppy, *Poecilia reticulata* (Pisces: Poeciliidae). Can. J. Zool. 59(4):684-701

ESCHMEYER, W.N., FRICKE, R. & VAN DER LAAN, R. (eds.). 2016. Catalog of fishes: genera, species, references. http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp (Access 19 Dec 2016).

FORNECK, S.C., DUTRA, F.M., ZACARKIM, C.E. & CUNICO, A.M. 2016. Invasion risks by non-native freshwater fishes due to aquaculture activity in a Neotropical stream. Hydrobiologia 773:193-205.

FROTA, A., DEPRÁ, G.C., PETENUCCI, L.M. & GRAÇA, W.J. 2016a. Inventory of the fish fauna from Ivaí River basin, Paraná State, Brazil. Biota Neotrop. 16(3):e20150151 http://dx.doi.org/10.1590/1676-0611-BN-2015-0151 (Access 21 Mar 2017).

FROTA, A., GONÇALVES, E.V.R., DEPRÁ, G.C. & GRAÇA, W.J. 2016b. Inventory of the ichthyofauna from the Jordão and Areia river basins (Iguaçu drainage, Brazil) reveals greater sharing of species than thought. Check List 12(6):1995.

FROTA, A. SOUZA, F. & SILVA, H.P. 2014. Análise morfométrica de *Gymnotus inaequilabiatus* (Valenciennes, 1839) (Gymnotiformes: Gymnotidae) em diferentes bacias hidrográficas brasileiras. Biota Amazôn. 4(4):27-32.

GALVES, W., SHIBATTA, O.A. & JEREP, F. C. 2009. Estudos sobre a diversidade de peixes da bacia do alto rio Paraná: uma revisão histórica. Semina 30(2):141-154.

GOGOLA, T.M., DAGA, V.S., SILVA, P.R.L., SANCHES, P.V., GUBIANI, É.A., BAUMGARTNER, G. & DELARIVA, R.L. 2010. Spatial and temporal distribution patterns of ichthyoplankton in a region affected by water regulation by dams. Neotrop. Ichthyol. 8(2):341-349.

GOGOLA, T.M., SANCHES P.V., GUBIANI É.A. & DA SILVA P.R.L. 2013. Spatial and temporal variations in fish larvae assemblages of Ilha Grande National Park, Brazil. Ecol. Freshw. Fish 22(1):95-105.

GOMIERO, L.M & BRAGA, F.M.S. 2007. Reproduction of a fish assemblage in the State of São Paulo, Southeastern Brazil. Braz. J. Biol. 67(2):283-292.

GRAÇA, W.J. & PAVANELLI, C.S. 2007. Peixes da planície de inundação do alto rio Paraná e áreas adjacentes. Eduem, Maringá.

GUBIANI, É.A., HOLZBACH, A.J., BAUMGARTNER, G., REZENDE NETO, L.B. & BERGMANN, F. 2006. Fish, Piquiri River, Upper Paraná River basin, Paraná State, Brazil. Check List 2(3):9-14.

GUBIANI, É.A., GOMES, L.C., AGOSTINHO, A.A. & BAUMGARTNER, G. 2010. Variations in fish assemblages in a tributary of the upper Paraná river, Brazil: a comparison between pre and post-closure phases of dams. River Res. Appl. 26(7):848-865.

HOEINGHAUS, D.J., AGOSTINHO, A.A., GOMES, L.C., PELICICE, F.M., OKADA, E.K., LATINI, J.D., KASHIWAQUI, E.A.L. & WINEMILLER, K.O. 2009. Effects of river impoundment on ecosystem services of large tropical rivers: embodied energy and market value of artisanal fisheries. Conserv. Biol. 23(5):1222-1231.

INGENITO, L.F.S., DUBOC, L.F. & ABILHOA, V. 2004. Contribuição ao conhecimento da ictiofauna da bacia do alto rio Iguaçu, Paraná, Brasil. Arquivos de Ciências Veterinárias e Zoológicas da UNIPAR 7(1):23-36.

IUCN - International Union for Conservation of Nature. 2017. IUCN Red List of Threatened Species. Version 2014.1 [http://www.iucnredlist.org] (Acess 15 Jan 2017).

JACKSON, D.A., PERES-NETO, P.R. & OLDEN, J.D. 2001. What controls who is where in freshwater fish communities - the roles of biotic, abiotic, and spatial factors. Can. J. Fish. Aquat. Sci. 58:157-170.

JÚLIO Jr., H.F., DEI TOS, C., AGOSTINHO, A.A. & PAVANELLI, C.S. 2009. A massive invasion of fish species after eliminating a natural barrier in the upper rio Paraná basin. Neotrop. Ichthyol. 7(4):709-718.

LANGEANI, F., CASTRO, R.M.C., OYAKAWA, O.T., SHIBATTA, O.A., PAVANELLI, C.S. & CASATTI, L. 2007. Diversidade da ictiofauna do alto Rio Paraná: composição atual e perspectivas futuras. Biota Neotrop. 7(3):181-197 http://www.biotaneotropica.org.br/v7n3/pt/abstract?article+bn03407032007 (Access 21 Mar 2017).

LIMA Jr., D.P., PELICICE, F.M., VITULE, J.R.S. & AGOSTINHO, A.A. 2012. Aquicultura, política e meio ambiente no Brasil: novas propostas e velhos equívocos. Nat. Conservação 10(1):88-91.

LIMA, L.B., OLIVEIRA, F.J.M., GIACOMINI, H.C. & LIMA-JUNIOR, D.P. 2016. Expansion of aquaculture parks and the increasing risk of non-native species invasions in Brazil. Rev. Aquacult. 0:1-12.

LÖWENBERG-NETO, P. & CARVALHO, C.J.B. 2004. Análise Parcimoniosa de Endemicidade (PAE) na delimitação de áreas de endemismos: inferências para conservação da biodiversidade na Região Sul do Brasil. Nat. Conservação 2(2):58-65.

MAACK, R. 2012. Geografia Física do Estado do Paraná. 4ª ed. Editora UEPG, Ponta Grossa.

MACHADO, A.B.M., DRUMMOND, G.M. & PAGLIA, A.P. (eds.). 2008. Livro vermelho da fauna brasileira ameaçada de extinção. 1ª ed. Ministério do Meio Ambiente, Brasília.

MORRONE, J. J. 1994. On the identification of areas of endemism. Syst. Biol. 43:438-444.

NAKATANI, K., AGOSTINHO, A.A., BAUMGARTNER, G., BIALETZKI, A., SANCHES, P.V., MAKRAKIS, M.C. & PAVANELLI, C.S. 2001. Ovos e larvas de peixes de água doce: desenvolvimento e manual de identificação. EDUEM, Maringá.

OLDEN, J.D. 2006. Biotic homogenization: a new research agenda for conservation biogeography. J. Biogeogr. 33(12):2027-2039.

OLIVEIRA, D.C. & BENNEMANN, S.T. 2005. Ictiofauna, recursos alimentares e relações com as interferências antrópicas em um riacho urbano no sul do Brasil. Biota Neotrop. 5(1):95-107 http://www.biotaneotropica.org.br/v5n1/pt/abstract?article+BN02905012005 (Access 21 Mar 2017).

OLIVEIRA, A.G., GOMES, L.C., LATINI, J.D. & AGOSTINHO, A.A. 2014. Implications of using a variety of fishing strategies and sampling techniques across different biotopes to determine fish species composition and diversity. Nat. Conservação 12(2):112-117.

ORSI, M.L. & AGOSTINHO, A.A. 1999. Introdução de espécies de peixes por escapes acidentais de tanques de cultivo em rios da Bacia do rio Paraná, Brasil. Rev. Bras. Zool. 16(2):557-560.

OTA, R.R., MESSAGE, H.J., GRAÇA, W.J. & PAVANELLI, C.S. 2015. Neotropical Siluriformes as a model for insights on determining biodiversity of animal groups. PLoS ONE 10(7): e0132913.

PADIAL, A.A., AGOSTINHO, A.A., AZEVEDO-SANTOS, V.M., FREHSE, F.A., LIMA-JUNIOR, D.P., MAGALHÃES, A.L.B., MORMUL, R.P., PELICICE, F.M., BEZERRA, L.A.V., ORSI, M.L., PETRERE-JUNIOR, M. & VITULE, J.R.S. 2017. The "Tilapia Law" encouraging non-native fish threatens Amazonian River basins. Biodivers. Conserv. 26(1):243-246.

PAGOTTO, J.P.A., VERÍSSIMO, S., GOULART, E. & MISE, F.T. 2012. Fishes (Osteichthyes: Actinopterygii) from the Pirapó River drainage, upper Paraná River basin, Paraná state, Brazil. Check List 8(3):463-468.

PAIVA, G.V. 1982. Grandes represas do Brasil. Editerra, Brasília.

PAVANELLI, C.S. 2006. New species of *Apareiodon* (Teleostei: Parodontidae) from the rio Piquiri, Upper Paraná Basin, Brazil. Copeia 2006(1):89-95.

PELICICE, F.M. & AGOSTINHO, A.A. 2008. Fish-passage facilities as ecological traps in large Neotropical rivers. Conserv. Biol. 22(1):180–188.

PELICICE, F.M. & AGOSTINHO, A.A. 2009. Fish fauna destruction after the introduction of a non-native predator (*Cichla kelberi*) in a Neotropical reservoir. Biol. Invasions 11:1789-1801.

PELICICE, F.M., VITULE, J.R.S., LIMA JUNIOR, D.P., ORSI, M.L. & AGOSTINHO, A.A. 2014. A serious new threat to Brazilian freshwater ecosystems: the naturalization of nonnative fish by decree. Conserv. Lett. 7(1):55-60.

PELICICE, F.M., LATINI, J.D. & AGOSTINHO, A.A. 2015. Fish fauna disassembly after the introduction of a voracious predator: main drivers and the role of the invader's demography. Hydrobiologia 746(1):271-283.

PELICICE, F.M., AZEVEDO-SANTOS, V.M., VITULE, J.R.S., ORSI, M., LIMA-JUNIOR, D.P., MAGALHÃES, A.L.B., POMPEU, P.S., PETRERE Jr., M. & AGOSTINHO, A.A. 2017. Neotropical freshwater fishes imperilled by unsustainable policies. Fish. Fish. 18(6):1119-1133.

PEREIRA, A.L., RIBEIRO, V.R., GUBIANI, É.A., ZACARKIM, C.E. & CUNICO, A.M. 2014. Ichthyofauna of urban streams in the western region of Paraná State, Brazil. Check List 10(3):550-555.

PEREIRA, L.S., AGOSTINHO, A.A. & GOMES, L.C. 2015. Eating the competitor: a mechanism of invasion. Hydrobiologia 746(1):223-231.

PETRY, A.C., THOMAZ, S.M. & ESTEVES, F.A. 2011. Comunidade de peixes. In: Fundamentos de Limnologia. F.A. Esteves (Org.). 3ed. Editora Interciência, Rio de Janeiro, pp. 609-624.

POMPEU, P.S., AGOSTINHO, A.A. & PELICICE, F.M. 2012. Existing and future challenges: the concept of successful fish passage in South America. River Res. Appl. 28(4):504-512.

POMPEU, P.S. & ALVES, C.B.M. 2003. Local fish extinction in a small tropical lake in Brazil. Neotrop. Ichthyol. 1(2):133-135.

RAIO, C.B. & BENNEMANN, S.T. 2010. A ictiofauna da bacia do rio Tibagi e o projeto de construção da UHE Mauá, Paraná, Brasil. Semina 31(1):15-20.

REIS, R.E., KULLANDER, S.O. & JR. FERRARIS, C.J. 2003. Check list of the freshwater fishes of South and Central America. EDIPUCRS, Porto Alegre.

RIBEIRO, V.R., SILVA, P.R.L., GUBIANI, É.A., FARIA, L., DAGA, V.S. & VITULE, J.R.S. 2017. Imminent threat of the predator fish invasion *Salminus brasiliensis* in a Neotropical ecoregion: eco-vandalism masked as an environmental project. Perspectives in Ecology and Conservation 15:132-135.

ROCKSTRÖM, J., STEFFEN, W., NOONE, K., PERSSON, Å., CHAPIN, F.S., LAMBIN, E.F., LENTON, T.M., SCHEFFER, M., FOLKE, C., SCHELLNHUBER, H.J., NYKVIST, B., de WIT, C.A., HUGHES, T., van der LEEUW, S., RODHE, H., SÖRLIN, S., SNYDER, P.K., COSTANZA, R., SVEDIN, U., FALKENMARK, M., KARLBER, L., CORELL, R.W., FABRY, V.J., HANSEN, J., WALKER, B., LIVERMAN, D., RICHARDSON, K., CRUTZEN, P. & FOLEY, J.A. 2009. A safe operating space for humanity. Nature 461(282):472-475.

SEMA. Secretaria do Estado do Meio Ambiente e Recursos Hídricos. 2010. Bacias hidrográficas do Paraná: série histórica. SEMA, Curitiba http://www.meioambiente.pr.gov.br/arquivos/File/corh/Revista_Bacias_Hidrograficas_do_Parana.pdf (Access 23 Nov 2016).

STIGALL, A.L. 2010. Invasive species and biodiversity crises: testing the link in the late Devonian. PLoS ONE 5(12): e15584.

THOMAZ, S.M., AGOSTINHO, A.A. & HAHN, N.S. (eds.). 2004. The Upper Paraná River and its floodplain: physical aspects, ecology and conservation. Backhuys Publishers, Leiden.

VAZZOLER, A.E.A. de M. 1996. Biologia da reprodução de peixes teleósteos: teoria e prática. EDUEM, Maringá.

VITULE, J.R.S., SKÓRA, F. & ABILHOA, V. 2012. Homogenization of freshwater fish faunas after the elimination of a natural barrier by a dam in Neotropics. Divers. Distrib. 18(2):11-120.

*Received: 24/03/2017*
*Revised: 18/12/2017*
*Accepted: 06/03/2018*
*Published online: 12/04/2018*

Biota Neotropica 18(2): e20170395, 2018
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)

**Inventory**

# Human-modified landscape acts as refuge for mammals in Atlantic Forest

*Alex Augusto de Abreu Bovo*[1], *Marcelo Magioli*[1], *Alexandre Reis Percequillo*[1], *Cecilia Kruszynski*[2,3], *Vinicius Alberici*[1], *Marco A. R. Mello*[4], *Lidiani Silva Correa*[1], *João Carlos Zecchini Gebin*[1], *Yuri Geraldo Gomes Ribeiro*[1], *Francisco Borges Costa*[5], *Vanessa Nascimento Ramos*[5], *Hector Ribeiro Benatti*[5], *Beatriz Lopes*[1], *Maísa Z. A. Martins*[1], *Thais Rovere Diniz-Reis*[2], *Plínio Barbosa de Camargo*[6], *Marcelo Bahia Labruna*[5] & *Katia Maria Paschoaletto Micchi de Barros Ferraz*[1*]

*[1]Universidade de São Paulo, Escola Superior de Agricultura "Luiz de Queiroz", Departamento de Ciências Florestais, Laboratório de Ecologia, Manejo e Conservação da Fauna Silvestre, Av. Pádua Dias, 11, 13418-900, Piracicaba, SP, Brasil*
*[2]Universidade de São Paulo, Centro de Energia Nuclear na Agricultura, Piracicaba, SP, Brasil*
*[3]Leibniz Institut fur Zoo und Wildtierforschung eV, Berlin, Germany*
*[4]Universidade Federal de Minas Gerais, Biologia Geral, Belo Horizonte, MG, Brasil*
*[5]Universidade de São Paulo, Faculdade de Medicina Veterinária e Zootecnia, Departamento de Medicina Veterinária Preventiva e Saúde Animal, São Paulo, SP Brasil*
*[6]Universidade de São Paulo, Centro de Energia Nuclear na Agricultura, CENA - Laboratório de Ecologia Isotópica, Piracicaba, SP, Brasil*
**Corresponding author: Katia Maria Paschoaletto Micchi de Barros Ferraz, e-mail: katia.ferraz@usp.br*

BOVO, A.A.A, MAGIOLI, M.; PERCEQUILLO, A.R., KRUSZYNSKI, C., ALBERICI, V., MELLO, M.A.R., CORREA, L.S., GEBIN, J.C.Z., RIBEIRO, Y.G.G., COSTA, F.B.; RAMOS, V.N., BENATTI, H.R., LOPES, B., MARTINS, M.Z.A., DINIZ-REIS, T.R., CAMARGO, P.B.; LABRUNA, M.B., FERRAZ, K.M.P.M.B. **Human-modified landscape acts as refuge for mammals in Atlantic Forest**. Biota Neotropica. 18(2): e20170395. http://dx.doi.org/10.1590/1676-0611-BN-2017-0395

***Abstract:*** Human-modified landscapes (HMLs) are composed by small, isolated and defaunated forest fragments, which are surrounded by agricultural and urban areas. Information on species that thrives in these HMLs is essential to direct conservation strategies in local and regional scales. Since HMLs are dominant in the Atlantic Forest, we aimed to assess the mammalian diversity in a HML in southeastern Brazil and to propose conservation strategies. We collected data of terrestrial (small-, medium- and large-sized) and volant mammals in three small forest fragments (10, 14 and 26 ha) and adjacent areas, between 2003 and 2016, using complementary methods: active search, camera trapping, live-traps, mist nets and occasional records (i.e., roadkills). In addition, we used secondary data to complement our species list. We recorded 35 native mammal species (6 small-sized, 16 medium- and large-sized, and 13 bats) and seven exotic species in the HML. The recorded mammal assemblage (non-volant and volant), although mainly composed of common and generalist species, includes three medium- and large-sized species nationally threatened (*Leopardus guttulus*, *Puma concolor* and *Puma yagouaroundi*) and two data deficient species (*Galictis cuja* and *Histiotus velatus*), highlighting the importance of this HML for the maintenance and conservation of mammal populations. Despite highly impacted by anthropogenic disturbances, the study area harbors a significant richness of medium- and large-sized mammals, being an important biodiversity refuge in the region. However, this biodiversity is threatened by the low quality of the habitats, roadkills and abundant populations of domestic cats and dogs. Therefore, we stress the need of conservation strategies focusing on the medium- and large-sized mammals as an umbrella group, which could benefit all biodiversity in the landscape. We recommend actions that promotes biological restoration, aiming to increase structural composition and connectivity of the forest fragments, reducing roadkills and controlling the domestic cats and dogs' populations, in order to maintain and improve the diversity of mammals in long-term.

***Keywords:*** *Mammalia, Inventory, Conservation, Forest Remnants, Agroecosystem.*

# Paisagem antropicamente modificada atua como refúgio para mamíferos na Mata Atlântica

***Resumo:*** Paisagens antropicamente modificadas (HMLs) são compostas por fragmentos florestais pequenos, isolados e defaunados, imersos em áreas agrícolas e/ou urbanas. Informações sobre as espécies que habitam essas paisagens são importantes para o direcionamento de estratégias de conservação em escalas local e regional. Uma vez que as HMLs são as paisagens dominantes na Mata Atlântica, o objetivo deste trabalho foi avaliar a diversidade de mamíferos em uma HML do sudeste do Brasil e propor estratégias para sua conservação. Foram coletados dados de mamíferos terrestres (pequenos, médios e grandes) e voadores em três fragmentos florestais (10, 14 e 26 ha) e áreas adjacentes, entre 2003 e 2016, usando métodos complementares: busca ativa, armadilhamento fotográfico, armadilhas de captura e redes de neblina. Adicionalmente, foram utilizados dados de literatura para complementar a lista de espécies. Foram registradas 35 espécies de mamíferos nativos (6 de pequenos, 16 de médios e grandes e 13 de morcegos) e sete espécies exóticas. A assembleia de mamíferos registrada (terrestres e voadores), embora composta por espécies generalistas, apresentou três espécies de médio e grande porte ameaçadas de extinção nacionalmente (*Leopardus guttulus*, *Puma concolor* and *Puma yagouaroundi*) e duas deficientes em dados (*Galictis cuja* and *Histiotus velatus*), destacando a importância dessa HML para conservação e manutenção das populações de mamíferos. Embora inserida em uma paisagem extremamente modificada, a área de estudo abriga uma riqueza significativa de mamíferos de médio e grande porte, sendo um importante refúgio para a biodiversidade na região. Entretanto, essa biodiversidade está ameaçada pela baixa qualidade dos habitats, por atropelamentos e por abundantes populações de cães e gatos domésticos. Portanto, enfatizamos a necessidade de estratégias de conservação focadas nos mamíferos de médio e grande porte como grupo "guarda-chuva", o que pode beneficiar as demais espécies na paisagem. Recomendamos ações de conservação visando a restauração biológica, para melhorar a composição estrutural e conectividade dos fragmentos florestais, reduzir o número de atropelamentos e controlar as populações de cães e gatos domésticos, afim de manter e aumentar a diversidade local de mamíferos em longo prazo.

***Palavras-chave:*** *Mammalia, Inventário, Conservação, Fragmentos florestais, Agroecossistema.*

## Introduction

Economic development demands large amounts of land, modifying natural areas and creating human-modified landscapes (HMLs). HMLs are defined as areas composed by small and isolated forest fragments, usually defaunated and surrounded by agricultural and urban areas (Melo et al. 2013). The Brazilian Atlantic Forest is an example of a human-modified tropical forest, with only 11 to 15.3% of its original cover remaining (Ribeiro et al. 2009; SOS Mata Atlântica, 2017). This biome was strongly modified during the last centuries (Dean 1997), and nowadays is mainly composed by HMLs (Ribeiro et al. 2009).

The fauna inhabiting HMLs faces challenges due to the human activities (Peres et al. 2010), which alters the environment and reduces habitat availability. Nevertheless, these areas still act as habitat for a considerable number of resilient vertebrate species, such as mammals (Chiarello 2000a; Bogoni et al. 2013; Magioli et al. 2014a, 2016; Beca et al. 2017). Although most mammal species within HMLs are considered habitat-generalists, some threatened species can be found (Dotta & Verdade 2011; Reale et al. 2014; Magioli et al. 2016), also performing important ecological functions (Magioli et al. 2015).

For most of the remaining Brazilian Atlantic Forest, HMLs became the dominant landscape, usually harboring defaunated subsets of the assemblages found in less altered habitats (Silva Jr. & Pontes 2008; Jorge et al. 2013). Furthermore, the situation tends to get worse, as brazilian environmental laws have been recently altered to favor economic development (Laws Nº 12.651, from 25/05/2012 and Nº 12.727, from 17/10/2012; Stickler et al. 2013; Soares-Filho et al. 2014). Therefore, there is a need for assessing the remaining biodiversity in HMLs, as a first step for the maintenance of those communities, and their associated ecosystem functions and services. With this aim, we carried out an inventory of non-volant (small-, medium- and large-sized) and volant mammals in small forest fragments in a HML in southeastern Brazil, providing a diversity assessment that will allow future directions toward their conservation.

## Material and Methods

### 1. *Study site*

We carried out this study in two areas in Piracicaba, state of São Paulo, southeastern Brazil: ESALQ (Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo) and IPEF (Instituto de Pesquisas Florestais; Figure 1). Both areas are located in the Atlantic Forest biome, close to the Cerrado boundaries (IBGE 2004), with semideciduous forest fragments. Together, they cover 913.3 ha (874.3 ha from ESALQ and 39 ha from IPEF) and are composed of human constructions, agriculture experimental fields, pastures, gardens, watercourses, small forest fragments (i.e., forest remnants and riparian vegetation) and areas under ecological restoration. We selected three

http://dx.doi.org/10.1590/1676-0611-BN-2017-0395

forest fragments: Mata da Pedreira (14 ha), a secondary semideciduous forest; Mata do Aeroporto (10 ha), a small gallery forest surrounded by *Pinus* plantation; and Mata do IPEF (26 ha), a semideciduous forest restored in 2005/2006 around a pond (Figure 1). Mata da Pedreira is located 1.75 km from Mata do Aeroporto and from Mata do IPEF, while the two latter are 550 m apart from each other. There are three watercourses in the study area – Piracicaba river, the main river on the landscape, Piracicamirim river and a nameless intermittent stream, both tributary of Piracicaba river –, which are surrounded by riparian secondary vegetation that connects most of the studied fragments. The study area is located between Piracicaba city and the agricultural matrix of rural areas, composed mainly by sugarcane. Two protected areas are located near ESALQ and IPEF, Estação Experimental de Tupi (EE Tupi, ~7 km in a straight line) and Estação Ecológica de Ibicatu (ESEC Ibicatu, ~22 km in a straight line).

## 2. *Data collection*

### 2.1. Small non-volant mammals

Small mammals were sampled in Mata da Pedreira and Mata do Aeroporto (Figure 1). We carried out a conventional trapping, with Sherman and Tomahawk traps (Voss & Emmons 1996). We sampled Mata da Pedreira from July 22 to 27, 2015, where we installed five trap-lines; each trap-line was composed of five sampling stations, and each station had three traps (one tomahawk and one Sherman on the ground, and one Sherman on bushes or small trees, at a minimum height of 1.5 m). This resulted in a sampling effort of 375 trap-nights.

In Mata do Aeroporto, sampling was carried out from November 30 to December 4, 2015, and from June 13 to 17, 2016. In this sampling site, we installed 13 trap-lines resulting in a total sampling effort of 780 trap-nights in each campaign (1,560 trap-nights). Small mammal species recorded by active search (see below in item 2.3) were also included in the inventory.

### 2.2 Small volant mammals

Bats were sampled in two periods, 23 nights from December 2003 to May 2004, and 11 nights from December 2013 to June 2015, in a total sampling effort of 32,970 h.m² (see Straube & Bianconi 2002). As bats are flying species, besides to Mata da Pedreira, we also sampled other five sites in ESALQ, closer to urban and agricultural areas (Figure 1). For the first period, nets were placed on trails within forest fragments and on the edges. In the second sampling period, nets were placed randomly on the campus and around the urban area, where we found evidence of bat roosts (e.g., feces) in nearby buildings. At each site,

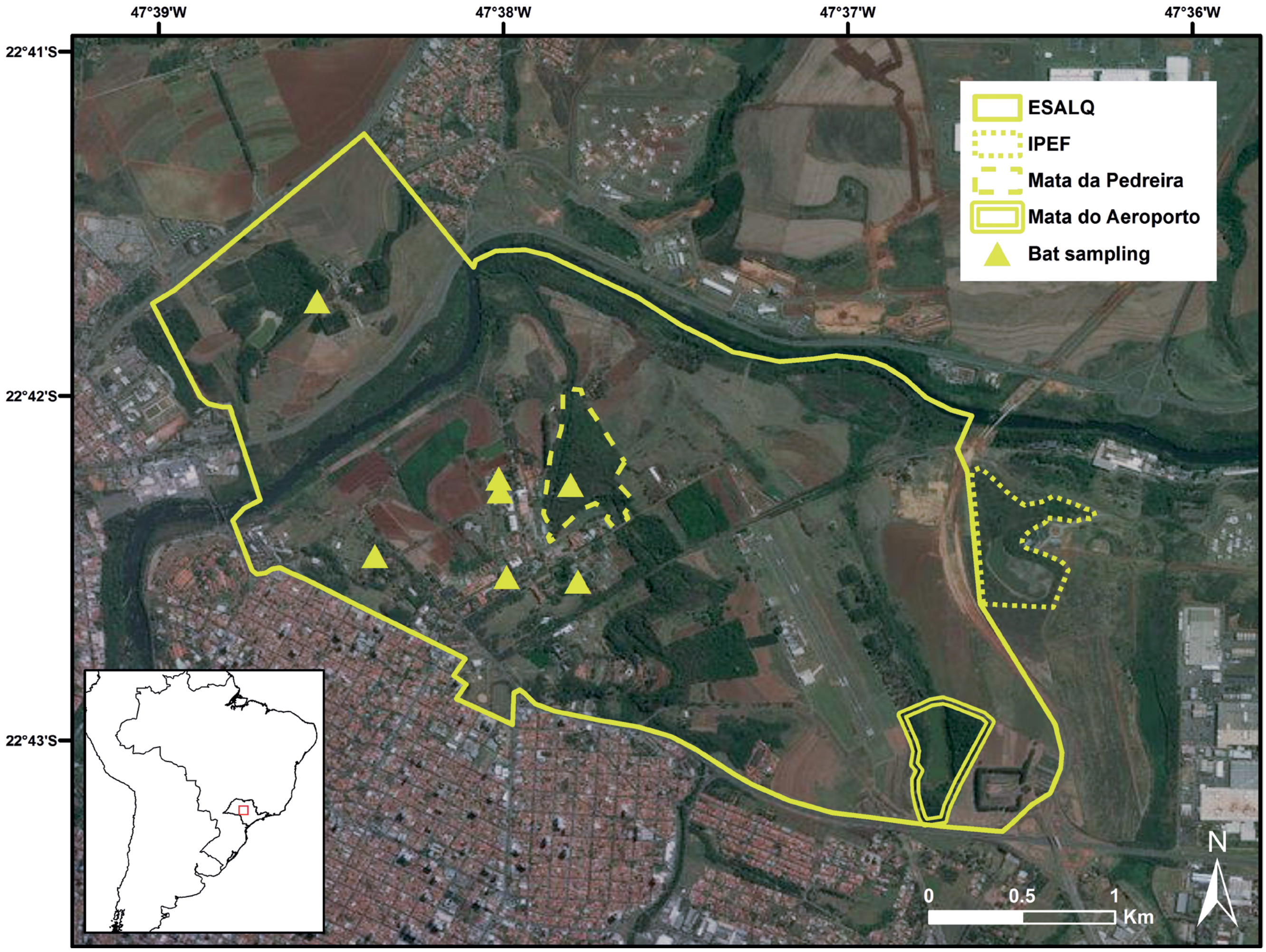

**Figure 1.** Study area located in southeastern Brazil, at Piracicaba municipality, state of São Paulo. The studied forest fragments are highlighted.

we opened three to six mist nets at sunset and closed after six hours of sampling. Net size ranged from 10 x 3 m to 12 x 3 m with 2.5 mm mesh (Ecotone Inc., Poland).

We identified all captured individuals and determined sex, age class and reproductive status; body was measured on forearm length and weight. Bats were identified to the finest possible taxonomic level by using specialized keys (Gregorin & Taddei 2002; Gardner 2007). The age classes (infant, juvenile or adult) were estimated based on the degree of ossification of the phalangeal epiphyses (Kunz and Anthony 1982).

### 2.3 Medium- and large-sized mammals

We considered as medium-sized mammals those weighing between 1 and 7 kg (Chiarello 2000b), and those weighing over 7 kg were considered large-sized (Emmons & Feer 1997). However, species of the genus *Didelphis* (weighing more than 1 kg) were considered small-sized, because they are commonly recorded in small mammal inventories, as well as species of the genus *Callithrix* (weighing less than 1 kg), which where considered in the medium- and large-sized category, for being commonly recorded in medium- and large-sized mammal inventories. We used two sampling methods – camera traps and active search – in Mata da Pedreira and IPEF fragment. We collected data using both methods in Mata da Pedreira from March to December 2012, and in IPEF between February 2011 and June 2013.

Sampling occurred for approximately five days in each month in a non-systematized way. We distributed five to eight camera traps (Bushnell 12 MP Trophy Cam HD) in both areas, resulting in a trapping effort of 1068 camera trap days (216 camera trap days in ESALQ, and 852 camera trap days in IPEF).

The active search method consisted of walking on dirt roads and trails inside the forest fragments, at an average speed of 1 km/h, searching for direct (i.e., sightings, vocalizations, carcasses) and indirect (i.e., tracks, feces, burrows, food leftovers) evidence of mammalian activity (Voss & Emmons 1996). This method was conducted simultaneously to the camera trapping.

During sampling, we carefully measured and photographed all visible mammal tracks, and then compared our evidence with field guides (Becker & Dalponte 1999; Oliveira & Cassaro 2005; Borges & Tomás 2008). To identify other medium- and large-sized mammal evidence (e.g. vestiges, sightings, vocalizations) and camera trap photos, we consulted specialized literature (Emmons & Feer 1997; Oliveira & Cassaro 2005; Borges & Tomás 2008) and experts (Tadeu de Oliveira for *Leopardus guttulus* and Mauricio Barbanti for *Mazama gouazoubira*).

We complemented our inventory with species recorded by a previous study, between 2001 and 2002, in areas that have not been much altered since then (Gheler-Costa et al. 2002). We also included occasional records of roadkilled mammals in a road that bisects ESALQ. This unstandardized sampling method also recovered medium- and large-sized mammal species that are preserved as vouchers at the Laboratório de Mamíferos, ESALQ, USP (LMUSP) (see Appendix 1).

### 3. *Data analysis*

For small non-volant mammals, we assessed the capture success in each forest fragment, and for the whole sampling, we used the relative frequency of captures by total sampling effort (total of trap-nights). We estimated species richness for medium- and large-sized mammals (only camera trap data) and bats using the first-order Jackknife, since this index is based on species recorded only once. We calculated the indexes only for these groups because the other methods for medium- and large-sized mammals were not standardized, and the number of small non-volant mammals captured was very low. We assigned threat categories (i.e., vulnerable, endangered, critically endangered) following Percequillo & Kierulff (2009), Brasil (2014) and IUCN (2016). Species nomenclature followed Paglia et al. (2012), Trigo et al. (2013) and Patton et al. (2015). We considered exotic species those occurring outside its natural range, as defined in Falk-Petersen et al. (2006). For bats, we also described the structure of the local assemblage using the recorded species list, a species richness index and an abundance distribution plot. We performed all analyses in R 3.2.4 (R Core Team 2016) using the packages 'bootstrap' and 'vegan'.

### 4. *Ethical procedures*

We carried out the fieldwork with small mammals following the guidelines of the American Society of Mammalogists (Sikes & Animal Care and Use Committee of the American Society of Mammalogists, 2016). We had permits from the Instituto Chico Mendes de Conservação da Biodiversidade (SISBIO #41352-1, for bats; #14419-1 and #43259-3, for marsupials and rodents) and from the Ethics Committee for Animal Experimentation of the Centro de Energia Nuclear na Agricultura (protocol #2013-18, for bats) and of the ESALQ (protocol #2014-29, for marsupials and rodents). Two bats individuals of each species captured were collected as vouchers for accurate identification and were deposited at the Laboratório de Mamíferos, ESALQ, USP (LMUSP) and at the Universidade Federal de Minas Gerais (UFMG; see Appendices 1 and 2).

## Results

We recorded 42 mammal species, belonging to 18 families and 8 orders. Among them, seven were small non-volant species, 22 medium- and large-sized species and 13 volant species, including seven exotic species (one small-sized and six medium- and large-sized) (Table 1; Figure 2; Appendices 3 and 4). Four species were recorded only by literature data: *Lutreolina crassicaudata*, *Callithrix jacchus*, *Calomys temer* and *Cavia aperea*.

### 1. *Small non-volant mammals*

The sampling effort in Mata da Pedreira recorded eight individuals from two small mammal species, *Didelphis albiventris* and *Oligoryzomys nigripes*, with a low capture success (2.1%; see Appendix 1, with the list of specimens examined). In Mata do Aeroporto, the capture success was even lower (0.57%), consisting of nine individuals of three species, *D. albiventris*, *Didelphis aurita* and *O. nigripes*. Other two native small mammals were added to our list from previous inventories carried out in the study area (Table 1). No species of small non-volant mammals recorded was threatened in local, national or global scale.

### 2. *Small volant mammals*

At ESALQ, we captured 533 bat individuals of 13 species and three families. The most diverse family was Phyllostomidae, with eight species, followed by Molossidae and Vespertillionidae, with three and two species, respectively. First-order Jackknife estimated a richness species of 16.75 (± 2.32). The most abundant and diverse

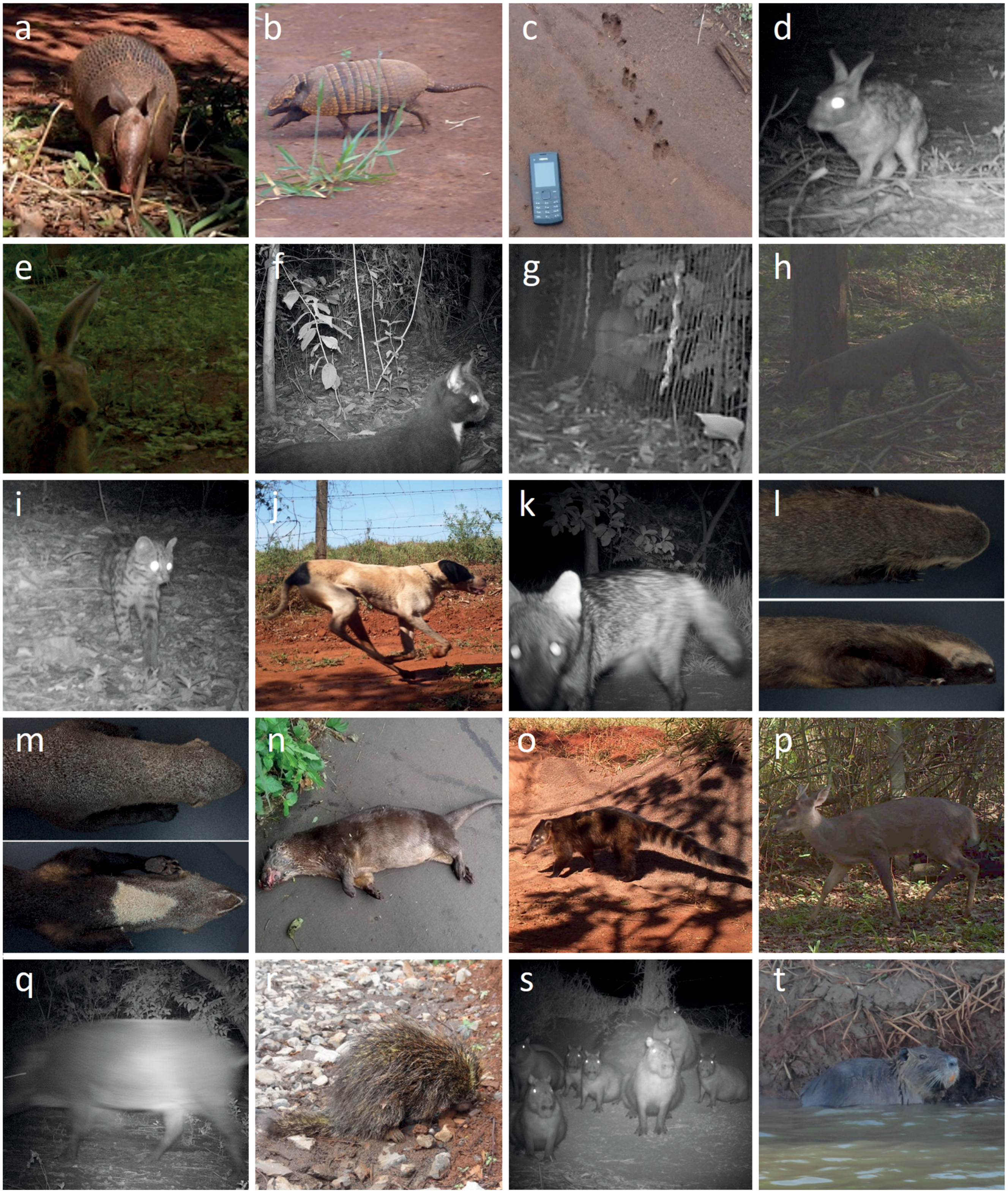

**Figure 2.** Recorded medium- and large-sized mammals at Piracicaba, state of São Paulo, Brazil: a: *Dasypus novemcinctus*; b: *Euphractus sexcinctus*; c: *Dasypus septemcinctus* footprints; d: *Sylvilagus brasiliensis*; e: *Lepus europaeus*; f: *Felis catus*; g: *Puma concolor* (video is available in Appendix 3); h: *Puma yagouaroundi*; i: *Leopardus guttulus*; j: *Canis familiaris*; k: *Cerdocyon thous*; l: *Galictis cuja*; m: *Eira barbara*; n: *Lontra longicaudis*; o: *Nasua nasua*; p: *Mazama gouazoubira*; q: *Sus scrofa*; r: *Coendou spinosus*; s: *Hydrochoerus hydrochaeris*; t: *Myocastor coypus*.

**Table 1.** Mammal species recorded at ESALQ, IPEF and surrounding areas in Piracicaba, state of São Paulo, Brazil. T = tracks; C = camera-trap; S = sighting; Tr = trapping; R = references (Gheler-Costa et al. 2002); Rk = roadkill; O = carcasses, food leftovers, burrows; M = mist net; * exotic species; ** voucher specimen; VU = vulnerable; DD = data deficient; SP = São Paulo state; Br = Brazil; W = world, IP = Mata do IPEF, MP = Mata da Pedreira, MA= Mata do Aeroporto.

| Taxon | Common name | Record type | Threaten level | Fragment |
|---|---|---|---|---|
| **DIDELPHIMORPHIA** | | | | |
| **Didelphidae** | | | | |
| *Didelphis albiventris* Lund, 1840 | White-eared opossum | Tr**, C, S, R, Rk | | IP, MP, MA |
| *Didelphis aurita* (Wied-Neuwied, 1826) | Big-eared opossum | Tr** | | MA |
| *Lutreolina crassicaudata* (Desmarest, 1804) | Lutrine opossum | R | | |
| **CINGULATA** | | | | |
| **Dasypodidae** | | | | |
| *Dasypus novemcinctus* Linnaeus, 1758 | Nine-banded armadillo | Tr**, C, T, S, R, Rk, O | | IP, MP, MA |
| *Dasypus septemcinctus* Linnaeus, 1758 | Seven-banded armadillo | T | | IP |
| *Euphractus sexcinctus* (Linnaeus, 1758) | Six-banded armadillo | C, T, S | | IP |
| **PRIMATES** | | | | |
| **Callitrichidae** | | | | |
| *Callithrix jacchus* (Linnaeus, 1758) * | Common marmoset | R | | |
| *Callithrix penicillata* (É. Geoffroy, 1812) | Black-pencilled marmoset | S, Rk** | | MP |
| **LAGOMORPHA** | | | | |
| **Leporidae** | | | | |
| *Lepus europaeus* (Linnaeus, 1758) * | European hare | C, T, S, R, Rk** | | IP |
| *Sylvilagus brasiliensis* (Linnaeus, 1758) | Brazilian rabbit | C, R | | IP, MP |
| **CARNIVORA** | | | | |
| **Felidae** | | | | |
| *Felis catus* (Linnaeus, 1758) * | Domestic cat | C, S, Rk** | | IP, MP |
| *Puma concolor* (Linnaeus, 1771) | Puma | C, S | VU (SP, BR) | IP, MP |
| *Puma yagouaroundi* (É. Geoffroy, 1803) | Jaguarundi | C | VU (BR) | IP |
| *Leopardus guttulus* (Schreber, 1775) | Oncilla | C | VU (SP, BR, W) | IP |
| **Canidae** | | | | |
| *Canis familiaris* (Linnaeus, 1758) * | Domestic dog | C, T, Rk | | IP |
| *Cerdocyon thous* (Linnaeus, 1766) | Crab-eating fox | C, T, S, R, Rk | | IP, MP |
| **Mustelidae** | | | | |
| *Galictis cuja* (Molina, 1782) | Lesser grisson | Rk** | DD (SP) | |
| *Eira barbara* (Linnaeus, 1758) | Tayra | Rk** | | |
| *Lontra longicaudis* (Olfers, 1818) | Neotropical otter | Rk** | | |
| **Procyonidae** | | | | |
| *Nasua nasua* (Linnaeus, 1766) | South american coati | C, T, S, R, Rk** | | IP, MP |
| **ARTIODACTYLA** | | | | |
| **Cervidae** | | | | |
| *Mazama gouazoubira* (G. Fischer, 1814) | Gray brocket deer | C, T, S, R | | IP |
| **Suidae** | | | | |
| *Sus scrofa* (Linnaeus, 1758) * | Feral pig | C | | IP |

**Continued Table 1.**

| Taxon | Common name | Record type | Threaten level | Fragment |
|---|---|---|---|---|
| **RODENTIA** | | | | |
| **Cricetidae** | | | | |
| *Calomys tener* (Winge, 1887) | Delicate vesper mouse | R | | |
| *Oligoryzomys nigripes* (Olfers, 1818) | Black-footed pygmy rice rat | Tr**, R | | MP, MA |
| **Muridae** | | | | |
| *Rattus rattus* (Linnaeus, 1758) * | Black rat | R, O** | | |
| **Erethizontidae** | | | | |
| *Coendou spinosus* (F. Cuvier, 1823) | Paraguayan hairy dwarf porcupine | C, S, R, Rk** | | IP |
| **Caviidae** | | | | |
| *Cavia aperea* Erxleben, 1777 | Brazilian guinea pig | R | | |
| *Hydrochoerus hydrochaeris* (Linnaeus, 1766) | Capybara | C, T, S, R, Rk** | | IP, MP |
| **Myocastoridae** | | | | |
| *Myocastor coypus* (Molina, 1782) * | Coypu | S, R | | IP |
| **CHIROPTERA** | | | | |
| **Molossidae** | | | | |
| *Molossops temminckii* (Burmeister, 1854) | Dwarf dog-faced Bat | M | | MP |
| *Molossus molossus* (Pallas, 1766) | Pallas's mastiff bat | M | | |
| *Molossus rufus* É. Geoffroy, 1805 | Black mastiff bat | M | TR | |
| **Phyllostomidae - Carolinae** | | | | |
| *Carollia perspicillata* (Linnaeus, 1758) | Seba's short-tailed bat | M | | |
| **Phyllostomidae - Desmodontinae** | | | | |
| *Desmodus rotundus* (É. Geoffroy, 1810) | Common vampire bat | M | | |
| **Phyllostomidae - Glossophaginae** | | | | |
| *Glossophaga soricina* (Pallas, 1766) | Pallas's long-tongued bat | M | TR | |
| **Phyllostomidae - Sternodermatinae** | | | | |
| *Artibeus concolor* Peters, 1865 | Brown fruit-eating bat | M | | |
| *Artibeus planirostris* (Spix, 1823) | Flat-faced fruit-eating bat | M | TR | |
| *Artibeus lituratus* (Olfers, 1818) | Great fruit-eating bat | M | | MP |
| *Platyrrhinus lineatus* (É. Geoffroy, 1810) | White-lined broad-nosed bat | M | | MP |
| *Sturnira lilium* (É. Geoffroy, 1810) | Little yellow-shouldered bat | M | | |
| **Vespertilionidae** | | | | |
| *Histiotus velatus* (I. Geoffroy, 1824) | Tropical big-eared brown bat | M | DD (SP) | |
| *Myotis nigricans* (Schinz, 1821) | Black myotis | M | TR | |

dietary category was frugivorous bats, represented by six species of two subfamilies (46% of the total richness), followed by insectivorous bats with five species (38%) (Appendices 5 and 6). The other two categories were nectarivorous bats represented by one species (7%), and one sanguivorous species (7%).

*Artibeus lituratus* (Phyllostomidae) was the most abundant species (57%), followed by *Platyrrhinus lineatus* (Phyllostomidae, 11%), *Sturnira lilium* (Phyllostomidae, 9%), *Glossophaga soricina* and *Molossus molossus* (Phyllostomidae and Molossidae, respectively, 5%), *A. concolor*, *Carollia perspiscillata*, *Histiotus velatus* (Phyllostomidae and Vespertilionidae, 2%) while *A. planirostris*, *Desmodus rotundus*, *Molossus rufus*, *Molossops temminckii* and *Myotis nigricans* were very rare (Phyllostomidae, Molossidae and Vespertilionidae, respectively, 0.18%). The bat assemblage recorded in the area had no threatened species, however, some of them have been considered in need of taxonomic revision (*A. planirostris*, *G. soricina*, *Molossus rufus*, *M. molossus*, *H. velatus*, *C. perspiscillata* and *Myiotis nigricans*) or as data deficient (*Molossops temminckii*) (Table 1).

### 3. *Medium- and large-sized mammals*

We recorded 22 species, including six exotics: *Callithrix jacchus*, *Myocastor coypus*, *Felis catus*, *Canis familiaris*, *Lepus europaeus* and *Sus scrofa;* the first two species are from our native fauna of Neotropical South America, and the remaining species from other zoogeographic regions.

The active search method resulted in the record of 14 species; *Dasypus septemcinctus* was recorded only by tracks (Figure 2). We also recorded 11 roadkilled species; these are the only records for *Eira barbara*, *Galictis cuja* and *Lontra longicaudis* in our study area (although one of the authors, ARP, sighted an individual of *L. longicaudis* 7 km away from the study area in 2012).

Using the camera trap method, we obtained 187 records of mammals, resulting in 15 species. *Sylvilagus brasiliensis*, *Puma yagouaroundi*, *Leopardus guttulus* and *Sus scrofa* were exclusively recorded by this method. The first-order Jackknife for camera trapping estimated a species richness of 15.25 (± 2.5).

The order Carnivora showed the largest number of species (N = 8), distributed in four families: Canidae, Felidae, Mustelidae and Procyonidae. Two species are considered threatened in São Paulo: *L. guttulus* and *Puma concolor* (Table 1). These two species, as well as *P. yagouaroundi*, are also considered threatened in Brazil. At the global scale, only *L. guttulus* is considered threatened. *G. cuja* is considered data deficient in the state of São Paulo.

Armadillos (Cingulata) were also present in the area, with three species. The seven-banded armadillo *D. septemcinctus* was recorded only once, in contrast to the records of *D. novemcinctus* (N = 27) and *Euphractus sexcinctus* (N = 5). Other orders (Primates, Lagomorpha, Artiodactyla) were represented by just one native species.

## Discussion

The mammal assemblage was mainly composed by species commonly found in anthropogenic areas. Nonetheless, some species, such as the threatened carnivores highlight the role of forest fragments as refuge and as corridors connecting habitats. The absence of more habitat specialists may be due to the location of our study site, between an urban area and an agricultural matrix. The species richness was expected for this HML, and our sampling effort was enough to the mammalian fauna of the area. Forest fragments near the study area also presented similar species richness and composition.

### 1. *Small non-volant mammals*

We recorded only three species in our trapping sampling effort, but available data from literature and species recorded by the active search method allowed us to increase the number of native species. However, the studied assemblage is very poor and composed by species considered tolerant and resilient to modified habitats (Pardini & Umetsu, 2006). Species richness in *Eucalyptus* and sugarcane plantations was higher (n=12 species; Rosalino et al. 2014) and similar (n=7; Gheler-Costa et al. 2013) than in ESALQ and IPEF, areas with higher habitat diversity. Besides that,we did not recover species previously recorded by Gheler-Costa et al. (2002), and this could be explained by some factors: (i) we sampled only one type of habitat, focusing on forest remnants, while Gheler-Costa et al. (2002) sampled several habitats (i.e. exotic tree plantations, pasture and agricultural areas); (ii) we performed a small sampling effort (1,935 trap-nights) versus a much larger effort (7,056 trap-nights) conducted by Gheler-Costa et al. (2002), although our trapping success was higher (2.1% and 0.57%) than that obtained by them (0.37%); (iii) those species might have been exterminated by a population of domestic cats established in the area a few years ago (see Campos et al. 2007), that is probably growing due to the habit of visitors of ESALQ to fed these animals and to the lack of management by the local authorities.

### 2. *Small volant mammals*

The recorded bat assemblage is composed of species commonly found in the state of São Paulo (Nogueira et al. 2014), either in protected areas (Passos et al. 2003), or anthropogenic ones, such as agricultural and urban landscapes (Chaves et al. 2012). Studies in the neighbor municipality found close bat species richness in restoration areas (n=12 species; Jacomassa 2015) and *Eucalyptus* plantation (n=9 species; Bortolotti 2015). HMLs near urban areas usually harbor poor communities (Avila-Flores & Fenton 2005; Siles et al. 2005; Pacheco et al. 2010; Jung & Kalko 2011), as found in the present study. This group also presented lower species richness and relative abundance of bats, and a high dominance by a few species, mainly from the subfamilies Sternodermatinae and Glossophaginae, and the family Molossidae (Bredt & Uieda 1996; Filho 2011), when compared to preserved areas.

### 3. *Medium- and large-sized mammals*

Contrasting with the small mammals (volant and non-volant), the richness of native medium- and large-sized mammals (n=17) was high considering the size of the forest fragments and the landscape characteristics. This richness represents ~35% of all medium- and large-sized mammals that occurs in the state of São Paulo (Vivo et al. 2011). A previous study at ESALQ appointed a lower species richness (ten medium- and large-sized mammals; Gheler-Costa et al. 2002), possibly because of the smaller sample effort and methods used. The recorded species richness is similar to other small Atlantic Forest or Cerrado fragments inserted in HMLs (Chiarello 2000a; Saciloto 2009; Reale et al. 2014; Magioli et al. 2016; Santos et al. 2016). Saciloto (2009) recorded *Conepatus semistriatus*, *Procyon cancrivorus* and *Dasyprocta azarae* in a forest fragment near our study area (EE Tupi), species commonly recorded at Atlantic Forest and Cerrado fragments (Bogoni et al. 2013; Pereira et al. 2013; Magioli et al. 2014a; Reale et al. 2014; Santos et al. 2016), but absent in our study. The capybara, *Hydrochoerus hydrochaeris*, has a large population in the area, a species that is favored by the habitat and food resource availability in HMLs (Ferraz et al. 2009), also showing up as a common roadkill (Bovo et al. 2016). Despite not being native of our study area, *C. penicillata* distribution limits is close to our study area (Rylands et al. 2009), suggesting that this species may be expanding its range. They may also impact local wildlife by preying on native birds (Alexandrino et al., 2012). *C. jacchus* is an exotic species, from the northern part of the Atlantic Forest (Rylands et al. 2009), introduced many years ago, but it was not sighted anymore in the study area and it is possibly absent.

The presence of three threatened species highlights the conservation value of these small forest fragments to this group. The largest predator remaining, *P. concolor*, is frequently recorded in HMLs (Lyra-Jorge et al. 2010; Dotta & Verdade 2011; Reale et al. 2014; Magioli et al. 2016; Santos et al. 2016), and seems to be adapted to agricultural areas, using them as food source and habitat (Magioli et al. 2014b). But these forest fragments, which are close to each other, along with the riparian vegetation alone, cannot support viable populations of most of the recorded species, especially the large-bodied ones and those with large home ranges such as *P. concolor*, *L. guttulus*, *P. yagouaroundi* and *M. gouazoubira*. However, these fragments act as stepping-stones and biological corridors for the fauna, which are essential for maintaining species diversity, genetic flow and functional diversity (Lyra-Jorge et al. 2010; Miotto et al. 2014; Magioli et al. 2015, 2016) and, therefore, should be targets for biological restoration. The restoration of riparian vegetation could be strengthened in areas that favors a connection between the studied HML and EE Tupi, which may augment habitat availability for species with large home ranges. Other problem to be addressed in this HML is the constant presence of domestic dogs and cats, which are known to transmit diseases and to predate wildlife, besides to compete for resources with wild carnivores (Campos et al. 2007).

### 4. *Implications for conservations*

Some applicable strategies can increase the effectiveness of the studied HML as a refuge for biodiversity, especially for medium- and large-sized mammals, which showed a richest assemblage than the other groups assessed. Moreover, improving habitat quality focusing on medium- and large-sized mammals may act as an umbrella strategy, favoring all biodiversity in the landscape, such as forest bird species that occurs in this HML (Alexandrino et al. 2013). Although forest remnants and riparian vegetation form structural corridors, they are degraded and fragmented, particularly considering the road that bisects ESALQ and the fragments, which acts as a population sink to local biodiversity. Therefore, in order to maintain long-term populations of large mammals in this HML, and to ensure safety conditions to drivers, we suggest the implementation of safe crossing passages to the fauna, both underpasses and overpasses, combined with fencing along the road (Beckmann et al. 2010, Teixeira et al. 2013, Huijser et al. 2016, Rytwinski et al. 2016). These measures may cause a positive impact over mammal populations, reducing the number of roadkilled individuals.

Regarding the forest fragments quality, we suggest biological restoration aiming to improve their structural composition, which is necessary to shelter species, providing food resources and fulfilment of biological and physiological needs (Benayas et al. 2009), also reducing edge effects. In addition, restoration of areas adjacent to riparian forests and small fragments can increase connectivity, which helps to maintain biodiversity and their functions (Ayram et al. 2015; Magioli et al. 2016). Based on our study landscape, the presence of areas with restricted access (the ESALQ university campus and IPEF, as a private property) and constant surveillance increase its potential as refuge for some species. The presence of forest fragments, even being degraded, allow the movement of these mammals in the area, including the threatened species. The intensively modified landscape and the low levels of forest cover highlight the importance of ESALQ and IPEF to local biodiversity.

Finally, one of the most widespread impacts in the study area is the ever-growing number of domestic cats abandoned on ESALQ, a huge threat to biodiversity maintenance due to predation and zoonotic diseases (Woods et al. 2003; Campos et al. 2007; Gerhold & Jessup 2013; Loss et al. 2013). Feeding cats and dogs is a common practice in ESALQ, which sustains and augment these animal's populations. An awareness and a control program are necessary to stop the abandon and feeding of these animals inside ESALQ, which may reduce the negative impacts on the local wildlife. Although ESALQ campus is used as a park by the local population for sports practice and leisure, the area harbors important biodiversity, and plays an essential role for wildlife conservation.

## Conclusion

The mammal species list presented in our study is more complete than previous reported. The small-sized mammal assemblage (volant and non-volant) recorded is poor, composed of generalist species that are resilient enough to persist in HMLs. In contrast, the medium- and large-sized assemblage presented higher species richness and, although mainly composed of generalist species, includes three nationally threatened species that reinforces the need for conservation measures. Small forest fragments are probably incapable of supporting viable populations of the species recorded, but they have an important role increasing the connectivity in HMLs. Therefore, we recommend restoration actions in the forest fragments focusing on medium- and large-sized mammals as umbrella species, as the implementation of safe crossing passages and road fencing to reduce roadkills, and control measures for reducing the impacts of domestic cats and dogs, improving the capability of this HML to act as refuge for mammal populations.

## Supplementary material

The following online material is available for this article:

**Appendix 1** - Species and individuals of small non-volant, and medium- and large-sized mammals preserved at the collection LMUSP recorded at Piracicaba, state of São Paulo, Brazil.

**Appendix 2** - Species and individuals of small volant mammals preserved at the collection LMUSP and UFMG recorded at Piracicaba, state of São Paulo, Brazil.

**Appendix 3** – Video.

**Appendix 4** - Frequency of ocurrence (FO) and number of individuals (in parentheses) of mammals recorded in the three forest fragments of the study area in Piracicaba, state of São Paulo, Brazil.

**Appendix 5** - Number of captured bat individuals by species, at Piracicaba, state of São Paulo, Brazil.

**Appendix 6** - Dietary categories of the captured bat species at Piracicaba, state of São Paulo, Brazil.

## Acknowledgements

We thank the Departamento de Ciências Florestais (Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo), the Programa de Pós-Graduação em Recursos Florestais (PPGRF), the Programa Interunidades de Pós-Graduação em Ecologia Aplicada (PPGI-EA), the Laboratório de Ecologia, Manejo e Conservação de Fauna Silvestre (LEMaC), the Superintendência de Gestão Ambiental (SGA), the Plano Diretor do campus "Luiz de Queiroz", the Prefeitura do campus "Luiz de Queiroz" and Instituto de Pesquisas e Estudos Florestais (IPEF). We thank Ariovaldo C. Neto and Roberto Haddad for providing the previous data on bat inventory and Elson F Lima, Erica V. Maggiorini, Fernanda V. Giannini, Luana Amorim and Victor H. Andrade for helping in data collection. We also thank IPEF for the grant conceded to AAAB and JCZG. We thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the scholarship conceded to CK, financial support (#561910/2010-3), and the productivity fellowship granted to KMPMBF (#308503/2014-7), to ARP (#307519/2015-5) and to MARM. We thank the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) for the grants to AAAB (#2013/24929-9 and #2014/23809-2), ARP (#2009/16009-1), MBL

(#2013/18046-7), MM (#2014/10192-7) and KMPMBF (#2014/09300-0). We also thank the Brazilian Coordination for the Improvement of Higher Education Personnel (CAPES) for the scholarships granted to MM, MZAM and VA, and funding MARM. MARM was also funded by the Minas Gerais Research Foundation (FAPEMIG), Research Dean of Federal University of Minas Gerais (PRPq-UFMG), Alexander von Humboldt Foundation (AvH), and the Research Program on the Biodiversity of the Atlantic Forest (PPBio-MA).

## Author contributions

Alex Augusto de Abreu Bovo: Substantial contribution in the concept and design of the study; Contribution to data collection; Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intelectual content.

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

Alexandre Reis Percequillo: Contribution to data collection; Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intelectual content.

Cecilia Kruszynski: Contribution to data collection; Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intelectual content.

Vinicius Alberici: Contribution to manuscript preparation; Contribution to critical revision, adding intelectual content.

Marco A. R. Mello: Contribution to manuscript preparation; Contribution to critical revision, adding intelectual content.

Lidiani Silva Correa: Contribution to data collection; Contribution to manuscript preparation.

João Carlos Zecchini Gebin: Contribution to data collection.

Yuri Geraldo Gomes Ribeiro: Contribution to data collection.

Francisco Borges Costa: Contribution to data collection.

Vanessa Nascimento Ramos: Contribution to data collection.

Hector Ribeiro Benatti: Contribution to data collection.

Beatriz Lopez: Contribution to data collection.

Maísa Z. A. Martins: Contribution to data collection; Contribution to manuscript preparation; Contribution to critical revision, adding intelectual content.

Thais Rovere Diniz-Reis: Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intelectual content.

Plínio Barbosa de Camargo: Contribution to data analysis and interpretation.

Marcelo Bahia Labruna: Contribution to data collection; Contribution to manuscript preparation;

Katia Maria Paschoaletto Micchi de Barros Ferraz: Substantial contribution in the concept and design of the study; Contribution to data collection; Contribution to data analysis and interpretation; Contribution to manuscript preparation; Contribution to critical revision, adding intelectual content.

## Conflicts of interest

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

## References

ALEXANDRINO, E.R., BOVO, A.A.A., LUZ, D.T.A., COSTA, J.C., BETINI, G.S., FERRAZ, K.M.P.M.B. & COUTO, H.T.Z. 2013. Aves do Campus “Luiz de Queiroz” (Piracicaba, SP) da Universidade de São Paulo: mais de 10 anos de observações neste ambiente antrópico. Atual. Ornitol. 173: 40-52.

ALEXANDRINO, E.R., LUZ, D.T.A., MAGGIORINI, E.V. & FERRAZ, K.M.P.M.D. 2012. Nest stolen: the first observation of nest predation by an invasive exotic marmoset (Callithrix penicillata) in an agricultural mosaic. Biota Neotrop. 12(2): 211-215 http://www.biotaneotropica.org.br/v12n2/pt/fullpaper?bn01612022012+en (last accessed on 03/Sep/2017).

AVILA-FLORES, R. & FENTON, M.B. 2005. Use of spatial features by foraging insectivorous bats in a large urban landscape. J. Mammal. 86(6): 1193-1204.

AYRAM, C.A.C., MENDOZA, M.E., ETTER, A. & SALICRUP, D.R.P. 2015. Habitat connectivity in biodiversity conservation: a review of recent studies and applications. Prog. Phys. Geog. 40(1): 7-37.

BECA, G., VANCINE, M.H., CARVALHO, C.S., PEDROSA, F., ALVES, R.S.C., BUSCARIOL, D., PERES, C.A., RIBEIRO, M.C. & GALETTI, M. 2017. High mammal species turnover in forest patches immersed in biofuel plantations. Biol. Conserv. 210: 352-359.

BECKER, M. & DALPONTE, J.C. 1999. Rastros de mamíferos silvestres. Editora Universidade de Brasília. Brasília.

BECKMANN, J.P, CLEVENGER, A.P., HUIJSER, M.P. & HILTY, J.A. 2010. Safe Passages: highways, wildlife, and habitat connectivity. Island Press, Washington.

BENAYAS, J.M.R., NEWTON, A.C., DIAZ, A. & BULLOCK, J.M. 2009. Enhancement of biodiversity and ecosystem services by ecological restoration: a meta-analysis. Science, 325(5944): 1121-1124.

BOGONI, J.A., BOGONI, T.C., GRAIPEL, M.E. & MARINHO, J.R. 2013. The influence of landscape & microhabitat on the diversity of large-and medium-sized mammals in Atlantic Forest remnants in a matrix of agroecosystem & silviculture. ISRN Forestry 2013: 1-13.

BORGES, P.A.L. & TOMÁS, W.M. 2008. Guia de rastros e outros vestígios de mamíferos do Pantanal. 1. ed. Embrapa Pantanal, Corumbá.

BORTOLOTTI, V.F.C. 2015. Riqueza, abundância e dieta de morcegos (Chiroptera) em floresta de eucaliptos. Monografia, Universidade Estadual Paulista “Júlio de Mesquita Filho”, Rio Claro.

BOVO A.A.A., FERRAZ, K.M.P.M.B., VERDADE, L.M. & MOREIRA, J.M. 2016. Capybaras (*Hydrochoerus hydrochaeris*) in anthropogenic environments: challenges & conflicts. In Biodiversity in agricultural landscapes of southeastern Brazil. (C. Gheler-Costa, M.C. Lyra-Jorge & L.M. Verdade, eds). De Gruyter Open, Berlin, p.178-189. http://dx.doi.org/10.1515/9783110480849-013

BRASIL. 2014. Ministério do Meio Ambiente. Lista Nacional Oficial das Espécies da Fauna Ameaçadas de Extinção. Portaria n. 444, de 17 de dezembro de 2014. Diário Oficial da União, Brasília www.icmbio.gov.br/portal/images/stories/biodiversidade/fauna-brasileira/avaliacao-do-risco/PORTARIA_Nº_444_DE_17_DE_DEZEMBRO_DE_2014.pdf (last access on 03/Apr/2017).

BREDT, A. & UIEDA, W. 1996. Bats from urban & rural environments of the Distrito Federal, mid-western Brazil. Chirop. Neotrop. 2(2): 54-57.

CAMPOS, C.B., ESTEVES, C.F., FERRAZ, K.M.P.M.B. CRAWSHAW JR., P.G. & VERDADE, L.M. 2007. Diet of free-ranging cats and dogs in a suburban and rural environment, south-eastern Brazil. J. Zool. 273(1): 14-20.

CHAVES, M.E., UIEDA, W., BOLOCHIO, C.E., SOUZA, C.A.I., BRAGA, D.D.A., FERREIRA, C.H., FIRMO, C.L., MARIANO, R.G.G.C., OLIVEIRA, K.C.S., SANTOS, E.G. & COSTA, F.M. 2012. Bats (Mammalia: Chiroptera) from Guarulhos, state of São Paulo, Brazil. Check List 8(6): 1117-1121.

CHIARELLO, A.G. 2000a. Conservation value of a native forest fragment in a region of extensive agriculture. Rev. Bras. Biol. 60(2): 237-247.

CHIARELLO, A.G. 2000b. Density and population size of mammals in remnants of Brazilian Atlantic Forest. Conserv. Biol. 14(6): 1649-1657.

DEAN, W. 1997. With broadax & firebrand: the destruction of the Brazilian Atlantic Forest. University of California Press.

DOTTA, G. & VERDADE, L.M. 2011. Medium to large-sized mammals in agricultural landscapes of south-eastern Brazil. Mammalia 75(4): 345-352.

EMMONS, L.H. & FEER, F. 1997. Neotropical rainforest mammals: a field guide. University of Chicago Press, Chicago.

FALK-PETERSEN, J., BØHN, T. & SANDLUND, O.T. 2006. On the numerous concepts in invasion biology. Biol. Invasions 8(6): 1409-1424.

FERRAZ, K.M.P.M.B., PETERSON, A.T., SCACHETTI-PEREIRA, R., VETTORAZZI, C.A. & VERDADE, L.M. 2009. Distribution of capybaras in an agroecosystem, Southeastern Brazil, based on ecological niche modeling. J. Mammal. 90(1): 189-194.

FILHO, H.O. 2011. Bats in natural & urban environments. In: 7th International Conference on Urban Pests, Ouro Preto, Brazil, 7-10 August 2011, 13-15.

GARDNER, A.L. 2007. Mammals of South America, v.1, Marsupials, Xenarthrans, Shrews, & Bats. University of Chicago Press, Chicago.

GERHOLD, R.W. & JESSUP, D.A. 2013. Zoonotic diseases associated with free-roaming cats. Zoonoses Public Health, 60(3): 189-195.

GHELER-COSTA, C., SABINO-SANTOS JR., G., AMORIM, L.S., ROSALINO, L.M., FIGUEIREDO, L.T.M. & VERDADE, L.M. 2013. The effect of pre-harvest fire on the small mammal assemblage in sugarcane fields. Agric. Ecosyst. Environ. 171: 85-89.

GHELER-COSTA, C., VERDADE, L.M. & ALMEIDA, A.D. 2002. Mamíferos não-voadores do campus" Luiz de Queiroz", Universidade de São Paulo, Piracicaba, Brasil. Rev. Bras. Zool. 19(2): 203-214.

GREGORIN, R. & TADDEI, V.A. 2002. Chave artificial para a identificação de molossídeos brasileiros (Mammalia, Chiroptera). Mastozool. Neotrop. 9(1): 13-32.

HUIJSER, M.P., FAIRBANK, E.R., CAMEL-MEANS, W., GRAHAM, J., WATSON, V., BASTING, P. & BECKER, D. 2016. Effectiveness of short sections of wildlife fencing and crossing structures along highways in reducing wildlife–vehicle collisions and providing safe crossing opportunities for large mammals. Biol. Conserv. 197, 61–68.

IBGE – INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. 2004. Mapa de biomas do Brasil. ftp://ftp.ibge.gov.br/Cartas_e_Mapas/Mapas_Murais/biomas_pdf.zip (last access on 10/Dec/2010).

IUCN – INTERNATIONAL UNION FOR CONSERVATION OF NATURE AND NATURAL RESOURCES. 2016. IUCN Red List of Threatened Species. Version 2016.3. www.iucnredlist.org (last accessed on 23/Nov/2016).

JACOMASSA, F.A.F. 2015. Assembleia, frugivoria e biologia reprodutiva de morcegos em áreas restauradas. Tese. Universidade Estadual Paulista "Júlio de Mesquita Filho", Rio Claro.

JORGE, M.L.S., GALETTI, M., RIBEIRO, M.C. & FERRAZ, K.M.P.M.B. 2013. Mammal defaunation as surrogate of trophic cascades in a biodiversity hotspot. Biol. Conserv. 163: 49-57.

JUNG, K. & KALKO, E.K. 2011. Adaptability & vulnerability of high flying Neotropical aerial insectivorous bats to urbanization. Divers. Distrib. 17(2), 262-274.

KUNZ, T.H. & ANTHONY, E.L. 1982. Age estimation & post-natal growth in the bat *Myotis lucifugus*. J. Mammal. 63(1): 23-32.

LOSS, S.R., WILL, T. & MARRA, P.P. 2013. The impact of free-ranging domestic cats on wildlife of the United States. Nature Communications 4: 1396.

LYRA-JORGE, M.C., RIBEIRO, M.C., CIOCHETI, G., TAMBOSI, L.R. & PIVELLO, V.R. 2010. Influence of multi-scale landscape structure on the occurrence of carnivorous mammals in a human-modified savanna, Brazil. Eur. J. Wildl.Res. 56(3): 359-368.

MAGIOLI, M., FERRAZ, K.M.P.M.B. & RODRIGUES, M.G. 2014a. Medium and large-sized mammals of an isolated Atlantic Forest remnant, southeast São Paulo State, Brazil. Check List 10(4): 850-856.

MAGIOLI, M., FERRAZ, K.M.P.M.B., SETZ, E.F., PERCEQUILLO, A.R., RONDON, M.V.S.S., KUHNEN, V.V., CANHOTO, M.C.S., SANTOS, K.E.A., KANDA, C.Z., FREGONEZI, G.L., PRADO, H.A., FERREIRA, M.K., RIBEIRO, M.C., VILLELA, P.M.S., COUTINHO, L.L. & RODRIGUES, M.G. 2016. Connectivity maintain mammal assemblages functional diversity within agricultural and fragmented landscapes. Eur. J. Wildl. Res. 62(4): 431-446.

MAGIOLI, M., MOREIRA, M.Z., FERRAZ, K.M.P.M.B., MIOTTO, R.A., CAMARGO, P.B., RODRIGUES, M.G., CANHOTO, M.C.S. & SETZ, E.Z.F. 2014b. Stable isotope evidence of *Puma concolor* (Felidae) feeding patterns in agricultural landscapes in southeastern Brazil. Biotropica 46(4): 451-460.

MAGIOLI, M., RIBEIRO, M.C., FERRAZ, K.M.P.M.B. & RODRIGUES, M.G. 2015. Thresholds in the relationship between functional diversity & patch size for mammals in the Brazilian Atlantic Forest. Animal Conservation 18(6): 499-511.

MELO, F. P., ARROYO-RODRÍGUEZ, V., FAHRIG, L., MARTÍNEZ-RAMOS, M. & TABARELLI, M. 2013. On the hope for biodiversity-friendly tropical landscapes. Trends Ecol. Evol. 28(8), 462-468.

MIOTTO, R.A., CERVINI, M., KAJIN, M., BEGOTTI, R.A. & GALETTI, P.M. 2014. Estimating puma *Puma concolor* population size in a human-disturbed landscape in Brazil, using DNA mark–recapture data. Oryx 48(02): 250-257.

NOGUEIRA, M.R., LIMA, I.P., MORATELLI, R., TAVARES, V.D.C., GREGORIN, R. & PERACCHI, A.L. 2014. Checklist of Brazilian bats, with comments on original records. Check List 10(4): 808–821. http://dx.doi.org/10.15560/10.4.808

OLIVEIRA, T.G. & CASSARO, K. 2006. Guia de campo dos felinos do Brasil. Instituto Pró-Carnívoros; Fundação do Parque Zoológico de São Paulo, Sociedade de Zoológicos do Brasil, Pró-Vida Brasil, São Paulo.

PACHECO, S.M., SODRÉ, M., GAMA, A.R., BREDT, A., CAVALLINI, E.M., MARQUES, R.V., GUIMARÃES, M.M. & BIANCONI, G. 2010. Morcegos urbanos: status do conhecimento e plano de ação para a conservação no Brasil. Chirop. Neotrop. 16(1): 629-647.

PAGLIA, A.P., FONSECA, G.A.B., RYLANDS, A.B., HERMANN, G., AGUIAR, L.M.S., CHIARELLO, A.G., LEITE, Y.L.R., COSTA, L.P., SICILIANO, S., KIERULFF, M.C.M., MENDES, S.L., TAVARES, V.C., MITTERMEIER, R.A. & PATTON, J.L. 2012. Annotated Checklist of Brazilian Mammals. 2. Ed. Occasional Papers in Conservation Biology, No. 6. Conservation International, Arlington, VA.

PARDINI, R. & UMETSU, F. 2006. Pequenos mamíferos não voadores da reserva florestal Morro Grande – distribuição das espécies e da diversidade em uma área de Mata Atlântica. Biota Neotrop. 6(2): 1-22 http://www.biotaneotropica.org.br/v6n2/pt/abstract?article+bn00606022006 (last accessed on 03/Sep/2016).

PASSOS, F.C., SILVA, W.R., PEDRO, W.A. & BONIN, M.R. 2003. Frugivoria em morcegos (Mammalia, Chiroptera) no Parque Estadual Intervales, sudeste do Brasil. Rev. Bras. Zool. 20: 511–517.

PATTON, J.L., PARDIÑAS, U.F.J. & D'ELÍA, G. 2015. Mammals of South America, v. 2, Rodents. University of Chicago Press, Chicago.

PERCEQUILLO, A.R. & KIERULFF, C. 2009. Mamíferos. In Fauna ameaça de extinção do Estado de São Paulo: vertebrados (Breassan, P.M., Kierulff, M.C.M. & Sugieda, A.M. eds.). Fundação Parque Zoológico de São Paulo, Secretaria do Meio Ambiente, São Paulo. pp. 31-41.

PEREIRA, S.N., DIAS, D., LIMA, I.P., MAAS, A.C.S., MARTINS, M.A., BOLZAN, D.P., FRANÇA, D.S., OLIVEIRA, M.B., PERACCHI, A.L. & FERREIRA, M.F.S. 2013. Mamíferos de um Fragmento Florestal em Volta Redonda, Estado do Rio de Janeiro. Biosci. J. 29(4): 1017-1027.

PERES, C.A., GARDNER, T.A., BARLOW, J., ZUANON, J., MICHALSKI, F., LEES, A.C., VIEIRA, I.C.G., MOREIRA, F.M.S. & FEELEY, K.J. 2010. Biodiversity conservation in human-modified Amazonian forest landscapes. Biol. Conserv. 143(10): 2314-2327.

R CORE TEAM. 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org. (last access on 14/Nov/2016).

REALE, R., FONSECA, R.C.B. & UIEDA, W. 2014. Medium & large-sized mammals in a private reserve of natural heritage in the municipality of Jaú, São Paulo, Brazil. Check List 10(5): 997-1004.

RIBEIRO, M.C., METZGER, J.P., MARTENSEN, A.C., PONZONI, F.J. & HIROTA, M.M. 2009. The Brazilian Atlantic Forest: how much is left, and how is the remaining forest distribuited? Implications for conservation. Biol. Conserv. 142(6): 1141-1153.

ROSALINO, L.M., MARTIN, P.S., GHELER-COSTA, C., LOPES, P.C. & VERDADE, L.M. 2014. Neotropical small mammals' diversity in the early cycle of commercial Eucalyptus plantations. Agrofor. Syst. 88(3): 427-436.

RYLANDS, A.B., COIMBRA-FILHO, A.F. & MITTERMEIER, R.A. 2009. The systematics and distributions of the marmosets (*Callithrix*, *Callibella*, *Cebuella*, and *Mico*) and callimico (*Callimico*)(Callitrichidae, Primates). In The smallest anthropoids (S.M. Ford, L.M. Porter & L.C. Davis). Springer, New York, p.25-61.

RYTWINSKI, T., SOANES, K., JAEGER J. A. G., FAHRIG, L., FINDLAY, C.S., HOULAHAN, J., VAN DER REE, R. & VAN DER GRIFT, E.A. 2016. How effective is road mitigation at reducing road-kill? A meta-analysis. PLoS ONE 11: e0166941.

SACILOTO, G.A.Z. 2009. Inventário de mastofauna de médio e grande porte na Estação Experimental de Tupi – Piracicaba - SP. Monografia, Universidade Metodista de Piracicaba, Piracicaba.

SANTOS, K.K., PACHECO, G.S.M. & PASSAMANI, M. 2016. Medium-sized & large mammals from Quedas do Rio Bonito Ecological Park, Minas Gerais, Brazil. Check List 12(1): 1830.

SIKES, R.S. & THE ANIMAL CARE AND USE COMMITTEE OF THE AMERICAN SOCIETY OF MAMMALOGISTS. 2016. Guidelines of the American Society of Mammalogists for the use of wild mammals in research and education. J. Mammal. 97(3): 663–688, https://doi.org/10.1093/jmammal/gyw078

SILES, L., PEÑARANDA, D., PÉREZ-ZUBIETA, J.C. & BARBOZA, K. 2005. Los murciélagos de la ciudad de Cochabamba. Rev. Bol. de Ecol. 18: 51-64.

SILVA, A.P. JR. & PONTES, A.R. 2008. The effect of a mega-fragmentation process on large mammal assemblages in the highly-threatened Pernambuco Endemism Centre, north-eastern Brazil. Biodiv. Conserv. 17(6): 1455-1464.

SOARES-FILHO, B., RAJÃO, R., MACEDO, M., CARNEIRO, A., COSTA, W., COE, M., RODRIGUES, H. & ALENCAR, A. 2014. Cracking Brazil's forest code. Science 344(6182): 363-364.

SOS MATA ATLÂNTICA. 2017. Atlas dos remanescentes florestais da Mata Atlantica período 2015–2016. São Paulo, Brasil. Fundação SOS Mata Atlantica. Instituto Nacional das Pesquisas Espaciais.

STICKLER, C.M., NEPSTAD, D.C., AZEVEDO, A.A. & MCGRATH, D.G. 2013. Defending public interests in private lands: compliance, costs & potential environmental consequences of the Brazilian Forest Code in Mato Grosso. Philos. T. Roy. Soc. B. 368(1619): 20120160.

STRAUBE, F.C. & BIANCONI, G.V. 2002. Sobre a grandeza e a unidade utilizada para estimar esforço de captura com utilização de redes-de-neblina. Chirop. Neotrop. 8(1/2): 150–152. http://dx.doi.org/10.1017/CBO9781107415324.004

TEIXEIRA, F.Z., COELHO, A.V.P., ESPERANDIO, I.B. & KINDEL, A. 2013. Vertebrate road mortality estimates: effects of sampling methods and carcass removal. Biol. Conserv.157, 317–323.

TRIGO, T.C., SCHNEIDER, A., OLIVEIRA, T.G., LEHUGEUR, L.M., SILVEIRA, L., FREITAS T.R. & EIZIRIK, E. 2013. Molecular data reveal complex hybridization & a cryptic species of Neotropical wild cat. Curr. Biol. 23(24): 2528-2533.

VIVO, M., CARMIGNOTTO, A.P., GREGORIN, R., HINGST-ZAHER, E., IACK-XIMENES, G.E., MIRETSKI, M., PERCEQUILLO, A.R., ROLLO JR., M.M., ROSSI, R.V. & TADEI, V.A. 2011. Checklist dos mamíferos do Estado de São Paulo, Brasil. Biota Neotrop. 11(1a): 1-21 http://www.biotaneotropica.org.br/v11n1a/pt/abstract?article+bn0071101a2011 (last accessed on 02/sep/2016).

VOSS, R.S. & EMMONS, L.H. 1996. Mammalian diversity in neotropical lowland rainforests: a preliminary assessment. Bull. Am. Mus. Nat. His. 230.

WOODS, M., MCDONALD, R.A. & HARRIS, S. 2003. Predation of wildlife by domestic cats *Felis catus* in Great Britain. Mammal Rev. 33: 174-188.

*Received: 21/06/2017*
*Revised: 02/02/2018*
*Accepted: 22/02/2018*
*Published online: 09/04/2018*