Biota Neotropica 16(1): e20150108, 2016
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)

short communication

Puma (*Puma concolor*) predation on tapir (*Tapirus terrestris*)

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AZEVEDO, F.C.C., CANUTO, V., SOUZA, F., WIDMER, C.E. **Puma (*Puma concolor*) predation on tapir (*Tapirus terrestris*).** Biota Neotropica. 16(1): e20150108. http://dx.doi.org/10.1590/1676-0611-BN-2015-0108

Abstract: The process of forest fragmentation affects mostly top predators, which are more prone to first disappear. Pumas, *Puma concolor*, are known to have a generalist diet that includes a wide variety of wild and domestic prey species. The capacity of adapting their diet to consuming prey in anthropogenic habitats may be the reason for this species' success in incorporating anthropogenic areas with different levels of fragmentation as part of its habitat. Here we report a case of puma consumption of a large wild prey species, the tapir, *Tapirus terrestris.* From March 2012 to October 2013 we collected 85 puma's scats opportunistically inside fragments of the Atlantic Forest in the Parana state, Brazil. In one of the scats we found hairs and some hooves of a tapir, as well as puma hairs. We propose two hypotheses that may explain the occurrence of tapir in a pumas scat: (1) an event of scavenging or (2) an event of predation on a juvenile tapir. The most likely explanation for this event may be the predation of a juvenile in response to a possible abundant presence of tapirs in the study area. This event adds to our understanding of the great plasticity of this species to adapt to an altered landscape. To our knowledge, this is the first report of a puma scavenging or predation event on a tapir.

Keywords: *predation, Puma concolor, scavenging, Tapirus terrestris.*

AZEVEDO, F.C.C., CANUTO, V., SOUZA, F., WIDMER, C.E. **Predação de anta (Tapirus terrestris) por onça-parda (Puma concolor).** Biota Neotropica. 16(1): e20150108. http://dx.doi.org/10.1590/1676-0611-BN-2015-0108

Resumo: O processo de fragmentação florestal afeta principalmente predadores de topo que são mais propensos a desaparecer. Onças-pardas, *Puma concolor*, são conhecidas por terem uma dieta generalistas que inclui uma grande variedade de presas silvestres e domésticas. A capacidade das onças de adaptar sua dieta ao consumo de presas presentes em habitats antropizados pode ser a razão do sucesso desta espécie em incorporar áreas antropizadas com diferentes níveis de fragmentação como parte de seu hábitat. Neste trabalho, nós apresentamos um caso de consumo de uma grande presa, a anta, *Tapirus terrestres*, por uma onça-parda. De março de 2012 a outubro de 2013 nós coletamos 85 fezes de onças-pardas de forma oportunista dentro de fragmentos de floresta Atlântica do estado do Paraná, Brasil. Em uma das amostras nós encontramos pelos e alguns pedaços de cascos de uma anta. Nós propomos duas hipóteses que podem explicar a ocorrência de uma anta nas fezes de onça-parda: (1) um evento de aproveitamento de carcaça ou (2) um evento de predação de uma anta jovem. A explicação mais provável para este evento de consumo é que se as antas ainda são comuns na região de estudo, um evento de predação pela onça sobre uma anta jovem pode ter ocorrido. Este caso acrescenta informações ao conhecimento da grande plasticidade das onças-pardas em se adaptar a paisagens alteradas. Este é provavelmente o primeiro registro de uma onça-parda consumindo uma carcaça de anta ou predando uma anta.

Palavras-chave: *predação, Puma concolor, aproveitamento, Tapirus terrestris.*

Introduction

The Atlantic Forest was one of the largest rainforests of the Americas, covering approximately 150 million hectares. Currently only 11.4% to 16% of the original forest remains, with more than 80% represented by fragments of less than 50 hectares in size (Ribeiro et al. 2009). This highly fragmented landscape affects mostly top predators and other large mammals, which are more prone to first disappear (Chiarello 1999). Considered the carnivore species with the widest distribution in the Americas, pumas are known to have a generalist diet that includes a wide variety of wild and domestic prey species (Currier 1983, Iriarte et al. 1990, Mazzoli et al. 2002, Azevedo 2008, Palmeira et al. 2008, Azevedo et al. 2010, Foster et al. 2010).

The capacity of adapting their diet to consuming available prey present in anthropogenic habitats may be the reason for this species success in incorporating anthropogenic areas with different levels of fragmentation as part of its habitat (Lyra-Jorge et al. 2008, Miotto et al. 2011, Mioto et al. 2012). The dominant agricultural matrix may represent a greater availability of prey (Miotto et al. 2014) and the fragmentation process of native areas has also been altering the array of prey choices available to pumas. In such landscapes, greater predation rates upon capybaras, armadillos, snakes, birds and lizards has been reported, which seemed to be the more dominant prey species in such environments (Magioli et al. 2014). In addition, in times of scarcity of more vulnerable small and medium prey species, large prey species may become more important in the composition of pumas diet (Branch et al. 1996, Bank et al. 2002, Azevedo 2008). Fragmentation is also a well-known factor for local extinction of jaguars (*Panthera onca*) (Gittleman et al. 2001) and the lack of this larger predator may be allowing pumas to exploit the empty functional niche (Azevedo 2008). If that is the case, pumas could eventually prey upon medium and large prey species known to be more present in jaguar's diet. However, data on the effect of habitat fragmentation on puma's diet are still scarce. Here we document a case of puma consumption of a large wild prey species, the tapir (*Tapirus terrestris*), which represents an event never previously reported.

Material and methods

Our research was part of a project conducted from 2012 to 2013 to investigate puma food habits in the southern part of the Atlantic Forest in Brazil (23°35' S e 52°20' W). Our study site was located on the northern part of Paraná State in a private area comprised of scattered fragments of Atlantic forest embedded in a matrix of agricultural land use interspersed with human habitats. Those fragments varied in size ranging from 0.2 to 2,300 hectares and were in most part connected to each other comprising a total area of about 5,000 hectares of forest. Most common mammal species in the area were agouti (*Dasyprocta azarae*), armadillo (*Dasypus novemcinctus*), capybara (*Hydrochoerus hydrochaeris*), coati (*Nasua nasua*), collared anteater (*Tamandua tetradactyla*), deer (Mazama sp.), paca (*Cuniculus paca*), rabbit (*Sylvilagus brasiliensis*) and tapir (Canuto 2014).

Only scats associated with puma's tracks close to the site of scat collection were considered puma's scats and were included in our analysis. Scats were dried at 72°C for 24 h and contents were separated under running water. Fragments were collected in a 600 μm sieve. Food contents were identified to genus and species using hair, skull fragments, teeth, scales, and via comparison with reference material (Azevedo 2008). We prepared hairs and analyzed medullary structures and cuticular scale patterns following Quadros and Monteiro-Filho (2006 a). Once the hairs were prepared, we took microphotographs amplified 100, 200, and 400 times using a light microscope fitted with a digital camera. We tried to define the type of hair (overhair or underhair) analyzing two regions, the shaft and shield. To identify the species present in the scat we focused on the composition of hair microstructure (medulla, and cuticle).

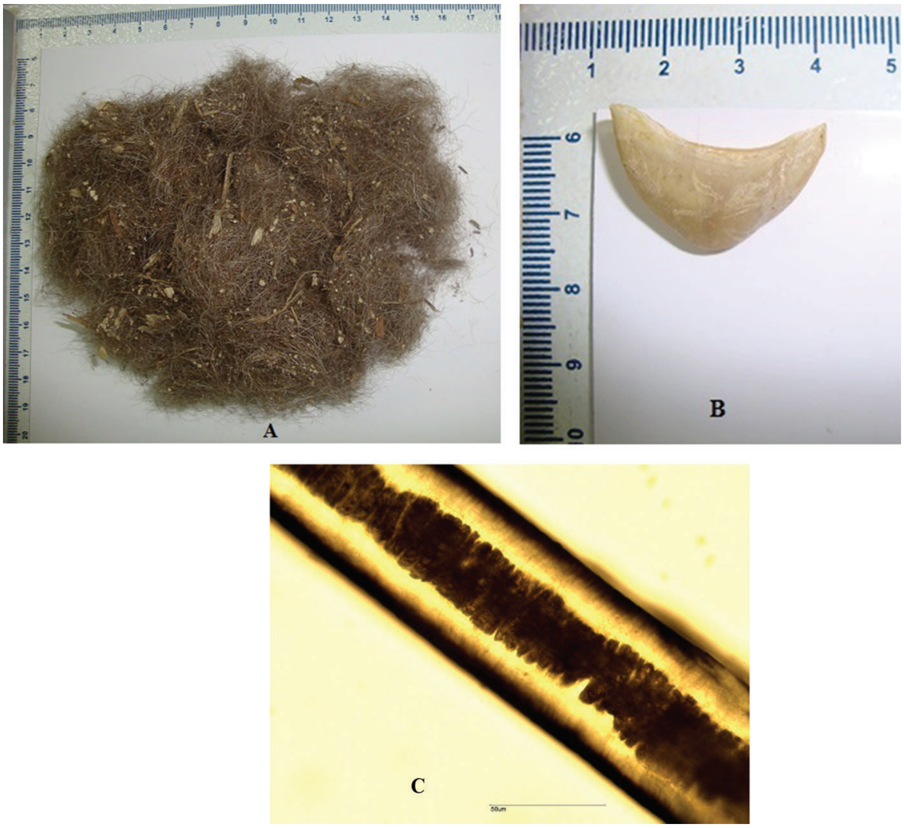

Figure 1. Hair, hooves, and microscopic structure of a puma's scat collected on the northern part of Paraná State along trails inside the study area from March 2012 to October 2013. (A) Hair contents of a puma's scat. (B) One of the juvenile tapir hooves present in the pumas scat. (C) Cloisonné medullar pattern on the shield of the juvenile tapir guard hair, amplified 400x.

Results and discussion

We collected 85 puma's scats opportunistically along trails inside the study area from March 2012 to October 2013. After analyzing all the contents, we found hairs and some hooves on one of the scats that we couldn't identify as one of the regular prey species for pumas. The microscopic analysis revealed a great amount of juvenile hairs characterized by regular wave pattern suggesting the occurrence of a tapir (Quadros and Monteiro-Filho 2006 b). This general pattern could possibly confound the identification of a tapir for domestic horse. However, the shape of the hooves present on thet scat, which were small and whitish, indicated the occurrence of a juvenile tapir (Figure 1). We also found hairs supposedly from the predator. The microscope analysis revealed guard hairs with regular wave cuticular pattern and a very large cortex at the medulla (Figure 2), indicating the predator as a puma (Quadros and Monteiro-Filho 2006 b).

Pumas are known to be generalist feeders and also scavengers (Bauer et al. 2005). Therefore, potential explanations for the occurrence of this species on puma diet are either an event of scavenging or an event of predation on a juvenile tapir. Due to the fragmentation of the original forest, the lack of a wide array of available prey species may have forced pumas to use whatever food resource was available in the region, and scavenging might be a reasonable alternative food source for pumas. Measuring the level of scavenging habits is crucial to estimate puma's energetic requirements (Elbroch et al. 2014) and would help to understand how these felids thrive on anthropogenic areas. The second possibility, a predation event on a juvenile tapir, may represent an alternative novel prey species in the puma's diet. Pumas and tapirs are sympatric species in geotropically forests (Azevedo 2008, Foster et al. 2010), however, puma predation on tapir has never been reported. Tapirs are prey for jaguars, which are larger in body size than pumas in places where they occur in sympatry (Taber et al. 1997, Garla et al. 2001, Cavalcanti and Gese 2010) whereas in other sites neither predator seemed to utilize tapirs as food source (Scognamillo et al. 2003, Novac et al. 2005, Weckel et al. 2006, Azevedo and Murray 2007, Foster et al. 2010). The large size of a tapir and the competition with jaguars seem to preclude puma predation on tapir. In most cases where the diet of pumas was recorded in fragmented areas, tapirs were no longer present in the landscapes and pumas utilized other available prey species (Magioli et al. 2014). However, in our study site, tapirs were still common and therefore, a puma predation event on a juvenile tapir may be another proof of the great plasticity of this species to adapt to an altered landscape. To our knowledge, this is the first report of a puma scavenging or predation event on a tapir.

Figure 2. Microscopic structure of puma's hair collected in scat on the northern part of Paraná State along trails inside the study area from March 2012 to October 2013.

Acknowledgements

We thank Companhia Melhoramentos Norte Paraná and ICMBio (Chico Mendes Institute for Biodiversity Conservation) for permission to conduct research in the study site. V.C.C. received a research fellowship from CNPq during the course of this study.

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Received 11/09/2015
Revised 06/01/2016
Accepted 29/01/2016

Biota Neotropica 16(1): e0118, 2016
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
article

Synopsis of the genus *Nyctibora* Burmeister, with description of two new species from Rio de Janeiro, Brazil (Ectobiidae, Nyctiborinae)

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LOPES, S.M., ASSUMPÇÃO, M. **Synopsis of the genus *Nyctibora* Burmeister, with description of two new species from Rio de Janeiro, Brazil (Ectobiidae, Nyctiborinae).** Biota Neotropica. 16(1): e0118. http://dx.doi.org/10.1590/1676-0611-BN-2015-0118

Abstract: Two new species of *Nyctibora* are described and considered similar to *Nyctibora sericea*. Coloration, morphology and genital pieces of males were analyzed. All the studied material shall be deposited in the Museu Nacional.

Keywords: *Blattodea, New species, Nyctibora, Taxonomy.*

LOPES, S.M., ASSUMPÇÃO, M. **Sinopse do gênero *Nyctibora* Burmeister, com descrição de duas novas espécies do Rio de Janeiro, Brasil (Ectobiidae, Nyctiborinae).** Biota Neotropica. 16(1): e0118. http://dx.doi.org/10.1590/1676-0611-BN-2015-0118

Resumo: Duas espécies novas de *Nyctibora* são descritas, similares à *Nyctibora sericea*. Dados sobre coloração, morfologia e peças genitais dos machos foram analisados. Todo o material estudado se encontra depositado no Museu Nacional.

Palavras-chave: *Blattodea, Espécies novas, Nyctibora, Taxonomia.*

Introduction

The genus *Nyctibora* was described by Burmeister in 1838, based on morphological characters of the head, antennae and pronotum; the tegmen often reaching beyond the apex of the abdomen; legs with very spiny femora; pulvilli developed, occupying almost completely the second quarter of tarsal articles; arolia present; supra-anal plate differentiated, with cerci widened, short and tomentose, as a basic characteristic. Rehn (1951), after delimiting tribes within the subfamily Nyctiborinae, placed *Nyctibora* in the tribe Nyctiborini, based on *Nyctibora noctivaga* Rehn, 1903, and characterized it based on the costal and subcostal veins of the tegmen.

Nyctiborinae includes 10 genera and 70 species, of which 32, distributed from Mexico to Argentina, are classified in *Nyctibora*. According to Vélez-Bravo & Franz (2011 in: Salazar & Maláver, 2012) Nyctiborinae can be considered paraphyletic, but more characters are necessary to confirm the position of *Muzoa* Hebard, 1921 outside the subfamily, they divided Nyctiborinae into two groups. Group 1 includes *Muzoa* Hebard, 1921, *Megaloblatta* Dohrn, 1887, *Eushelfordia* Hebard, 1924 and *Paratropes* Serville, 1839 and Group 2 includes *Pseudoischnoptera* Saussure, 1869, *Eunyctibora* Shelford, 1908 and *Nyctibora* Burmeister, 1838. They did not included *Eushelfordiella* Lopes & Oliveira, 2007, *Nyctantonina* Vélez, 2013 and *Paramuzoa* Roth, 1973 in their revision. Salazar & Maláver (2012) supported the results and called them the "true phylogeny of the subfamily". The results were based on a cladistic analysis of 53 genital characters scored from 24 species.

About half the members of the genus are diurnal, which is rare among Blattodea (Bell et al., 2007). Examples are *Paratropes*, *Eunyctibora* and *Eushelfordia*, which can be collected from vegetation during the day. Most nyctiborines are detritivores, consuming decomposing plant matter. Some species of *Nyctibora* prefer dead animals, whereas species of *Paratropes* feed on pollen and nectar (Perry 1978). According to Salazar & Maláver (2012), the taxonomy of *Nyctibora* is still poorly understood.

Two new species from the state of Rio de Janeiro, *Ny. bromelicola* and *Ny. isoldae,* are described here.

Materials and Methods

The morphology of the specimens described here was analyzed according to Lopes & Oliveira (2000). The terminology used for the genital parts is based on Roth (2003). The systematic position of the genus follows Beccaloni (2015). After analysis, the plates and genital parts were kept in microvials containing glycerin and were stored next to their respective pinned specimen (Gurney et al. 1964). The material is deposited in the collection of the Museu Nacional, Rio de Janeiro (MNRJ).

Results

1. Nyctibora bromelicola sp. nov.

General coloration: dark brown (Figure 1a). Head with ocelli and apex of labrum yellowish brown; palps and antennae golden tomentose (Figure 1b); pulvilli yellowish. Pronotum paler medio-basally (Figure 1c).

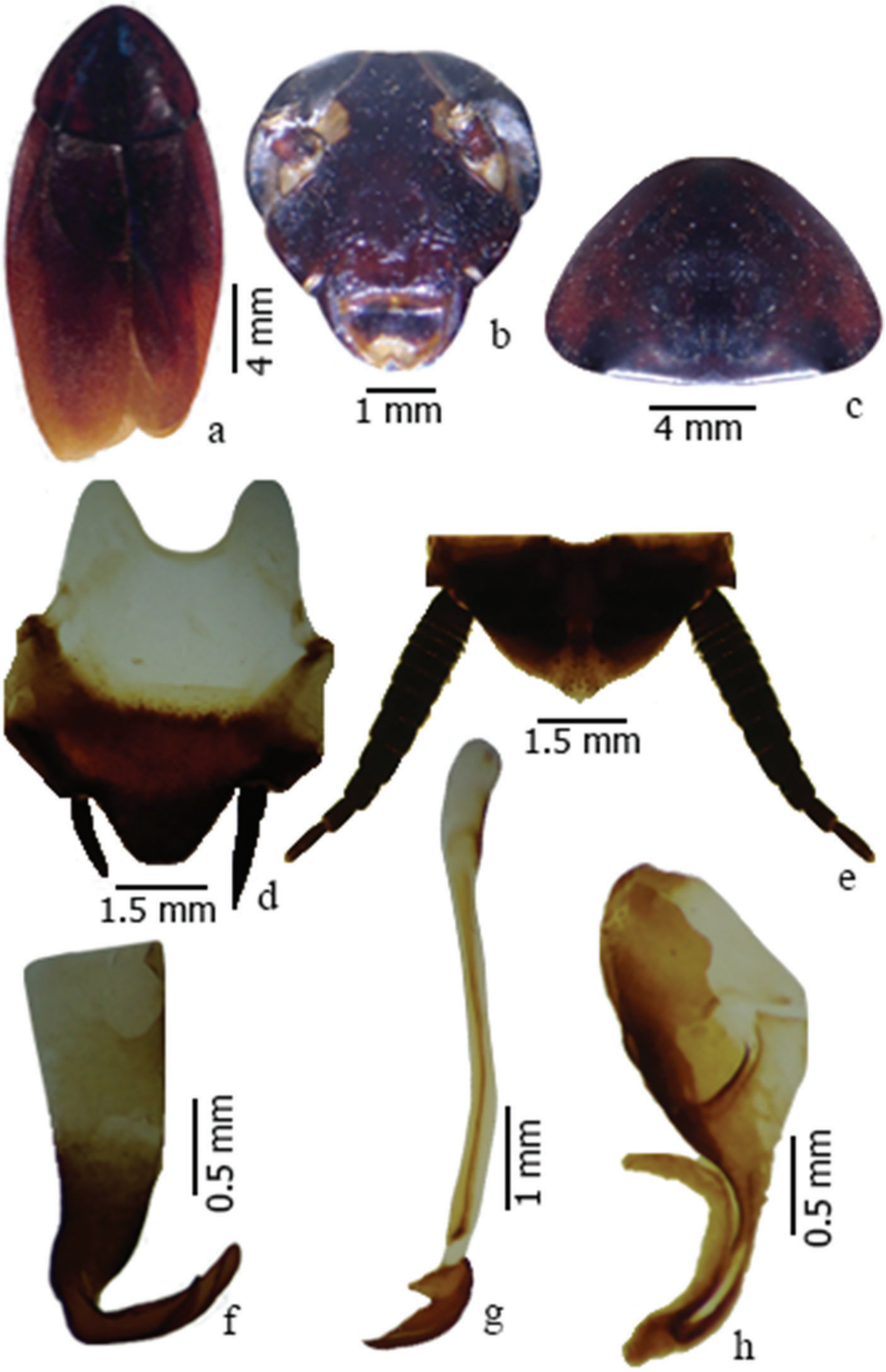

Figure 1. *Nyctibora bromelicola* sp. nov. holotype male. a. Habitus; b. Head, ventral view; c. Pronotum, dorsal view; d. Subgenital plate, ventral view; e; supra anal plate, dorsal view; f. left phallomere, dorsal view; g. median sclerite, dorsal view; h. right phallomere, dorsal view.

Dimensions (mm) ♂: Total length: 32.0; Length of pronotum: 9.0; width of pronotum: 12.0; length of tegmen: 26.0; width of tegmen: 11.0.

Head "triangular", vertex covered by pronotum in dorsal view; interocular space narrow, about one-fourth distance between antennal insertions; ocelli well defined; maxillary palp with last segment dilated, tomentose and larger than remaining segments.

Thorax with pronotum subtriangular, convex, transverse, sparsely tomentose. Fore femur with anteroventral surface bearing 10 robust spines, small and decreasing in size toward apex, plus two pre-apical spines slightly larger than the anterior spines, and two large apical spines; posteroventral surface with five robust spaced spines, one apical. Mid- and hind femora with six to eight robust spaced spines, one apical, on ventral surfaces; one genicular spine present on hind femora. Pulvilli present on all tarsal articles; arolia present; claws asymmetrical and simple.

Tegmen tomentose and long, reaching beyond apex of cerci, marginal field short; scapular field narrow with oblique venular arrangement; discoidal field with longitudinal venular arrangement;

anal field ample and well marked. Wings with anterior field with apexes of rami not dilated; apical triangle slightly developed, and anal field fan-folded.

Abdomen with subgenital plate widened and with rounded medio-apical projections. Styles differentiated, right style slightly larger than left (Figure 1d). Supra-anal plate triangular, projected and rounded medio-apically; cerci long, tapering apically (Figure 1e). Genitalia with right phallomere sclerotized medially (Figure 1f); median sclerite slender apically; median sclerite tapering apically, sickle-shaped (Figure 1g); left phallomere hook-shaped, rounded apically (Figure 1h).

Material examined: Holotype ♂, Brazil, Rio de Janeiro, Marambaia, 8/VI/1981, Roberto Xerez col. (on bromeliad).

Discussion

The species differs from *Ny. sericea* Burmeister, 1838 by coloration totally blackened pronotum and not to present the yellow spot in the marginal field; by setting the subgenital plate more pronounced medially; triangular supra-anal plate with apex acuminate medially; left phallomere hook-shaped with

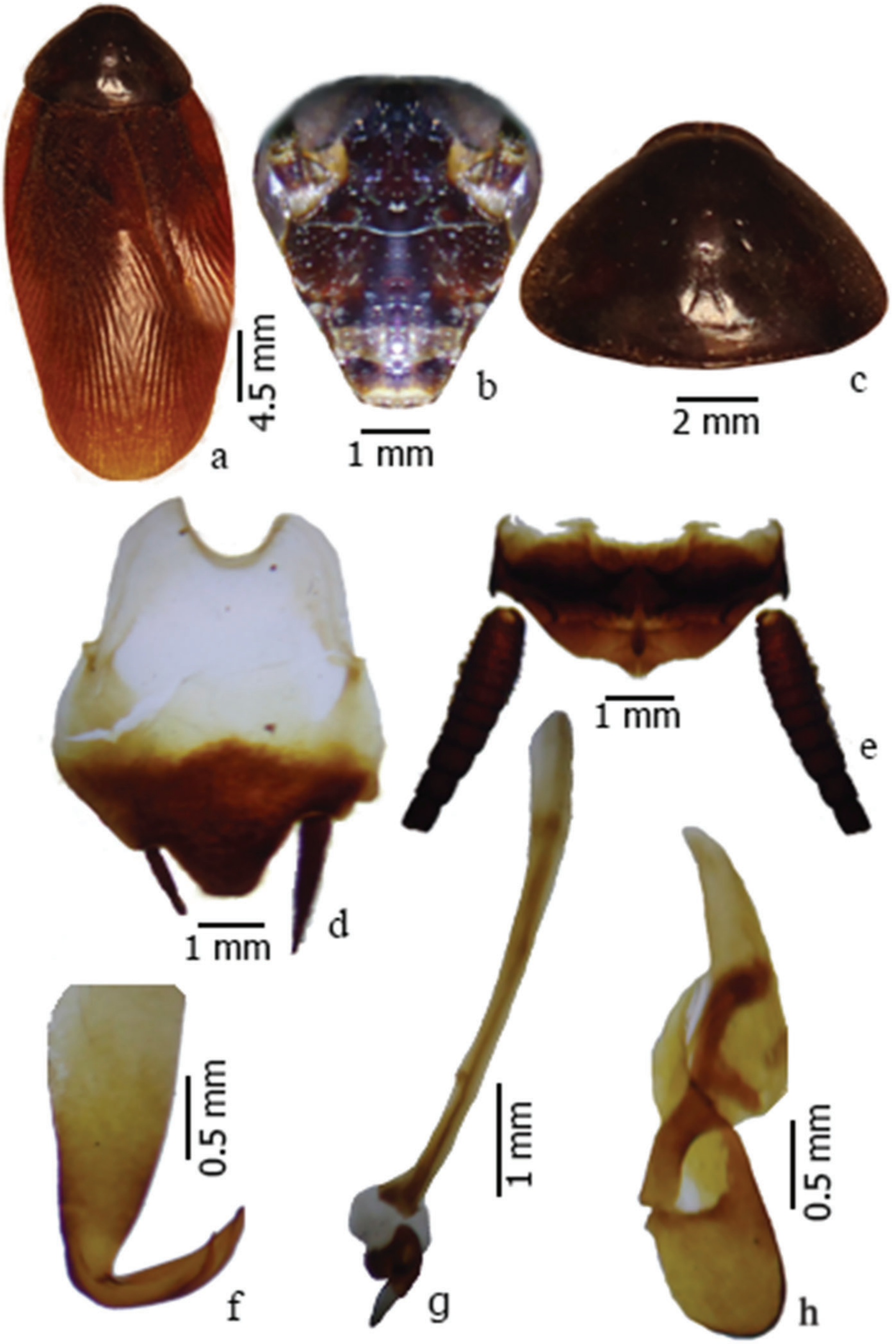

Figure 2. *Nyctibora isoldae* sp. nov. holotype male. a. Habitus; b. Head, ventral view; c. Pronotum, dorsal view; d. Subgenital plate, ventral view; e; supra anal plate, dorsal view; f. left phallomere, dorsal view; g. median sclerite, dorsal view; h. right phallomere, dorsal view.

tapered apically and higher in length; median sclerit rounded in the base with the apex in the shape of a sickle.

Etymology

The species epithet refers to the habitat where it was collected, a bromeliad.

2. *Nyctibora isoldae* sp. nov.

General coloration: dark brown (Figure 2a). Head dark with ocelli (Figure 2b), apex of maxillar and labial palps yellowish, golden tomentose. Pronotum uniformly colored (Figure 2c); legs with pulvilli yellowish; tegmen dark, yellowish tomentose.

Dimensions (mm): Holotype ♂: Total length: 30.0; Length of pronotum: 7.0; width of pronotum: 10.0; length of tegmen: 26.5; width of tegmen: 10.0. Paratype ♀: Total length: 32.0; length of pronotum: 8.0; width of pronotum: 10.5; length of tegmen: 27.5; width of tegmen: 10.5.

Head "triangular", vertex covered by pronotum in dorsal view; interocular space narrow, measuring about one-sixth distance between antennal bases; ocelli well-defined; maxillary palp with fifth segment dilated, longer and more tomentose than the others.

Thorax with pronotum subtriangular, convex, transverse, sparsely tomentose; legs with fore femur with anteroventral surface bearing a row of ten spines from base to median region, two apical spines slightly larger than anterior spines; plus two large apical spines; posteroventral surface with four robust spaced spines on apex, one on apical third. Mid- and hind femora bearing six to eight robust and spaced spines, one apical, on ventral surface; genicular spines present on last two femora. Pulvilli present on all tarsal segments; arolia present and well developed; nails asymmetrical and simple. Tegmen long, reaching beyond apex of cerci, subcostal venation well differentiated toward scapular field; marginal field short; scapular field narrow with oblique veins; discoidal field with longitudinal veins; anal field ample and well demarcated. Wings developed, not reaching beyond apex of tegmen; anterior field with apex of rami of radial not dilated, apical triangle little developed, and anal field ample, fan-folded.

Abdomen with subgenital plate wide and asymmetrical, with apex rounded medially and projected between styles. Styles differentiated, right style more developed than left (Figure 2d); supra-anal plate symmetrical, medio-apically produced, short with sparse cilia. Cerci long, ciliated, tapering toward apex (Figure 2e). Genitalia with right phallomere sclerotized medially (Figure 2f); median sclerite slender, widened apically; apical sclerite sclerotized, without defined shape (Figure 2g); left phallomere hook-shaped apically, slender, with pre-apical notch (Figure 2h).

Material examined: Holotype ♂, Brazil, Petrópolis, Mosela, 12/II/1975, Isolda Rocha e Silva col. Paratype 2 ♀, data same as holotype.

Discussion

Ny. isoldae sp. nov. differs from *N. sericea* by coloration totally, blackened pronotum and tegmen and without yellow spot in the pronotum; subgenital plate similar to *Ny. bromelicola* sp. nov. and differs from *Ny. bromelicola* sp. nov. and *Ny. sericea* by configuration of the sinous apex apical of supra-anal plate and little acuminated compared to *Ny. bromelicola* sp. nov . In *Ny sericea* is absent. Left phallomere has hook-shaped with elongated and tapered apex as in *Ny. bromelicola* sp. nov, but with reentrance sub-apical. Sclerite very long in length, rounded at the base; apex with rounded in the base and tapered apex, which sets it apart from *Ny. bromelicola* sp. nov. and *Ny. sericea* which does not have this configuration.

Etymology

The name honors Isolda Rocha e Silva, former researcher on Blattodea at the Museu Nacional, now retired.

Acknowledgements

The text was edited by Dr. Janet W. Reid.

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Received 13/10/2015
Revised 27/12/2015
Accepted 20/01/2016

Biota Neotropica 16(1): e0045, 2016
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
article

Survey of Bioluminescent Coleoptera in the Atlantic Rain Forest of Serra da Paranapiacaba in São Paulo State (Brazil)

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SANTOS, R.M., SCHLINDWEIN, M.N., VIVIANI, V.R. **Survey of Bioluminescent Coleoptera in the Atlantic Rain Forest of Serra da Paranapiacaba in São Paulo State (Brazil).** Biota Neotropica. 16(1): e0045. http://dx.doi.org/10.1590/1676-0611-BN-2015-0045

Abstract: Brazil is the country with the largest number of bioluminescent beetle species in the world. However, estimates suggest that this number could much be higher, since many species remain to be discovered. In this work we made a survey of the species of bioluminescent beetles in Serra de Paranapiacaba – the largest remnant of Atlantic Forest in São Paulo State. The survey was done at Intervales State Park, Carlos Botelho State Park and municipality of Tapiraí and the following species were collected: *Aspisoma lineatum*, *Aspisoma physonotum*, *Aspisoma fenestrata*, *Cratomorphus besckey*, *Cratomorphus distinctus*, *Photinus penai*, *Photinus* sp$_1$, *Photinus* sp$_9$, *Ethra aff. malledicta* or *axilaris, Ethra aff. adicta* , Lucidotini *incertae sedis*, *Cladodes flabellicornis, Cladodes demoulini*, *Amydetes lucernuta*, *Bicellonycha* sp$_8$, *Bicellonycha ornaticollis*, *Pyrogaster lunifer*, *Pyrogaster moestus*, *Pyrogaster* sp$_2$, *Pyrogaster* sp$_5$, *Pyrogaster* sp$_6$, *Photuris lugubris*, *Photuris* sp$_1$, *Photuris* sp$_7$, *Stenophrixotrix* sp$_1$, *Brasilocerus* sp$_1$, *Pseudophengodes* sp$_1$, *Hapsodrilus pyrotis*, *Hypsiophtalmus* sp$_1$, *Ptesimopsia luculenta*, *Pyroptesis cincticollis*, *Pyrearinus brevicolis*, *Pyrearinus candelarius*, *Pyrearinus micatus*, *Pyrophorus divergens*. Our data show that Serra de Paranapiacaba is the second richest area in São Paulo state, especially in elaterids, with unique species typical of this area and species common to other investigated sites such as the Biological Station of Boracéia (in Salesópolis county) and the urbanized areas in the between Campinas - Sorocaba- São Paulo, originally covered to the Atlantic Rainforest.

Keywords: *Lampyridae, Phengodidae, Elateridae, Elateroidea, Staphylinidae, bioluminescence, Fireflies, Atlantic Rainforest.*

SANTOS, R.M., SCHLINDWEIN, M.N., VIVIANI, V.R. **Levantamento de Coleópteros bioluminescentes na Mata Atlantica da Serra da Paranapiacaba.** Biota Neotropica. 16(1): e0045. http://dx.doi.org/10.1590/1676-0611-BN-2015-0045

Resumo: O Brasil é o país que possui o maior número de espécies de coleópteros bioluminescentes no mundo. Entretanto, estimativas sugerem que este número possa ser bem maior, dado que muitas espécies ainda não foram descritas. Neste trabalho foi realizado um levantamento das espécies de coleópteros bioluminescentes em três localidades na Serra da Paranapiacaba – a maior área remanescente contígua de Mata Atlântica no país, com associação ao respectivo habitat. No Parque Estadual Intervales, Parque Estadual Carlos Botelho e Tapiraí foram coletadas as seguintes espécies: (Lampyidae) *Aspisoma lineatum*, *Aspisoma physonotum*, *Aspisoma fenestrata*, *Cratomorphus besckey*, *Cratomorphus distinctus*, *Photinus penai*, *Photinus* sp$_1$, *Photinus* sp$_9$, *Ethra aff. malledicta* ou *axilaris, Ethra aff. adicta*, Lucidotini *incertae sedis*, *Cladodes flabellicornis, Cladodes demoulini*, *Amydetes* sp$_1$, *Bicellonycha* sp$_8$, *Bicellonycha ornaticollis*, *Pyrogaster lunifer*, *Pyrogaster moestus*, *Pyrogaster* sp$_2$, *Pyrogaster* sp$_5$, *Pyrogaster* sp$_6$, *Photuris lugubris*, *Photuris* sp$_1$, *Photuris* sp$_7$; (Phengodidae) *Stenophrixotrix* sp$_1$, *Brasilocerus* sp$_2$, *Pseudophengodes* sp$_1$; (Elateridae) *Hapsodrilus pyrotis*, *Hypsiophtalmus* sp$_1$, *Ptesimopsia luculenta, Pyroptesis cincticollis*, *Pyrearinus brevicolis*, *Pyrearinus candelarius*, *Pyrearinus micatus*, *Pyrophorus divergens*. Estes dados mostram que esta constitui a segunda área mais rica em espécies luminescentes do Estado de São Paulo, depois da Est. Biológica de Boracéia, especialmente em elaterídeos, com espécies únicas características destas localidades e espécies comuns à outras áreas investigadas, como as da Estação Biológica de Boracéia (Salesópolis, SP) e áreas urbanizadas no triângulo Campinas - Sorocaba - São Paulo, originalmente cobertas por Mata Atlântica.

Palavras-chave: *Lampyridae, Phengodidae, Elateridae, Elateroidea, Staphylinidae, vaga-lumes, bioluminescência, mata atlântica.*

Introduction

Brazil has the largest diversity of luminescent beetles in the world, about 500 described species, corresponding about 23% of described species in the world (Costa 2000; Viviani *et al.* 2010). These species are distributed mainly in the three main families of Elateroidea: Lampyridae, Phengodidae and Elateridae. Furthermore, two species of luminescent Staphylinidae were reported (Costa *et al.* 1986; Rosa 2010). These species are distributed mainly in the following biomes: Atlantic Rainforest, Cerrado (Savannah), Pantanal (Marshies) and Amazon Rainforest. Among these ecosystems, the Atlantic Rainforest is one of the richest and also most threatened ones, currently with only around 7-8% of the original cover or 11.4 -16% when considering the the small woods (Ribeiro *et al.* 2009).

Despite their biodiversity, taxonomic and systematic studies on bioluminescent beetles in Brazil are still scarce. Detailed modern taxonomical studies are found mainly for Elateridae by Costa e collaborators (Costa *et al.* 1988, Costa 1971a, 1971b; 1972, 1975). However, the families Lampyridae and Phengodidae lack recent reviews and their systematics remains troublesome. Some studies on the biology and ecology were performed for some species of Elateridae (Costa 1975, Costa *et al.* 1988) and Phengodidae (Costa *et al.* 1999, Viviani & Bechara 1997). In the family Lampyridae, bionomic studies were done for two semi-aquatic species of *Aspisoma* spp. (Costa *et al.* 1988, Viviani 1989), *Aspisoma lineatum* Gyllenhal, 1817 (Viviani et al., 2012), some lampyrid species of São Paulo State (Viviani 2001) and for *Photuris fulvipes* Blanchard 1837(Rosa 2007). Recently, the genus *Amydetes* was revised with the description of several new species (Da Silveira and Mermudes, 2014).

Considering the growing importance of fireflies and bioluminescent beetles as potential environmental indicators (Viviani *et al.* 2010), mainly for the impact of artificial night-lighting (Lloyd 2006; Viviani et al., 2010; Hagen et al., 2014), and their importance for scientific studies and in biotechnology as source of bioluminescent reagents (Viviani 2007), it is urgent to make biodiversity surveys to aid conservation and bioprospection programs.

The Atlantic Forest is, after the Amazon, the second largest forest type in South America. The last corridor of this forest is located mostly in São Paulo state, being composed of a series of protected areas with more than 17.300 km^2 of forests (Galleti Jr *et al.* 2008). Considering the lack of knowledge about bioluminescent beetles in Brazil, in the nineties, and especially from 2006 we made surveys in the Atlantic rain forest. We already made lists of species occurring near the urban areas of Campinas, Rio Claro, Sorocaba and Votorantim cities in São Paulo State, which were mostly covered by seasonal Atlantic rain forest in the past (Viviani 2001, Viviani *et al.* 2010) and more recently about the bioluminescent species occurring in the hotspot of Biological Station of Boracéia located in the second largest remnant of Atlantic rain forest of Serra do Mar, along the coastline (Viviani & Santos 2012).

In this study we present a first survey made from 2007-2012 in the largest and most preserved remnant of Atlantic rain forest in São Paulo State, which is located along of Serra da Paranapiacaba, including three main investigated sites: (I) Cachoeira do Chá in the municipality of Tapiraí at its Northern border; (II) Parque Carlos Botelho in the middle and (III) Parque Intervales in the Southern part.

Materials and Methods

Habitats description. The investigated sites are located in a largest continuous remnant of Atlantic rain forest along the scarp chain Serra da Paranapiacaba, which is a subdomain of the Serra do Mar scarp chain, located about 100 km from the coast between the hydrographic basins: Sorocaba-Médio Tietê, Paranapanema and Ribeira-Southern Shore. The main kind of forest is dense mountain ombrophyl forest (Fig.1) with the following phytophysionomic divisions: (I) mountain forest located over the mountains which include tall trees; (II) humid forest located between mountains over water bodies, which includes similar vegetation to the former habitat but with the presence of species better adapted to humid environments; (III) marshy areas at the borders of water bodies and streams which display typical grasses, and (IV) open fields surrounding the reservation or along thoroughfares opened in the forest. The following sites were investigated:

Cachoeira do Chá, Tapiraí. (24°01'47.50"S - 47°3429.47"W, 595m asl). This is a trail located along a stream at the Northern border of the large remnant, borthered by the route SP-79 and located 15 km from Tapiraí municipality. In this site the mountains display an escarpment ending at Ribeira River Valley.

Carlos Botelho. (24°03'46.48"S - 47°59'30.31"W, 763m asl). This park features a rugged terrain in the upper level followed by escarpment ending at the Ribeira River Valley in the lower part (Fig.1). Located in the north, at higher elevations there is a watershed of Ribeira River Valley Basin and another (Taquaral river) of Paranapanema River Basin. The mountains have dense rain forest (Montana forest), whereas in the lower part of the drive at the southeast, the vegetation is composed mainly by lowland tropical rain forest (Submontana forest). The survey sites within this unit are located near the headquarters, in the Northern part of the Park in the municipality of São Miguel Arcanjo.

Fazenda Intervales. (24°16'12.46"S - 48°25'17.11"W, 826m asl). This site is located on the Serra da Paranapiacaba, and also on the Planalto de Guapiara, with very rough relief cut by headwater streams. The study site in this reserve was located between Guapiara and Ribeirão Grande municipalities. The present forest coverage is characterized as Montana forest as described above and the differential in this area is the geological and geomorphological formation, with many valleys and hills. The investigated areas were all located in the protected area, with the trails in the northwestern part of the Park.

Collecting techniques. The collecting and observations were originally done in 1991 and 1993 at Intervales, and then yearly from 2007-2012. In Intervales, collecting and observations were done in the period of October-April and eventually in July. In Carlos Botelho the observations and collecting were made weekly between July and December from 2007-2010. In Tapiraí, observations were done from 2009-2012, with sporadic visits in the same period from November through March.

Adult lampyrids and elaterids were located by their own light at night and collected in flight with entomological net, or in the bushes or in the litterfall, during the period from August to April. They were also collected on the foliage during the day, especially diurnal lampyrids. Luminescent click-beetles and even some lampyrids such as *Cratomorphus distinctus* Olivier 1895 firefly could also be attracted to green chemiluminescent light sticks. Adult male phengodids were collected, in rare occasions, on soil and on the grass. Firefly larvae were collected on the undergrowth, in litterfall

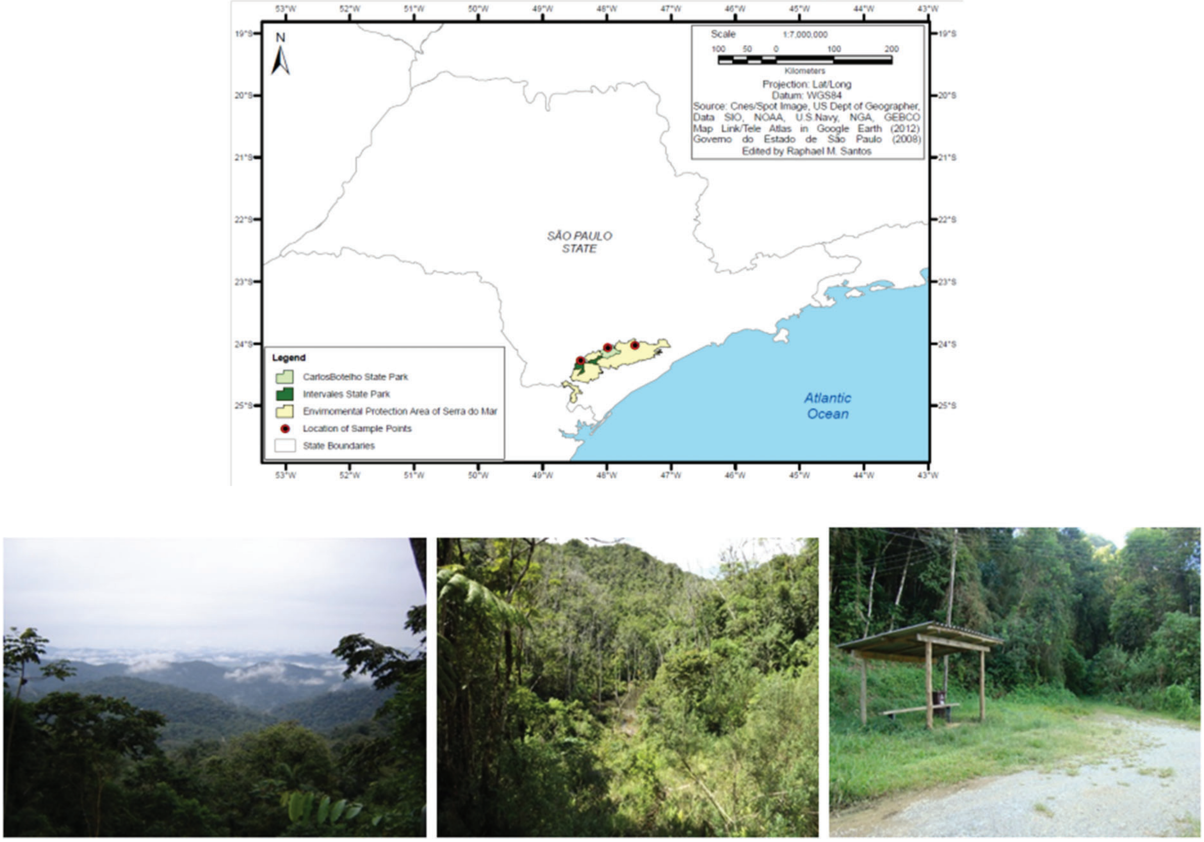

Figure 1. (Upper panel) Map of São Paulo State showing the investigated sites; (Lower panels) main vegetation types on the study area: **(a)** Mountain Atlantic Rainforest in the top of hills in Carlos Botelho State Park, here the view of the Submontane Forest in the Ribeira Valey Basin is shown; **(b)** Humid forest at Carlos Botelho State Park. View of a marshy area along riparian woods in the Taquaral stream; **(c)** Open field with vegetal species more light tolerant, including grasses at the ground level and creepers at the edge of woods. This image represents a site with occurrence of *Bicellonycha* sp8. – a brazilian synchronous firefly – in Intervales State Park.

Figura 1. (Painel superior) Mapa do Estado de São Paulo, com os pontos onde foram realizados os levantamentos; (Paineis inferiores) principais tipos de vegetação nas áreas de estudo. **(a)** Floresta Atlântica Montana no Parque Estadual Carlos Botelho, aqui é mostrado a vista para a Floresta Submontana no Vale do Ribeira; **(b)** Floresta pluvial no Parque Carlos Botelho. Vista de uma área brejosa de mata ripária no Rio Taquaral; **(c)** Área aberta com espécies vegetais mais tolerantes à luminosidade, como gramíneas e lianas. Esta imagem apresenta um local com ocorrência de *Bicellonycha* sp8 – um vagalume sincrônico brasileiro – no Parque Estadual Intervales.

and soil at night, by the location of their glows (Viviani 2001, Viviani *et al.* 2010). Phengodid larvae were also collected at night in the soil, in embankments, and eventually on the underbrush by location of their luminescence (Viviani & Bechara 1997).

Identification. Specimens of fireflies and their larvae were identified first by comparison with scientific collection of Professor Viviani at UFSCar, which was previously identified by comparison with the collections of Museu de Zoologia da Universidade de São Paulo (São Paulo, Brazil), Natural History Museum of Paris (France) and British Museum (London,UK). Some species were identified by Dra. S. P. Rosa during her visit at the Natural History Museum of Paris (France). Elateridae species were previously identified by Dra. C. Costa (MZUSP) and Dra. S. P. Rosa. Several lampyrid and phengodid species could not be identified, and were catalogued by the name of the genus followed by a specific number (separated in morph species), according to Viviani & Bechara (1997) and Viviani (2001). The specimens were deposited in the collection in UFSCar under curatorship of V. Viviani.

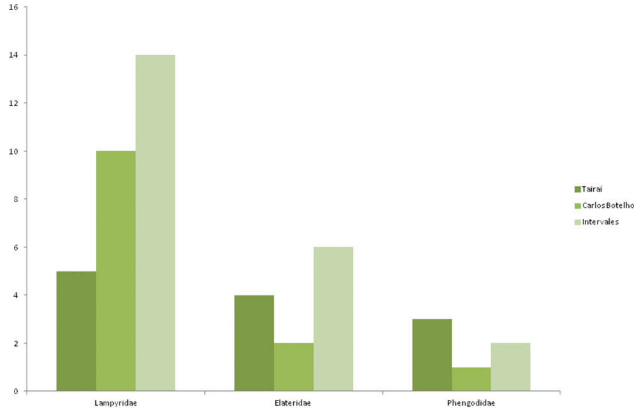

Figure 2. Number of bioluminescent Coleoptera species of different families in each site ofthe Serra da Paranapiacaba.

Figura 2. Número de espécies de coleopteros bioluminescentes por família em cada local de coletas e observações na Serra da Paranapiacaba.

Table 1. Species of bioluminescent beetles collected in the three different sites of Serra de Paranapiacaba.
Tabela 1. Espécies de besouros bioluminescentes coletados nas três localidades de estudo na Serra de Paranapiacaba.

Taxon	Tapiraí	PECB	PE Intervales	Reference collection
Lampyridae				
Cratomorphini				
Aspisoma lineatum Gyllenhal		*ok* (4)		Col. MZUSP
Aspisoma physonotum Gorham, 1884			*ok* (2,3)	Col. MZUSP
Aspisoma sp2	*ok* (1,2)		*ok* (1,2)	Col. V. Viviani
Cratomorphus besckei Olivier 1895	*ok* (2)		*ok* (2)	Col. MZUSP
Cratomorphus giganteus Druty, 1782	*ok* (1)	*ok* (1)	*ok* (1)	Col. MZUSP
Photinini				
Photinoides jenai McDormott, 1963	*ok** (1,2,3,4)	*ok* (1,2,3,4)	*ok* (1,2,3,4)	Col. MZUSP
Photinus sp$_1$		*ok* (1)	*ok* (1)	Col. V. Viviani
Photinus sp$_9$	*ok* (2)			Col. V. Viviani
Lucidotini				
Ethra aff. malledicta or axilaris		*ok* (1)		*
Ethra aff. adicta			*ok* (1)	*
Lamprocerini				
Cladodes demoulini			*ok* (1)	Col. MZUSP
Cladodes flabellicornis		*ok* (1)		Col. V. Viviani
Amydetinae				
Amydetes lucernuta			*ok* (4)	-
Photurinae				
Bicellonycha sp.		*ok* (3,4)		-
Bicellonycha sp$_8$	*ok** (3,4)		*ok* (3,4)	Col. V. Viviani
Pyrogaster lunifer Eschscholtz, 1822		*ok* (1)		Col. V. Viviani
Pyrogaster moestus Germar 1824		*ok* (1,2)	*ok* (1,2)	Col. V. Viviani
Pyrogaster sp$_3$			*ok* (1)	PORTO (2011)
Photuris lugubris Gorham 1881		*ok* (1,2)	*ok* (1,2)	Col. V. Viviani
Photuris sp$_7$			*ok* (1)	Col. V. Viviani
Phengodidae				
Mastinocerini				
Stenophrixotrix sp$_1$	*ok* (1)	*ok* (1)	*ok* (1)	Col. V. Viviani
Brasilocerus sp$_1$	*ok* (1,2)			-
Phrixotrix hirtus Olivier, 1909	*ok** (2)			Col. V. Viviani
Phengodini				
Pseudophengodes sp$_1$			*ok* (1,2)	-
Elateridae				
Agrypininae/Pyrophorini				
Hapsodrilus pyrotis Germar, 1841	*ok* (1)		*ok* (1)	Col. MZUSP
Pyroptesis cincticollis Germar 1841	*ok* (1,3)		*ok* (1,3)	Col. MZUSP
Ptesimopsia luculenta Germar, 1841			*ok* (1,2)	Col. MZUSP
Pyrearinus brevicollis Eschsdioltz 1829		*ok* (1)		Col. MZUSP
Pyrearinus candelarius Germar 1841			*ok* (1)	Col. V. Viviani
Pyrearinus micatus Costa 1978	*ok* (1,2)		*ok* (1,2)	Col. V. Viviani
Pyrophorus divergens Eschscholtz 1829	*ok* (1)	*ok* (1)	*ok* (1)	Col. V. Viviani

Legenda: ok = ocorrência; *ok** = ocorrência mas sem material fixado; (1) = floresta Montana; (2) = floresta úmida; (3) = áreas brejosas; (4) = áreas abertas. ** identificação pela chave.

Legend: ok = collected; *ok** = occurence recorded but no fixed material; (1) = montane forest; (2) = umid forest; (3) = marshy areas; (4) = open field. ** identificação pela chave.

Results and Discussion

Taxonomic survey. Thirty one species of luminescent beetles were cataloged in the Serra da Paranapiacaba: 20 Lampyidae, 7 Elateridae, 4 Phengodidae and 1 Staphylinidae (Table 1).

The richness of each family of luminous beetles in each conservation unit is summarized in Figure 2.

Lampyridae (Fig. 3). The number of observed lampyrid species was 10 in Carlos Botelho and 14 in the Intervales. In Tapiraí only five species were found (see Table 1). The smaller number found in Tapiraí could be due to the lower frequency and smaller scanned area of collecting made in this site. The following species were unique to Carlos Botelho: *Aspisoma lineatum*, *Photinus* sp$_1$, *Ethra aff maledicta or axillaris*, Lucidotini *incertae sedis*, *Cladodes flabellicornis*, *Pyrogaster lunifer*, *Pyrogaster* sp$_5$ and *Pyrogaster* sp$_6$. Seven species were found at Intervales but were not been found in Carlos Botelho and Tapiraí: *Aspisoma physonotum*, *Aspisoma fenestrata*, *Amydetes lucernuta*, *Bicellonychia ornaticollis*, *Pyrogaster moestus*, *Photuris* sp$_1$ and *Photuris* sp$_7$.

Figure 3. Some species of fireflies sampled on SA de Paranapiacaba: (a) *Cratomorphus giganteus*; (b) *Cratomorphus besckei*; (c) *Aspisoma lineatum*; (d) *Aspisoma physonotum*; (e) *Aspisoma sp*$_{2}$; (f) *Photinoides jenai*; (g) *Photinus sp*$_{1}$; (h) *Photinus sp*$_{9}$; (i) *Aethra aff. malledicta* or *axilaris*; (j); (k) *Amydetes lucernuta*; (l) *Cladodes flabellicornis*; (m) *Cladodes demoulini*; (n) *Photuris lugubris*; (o) *Photuris sp*$_{7}$; (p) *Pyrogaster moestus*; (q) *Pyrogaster lunifer*; (r) *Pyrogastes sp*$_{3}$ (ref. Diego S. Porto).

Figura 3. Algumas especies de lampirídeos coletadas na SA de Paranapiacaba: (a) *Cratomorphus giganteus*; (b) *Cratomorphus besckei*; (c) *Aspisoma lineatum*; (d) *Aspisoma physonotum*; (e) *Aspisoma sp*$_{2}$; (f) *Photinoides penai*; (g) *Photinus sp*$_{1}$; (h) *Photinus sp*$_{9}$; (i) *Aethra aff. malledicta* ou *axilaris*; (j); (k) *Amydetes lucernuta*; (l) *Cladodes flabellicornis*; (m) *Cladodes demoulini*; (n) *Photuris lugubris*; (o) *Photuris sp*$_{7}$; (p) *Pyrogaster moestus*; (q) *Pyrogaster lunifer*; (r) *Pyrogastes sp*$_{3}$ (ref. Diego S. Porto).

There is a unique species which was collected only in Tapiraí – *Photinus* sp$_{9}$ – which displays a different bioluminescent signal from other *Photinus* species collected in Brazil, being characterized by a bimodal flash with bioluminescence spectrum peaking at 561 nm which is slightly blue-shifted in relation to other species of the genus found in the region (Viviani *et al.* 2010). **Phengodidae**. Only four species of phengodids were found in Paranapiacaba. In Carlos Botelho only the arboreal *Stenophrixotrix* sp$_{1}$ larvae were

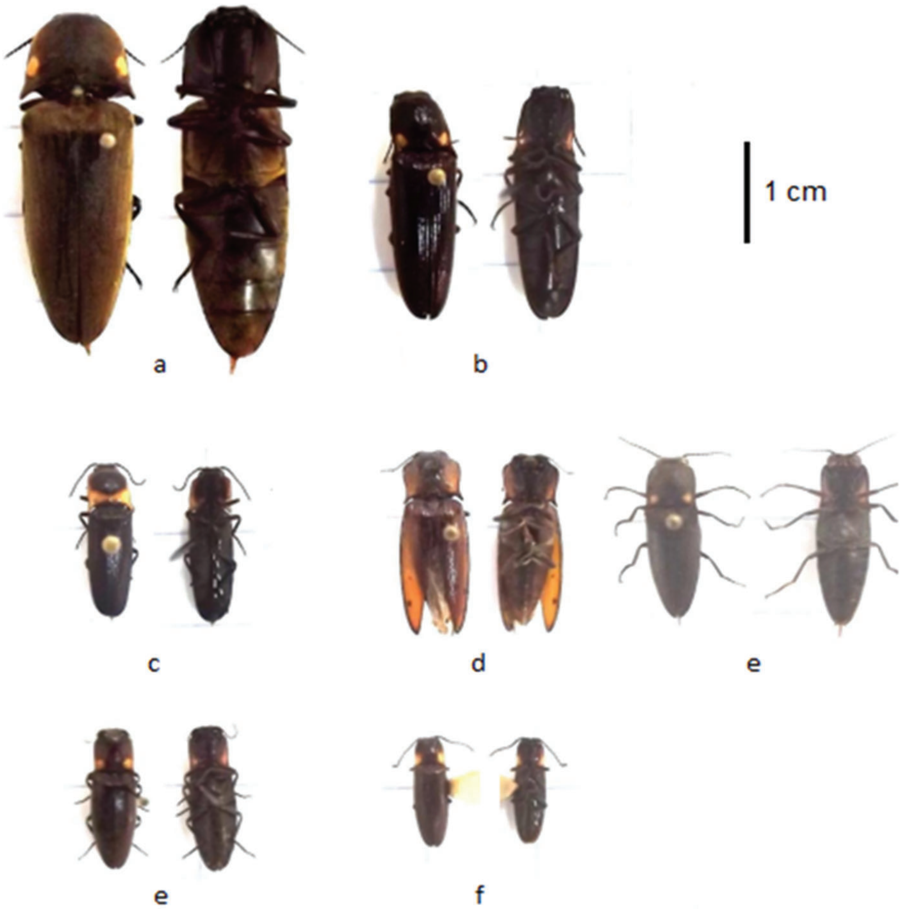

Figure 4. Bioluminescent click-beetles of SA de Paranapiacaba: (a) *Pyrophorus divergens*; (b) *Ptesimopsia luculenta*; (c) *Ptesimopsia cincticollis*; (d) *Pyrearinus candelarius*; (e) *Pyrearinus micatus*, (f) *Pyrearinus brevicollis*; (g) *Hapsodrilus pyrotis*.

Figura 4. Elaterideos bioluminescentes da SA de Paranapiacaba: (a) *Pyrophorus divergens*; (b) *Ptesimopsia luculenta*; (c) *Ptesimopsia cincticollis*; (d) *Pyrearinus candelarius*; (e) *Pyrearinus micatus*, (f) *Pyrearinus brevicollis*; (g) *Hapsodrilus pyrotis*.

found. In Tapiraí *Brasilocerus* sp$_2$ and *Phrixotrix hirtus* were found and in Intervales *Pseudophengodes* sp$_1$. The arboreal *Stenophrixotrix* sp$_1$ was common to all three areas. When compared with Boraceia, the number of species and abundance of phengodids was lower. The following species were found in both places: *Brasilocerus* sp2, *Phrixotrix hirtus* and *Stenophrixotrix*.

Elateridae (Fig. 4). The studied area was especially rich in luminescent click-beetles, with eight species: *Hapsodrilus pyrotis* Germar 1841, *Hypsiophtalmus* sp$_1$, *Ptesimopsia luculenta*, *Pyrearinus brevicollis*, *Pyrearinus candelarius*, *Pyrearinus micatus*, *Pyrearinus* sp., *Pyrophorus divergens*. All these species were found at Intervales.

In Tapiraí, four species of bioluminescent click-beetles were found: *Pyrophorus divergens*, *Hypsiophtalmus* sp$_1$, *Pyrearinus micatus* and *Pyrearinus meatus*: The species *Hapsodrylus pyrotis*, *Ptesimopsia luculenta* and *Pyrearinus candelarius* were not observed in Tapiraí and Carlos Botelho. Comparatively, Boraceia Biological Station showed only three species (*Pyrophorus divergens*, *Pyrearinus micatus* and *Hapsodrilus pyrotis*) and the municipalites of Campinas and Sorocaba four species (*Hapsodrilus ignifer*, *Pyrearinus candelarius, Pyrearinus micatus* and *Pyrophorus divergens*).

Considering that the surveys were conducted in the same morphoclimatic domain and continuous geographic Mountain Tropical Rain Forest, it was surprising that several of these species were not found more widely distributed among these areas. This could be due to two reasons: (1) there is more heterogeneity in the habitats than assumed, and the same kind of specific habitats were not sampled in the three localities, or (2) because the survey was not conducted simultaneously in the three areas. In this case, the seasonality of adults of a given species may vary between areas.

Comparison with other sites of Atlantic forest. When comparing this survey to Biol. St. of Boraceía, which is the second largest remnant of Atlantic Rainforest in São Paulo State, Paranapiacaba remnant showed a slightly smaller biodiversity. The following species were found in common in these two sites: *Aspisoma physonotum* Gorham 1884, *Cratomorphus besckei* Olivier 1895, *Cratomorphus distinctus* Olivier 1895, *Photinus penai* Germar 1824, *Cladodes flabellicornis* Motsch 1853, *Pyrogaster moestus* Germar 1824, *Pyrogaster* sp$_2$, *Photuris lugubris* Gorham 1881, *Photuris* sp$_7$, *Haspodrilus pyrotis* Germar 1841, *Pyrophorus divergens* Eschsholtz 1829 and *Pyrearinus micatus* Costa 1978. Paranapiacaba forests were especially rich in

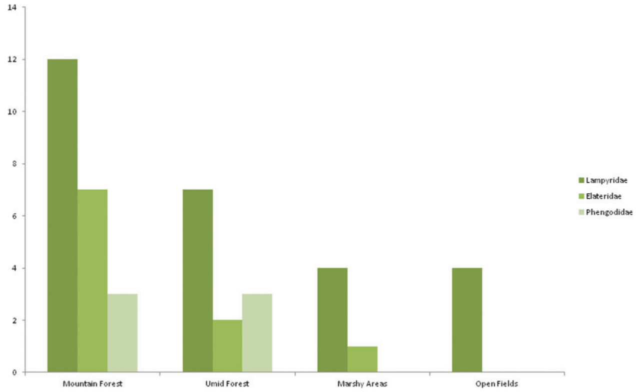

Figure 5. Distribution per habitat of the main families of bioluminescent beetles in Serra da Paranapiacaba.
Figura 5. Distribuição por habitats de familias de besouros bioluminescentes da Serra de Paranapiacaba.

elaterids, whereas Boracéia was richer in fireflies. When compared with the fragmented remnants of the semi-seasonal forests and secondary growths of urbanized areas of Campinas, Sorocaba and Rio Claro municipalities, only the following species were found in common: *Aspisoma lineatum*, *Aspisoma physonotum* Gorham 1884, *Cratomorphus distinctus* Olivier 1895, *Photinus* sp$_1$, *Photinus* sp$_2$, *Amydetes lucernuta*, *Bicellonycha ornaticollis* Blanch, *Pyrogaster moestus* Germar 1824, *Photuris* sp$_7$, *Pyrearinus micatus* Costa 1978 and *Pyrophorus divergens* Eschsholtz 1829. Thus, the species: *Aspisoma fenestrata*, *Ethra aff maledicta or axillaris*, *Bicellonycha* sp$_8$, *Pyrogaster lunifer* Eschsholtz., *Photuris* sp$_1$, *Brasilocerus* sp$_2$, *Hypsiophtalmus* sp$_1$, *Ptesimopsia luculenta*, *Pyrearinus brevicolis* and *Pyrearinus* sp$_1$ were apparently unique to Paranapiacaba forests.

The frequency of species per family in places where they are visibly more abundant is shown on Fig. 5. There is an apparent trend for greater richness for all families in Mountain Forest. More refined analysis with quantification of abundance is however required, to confirm whether the diversity of habitats is significant or not. Marshy areas seem to harbor a lower number of species.

Conclusions

The Serra de Paranapiacaba displays the second largest diversity of luminescent beetles in the Atlantic rain forest morphoclimatic domain of São Paulo state, with 34 species. Some species are common to sampled areas of semi-seasonal forest close to urbanized areas of inner São Paulo state and to the second largest and most preserved area of Biological Station of Boracéia. This area is especially rich in elaterid luminescent beetles, but displays poorer diversity of Phengodidae.

Acknowledgements

We are grateful to Dra. Simone Policena Rosa (MZUSP) for the identification of the specimens to Édipo F. V. da Silva and Pedro R. Busana (UFSCar) for assistance in the field activities and to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Biota Project - FAPESP (Proc. 2011/19427-9) for financial support.

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Received 21/04/2015
Revised 16/10/2015
Accepted 28/10/2015

Biota Neotropica 16(1): e20160101, 2016
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)

editorial

Summary for policymakers of the thematic assessment on pollinators, pollination and food production

Key messages

Values of pollinators and pollination

1. **Animal pollination plays a vital role as a regulating ecosystem service in nature**. Globally, nearly 90 per cent of wild flowering plant species depend, at least in part, on the transfer of pollen by animals. These plants are critical for the continued functioning of ecosystems as they provide food, form habitats, and provide other resources for a wide range of other species.

2. **More than three quarters of the leading types of global food crops rely to some extent on animal pollination for yield and/or quality**. Pollinator-dependent crops contribute to 35 per cent of global crop production volume.

3. **Given that pollinator-dependent crops rely on animal pollination to varying degrees, it is estimated that 5–8 per cent of current global crop production is directly attributed to animal pollination with an annual market value of $235 billion–$577 billion (in 2015, United States dollars[1]) worldwide.**

4. **The importance of animal pollination varies substantially among crops, and therefore among regional crop economies**. Many of the world's most important cash crops benefit from animal pollination in terms of yield and/or quality and are leading export products in developing countries (e.g., coffee and cocoa) and developed countries (e.g., almond), providing employment and income for millions of people.

5. **Pollinator-dependent food products are important contributors to healthy human diets and nutrition**. Pollinator-dependent species encompass many fruit, vegetable, seed, nut and oil crops, which supply major proportions of micronutrients, vitamins, and minerals in the human diet.

6. **The vast majority of pollinator species are wild, including more than 20,000 species of bees, and some species of flies, butterflies, moths, wasps, beetles, thrips, birds and bats and other vertebrates**. A few species of bees are widely managed, including the western honey bee[2]. (*Apis mellifera*), the eastern honey bee (*Apis cerana*), some bumble bees, some stingless bees, and a few solitary bees. Beekeeping provides an important source of income for many rural livelihoods. The western honey bee is the most widespread managed pollinator in the world, and globally there are about 81 million hives producing an estimated 1.6 million tonnes of honey annually.

7. **Both wild and managed pollinators have a globally significant role in crop pollination, although their relative contributions differ according to crop and location**. Crop yield and/or quality depends on both the abundance and diversity of pollinators. A diverse community of pollinators generally provides more effective and stable crop pollination than any single species. Pollinator diversity contributes to crop pollination even when managed species (e.g., honey bees) are present in high abundance. The contribution of wild pollinators to crop production is undervalued.

8. **Pollinators are a source of multiple benefits to people, beyond food provisioning, contributing directly to medicines, biofuels (e.g. canola[3], palm oil), fibres (e.g, cotton, linen) construction materials (timbers), musical instruments, arts and crafts, recreational activities and as sources of inspiration for art, music, literature, religion, traditions, technology and education.** Pollinators serve as important spiritual symbols in many cultures. Sacred passages about bees in all the worlds' major religions highlight their significance to human societies over millennia.

9. **A good quality of life for many people relies on ongoing roles of pollinators in globally significant heritage; as symbols of identity; as aesthetically significant landscapes and animals; in social relations; for education and recreation; and governance interactions**. Pollinators and pollination are critical to the implementation of: the Convention for the Safeguarding of the Intangible Cultural Heritage (UNESCO); the Convention Concerning the Protection of the World Cultural and Natural Heritage (UNESCO); and Globally Important Agricultural Heritage Systems (FAO).

Status and trends in pollinators and pollination

10. **Wild pollinators have declined in occurrence and diversity (and abundance for certain species) at local and regional scales, in North West Europe and North America.** Although a lack of wild pollinator data (species identity, distribution and abundance) for Latin America, Africa, Asia and Oceania preclude any general statement on their regional status, local declines have been recorded. Long-term international or national monitoring of both pollinators and pollination is urgently required to provide information on status and trends for most species and most parts of the world.

11. **The number of managed western honey bee hives has increased globally over the last five decades, even though declines have been recorded in some European countries and North America over the same period.** Seasonal colony loss of western honey bees has in recent years been high at least in some parts of the temperate Northern Hemisphere and in South Africa. Beekeepers can under some conditions, with associated economic costs, make up such losses through splitting of managed colonies.

12. **The International Union for Conservation of Nature (IUCN) Red List assessments indicate that 16.5 per cent of vertebrate pollinators are threatened with global extinction (increasing to 30 per cent for island species).** There are no global Red List assessments specifically for insect pollinators. However, regional and national assessments indicate high levels of threat for some bees and butterflies. In Europe, 9 per cent of bee and butterfly species are threatened and populations are declining

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[1] Value adjusted to 2015 United States dollars taking into account inflation only.

[2] Also called the European honey bee, native to Africa, Europe and Western Asia, but spread around the globe by beekeepers and queen breeders.

[3] Also called oil seed rape.

http://dx.doi.org/10.1590/1676-0611201600010001

for 37 per cent of bees and 31 per cent of butterflies (excluding data deficient species, which includes 57 per cent of bees). Where national Red List assessments are available, they show that often more than 40 per cent of bee species may be threatened.

13. **The volume of production of pollinator-dependent crops has increased by 300 per cent over the last five decades making livelihoods increasingly dependent on the provision of pollination.** However, overall these crops have experienced lower growth and lower stability of yield than pollinator-independent crops. Yield per hectare of pollinator-dependent crops has increased less, and varies more year to year than yield per hectare of pollinator-independent crops. While the drivers of this trend are not clear, studies of several crops at local scales show that production declines when pollinators decline.

Drivers of change, risks and opportunities, and policy and management options

14. **The abundance, diversity and health of pollinators and the provision of pollination are threatened by direct drivers which generate risks to societies and ecosystems.** Threats include land-use change, intensive agricultural management and pesticide use, environmental pollution, invasive alien species, pathogens and climate change. Explicitly linking pollinator declines to individual or combinations of direct drivers is limited by data availability or complexity, yet a wealth of individual case studies worldwide suggests that these direct drivers often affect pollinators negatively.

15. **Strategic responses to the risks and opportunities associated with pollinators and pollination range in ambition and timescale, from immediate, relatively straightforward responses that reduce or avoid risks, to larger scale and longer-term responses that aim to transform agriculture, or society's relationship with nature.** There are seven broad strategies, linked to actions, for responding to risks and opportunities, including a range of solutions that draw on indigenous and local knowledge. These strategies can be adopted in parallel, and would be expected to reduce risks associated with pollinator decline in any region of the world, regardless of the extent of available knowledge about the status of pollinators or the effectiveness of interventions.

16. **A number of features of current intensive agricultural practices threaten pollinators and pollination**. Moving towards more sustainable agriculture and reversing the simplification of agricultural landscapes offer key strategic responses to risks associated with pollinator decline. Three complementary approaches to maintaining healthy pollinator communities and productive agriculture are: (a) ecological intensification (i.e., managing nature's ecological functions to improve agricultural production and livelihoods while minimizing environmental damage); (b) strengthening existing diversified farming systems (including forest gardens, home gardens, agroforestry and mixed cropping and livestock systems) to foster pollinators and pollination through practices validated by science or indigenous and local knowledge (e.g., crop rotation); and (c) investing in ecological infrastructure by protecting, restoring and connecting patches of natural and semi-natural habitats throughout productive agricultural landscapes. These strategies can concurrently mitigate the impacts of land-use change, land management intensity, pesticide use and climate change on pollinators.

17. **Practices based on indigenous and local knowledge, in supporting an abundance and diversity of pollinators can, in co-production with science, be a source of solutions to current challenges**. Practices include diverse farming systems; favouring heterogeneity in landscapes and gardens; kinship relationships that protect many specific pollinators; using seasonal indicators (e.g., flowering) to trigger actions (e.g., planting); distinguishing a wide range of pollinators; and tending to nest trees, and floral and other pollinator resources. Knowledge co-production has led to improvements in hive design; new understanding of parasite impacts; and the identification of stingless bees new to science.

18. **The risk to pollinators from pesticides is through a combination of the toxicity and the level of exposure, which varies geographically with compounds used, and the scale of land management and habitat in the landscape.** Pesticides, particularly insecticides, have been demonstrated to have a broad range of lethal and sublethal effects on pollinators in controlled experimental conditions. The few available field studies assessing effects of field-realistic exposure provide conflicting evidence of effects based on species studied and pesticide usage. It is currently unresolved how sublethal effects of pesticide exposure recorded for individual insects affect colonies and populations of managed bees and wild pollinators, especially over the longer-term. Recent research focusing on neonicotinoid insecticides shows evidence of lethal and sublethal effects on bees and some evidence of impacts on the pollination they provide. There is evidence from a recent study which shows impacts of neonicotinoids on wild pollinator survival and reproduction at actual field exposure.[4] Evidence, from this and other studies, for effects on managed honey bee colonies is conflicting

19. **Exposure of pollinators to pesticides can be decreased by reducing the use of pesticides seeking alternative forms of pest control, and adopting a range of specific application practices, including technologies to reduce pesticide drift.** Actions to reduce pesticide use include promoting Integrated Pest Management supported by educating farmers, organic farming and policies to reduce overall use. Risk assessment can be an effective tool to define pollinator-safe uses of pesticides, which should consider different levels of risk among wild and managed pollinator species according to their biology. Subsequent use regulations (including labelling) are important steps towards avoiding the misuse of specific pesticides. The International Code of Conduct on the Distribution and Use of Pesticides of the Food and Agriculture Organization of the United Nations (FAO) provides a set of voluntary actions for Government and industry to reduce risks for human health and environment, although only 15 per cent of countries are using this.[5]

20. **Most agricultural genetically modified organisms (GMOs) carry traits for herbicide tolerance (HT) or insect resistance (IR). Reduced weed populations are likely to accompany most HT crops, diminishing food resources for pollinators.** The actual consequences for the abundance and diversity of pollinators foraging in HT-crop fields is unknown. IR crops can result in the reduction of insecticide use which varies regionally according

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[4] Rundlof et al., 2015. Seed coating with a neonicotinoid insecticide negatively affects wild bees. Nature 521: 77-80 doi: 10.1038/nature14420.

[5] Based on a survey from 2004–2005; Ekström, G., and Ekbom, B. 2010. Can the IOMC Revive the 'FAO Code' and take stakeholder initiatives to the developing world? Outlooks on Pest Management 21:125-131.

to the prevalence of pests, the emergence of secondary outbreaks of non-target pests or primary pest resistance. If sustained, this reduction in insecticide use could reduce this pressure on non-target insects. How IR-crop use and reduced pesticide use affect pollinator abundance and diversity is unknown. Risk assessment required for the approval of GMO crops in most countries does not adequately address the direct sublethal effects of IR crops or the indirect effects of HT and IR crops, partly because of the lack of data.

21. **Bees suffer from a broad range of parasites, including Varroa mites in western and eastern honey bees.** Emerging and re-emerging diseases are a significant threat to the health of honey bees, bumble bees and solitary bees especially when managed commercially. Greater emphasis on hygiene and the control of pathogens would help reduce the spread of disease across the entire community of pollinators, managed and wild. Mass breeding and large-scale transport of managed pollinators can pose risks for the transmission of pathogens and parasites, and increase the likelihood of selection for more virulent pathogens, alien species invasions, and regional extinctions of native pollinator species. The risk of unintended harm to wild and managed pollinators could be decreased by better regulation of their trade and use.

22. **The ranges, abundances, and seasonal activities of some wild pollinator species (e.g., bumble bees and butterflies) have changed in response to observed climate change over recent decades**. Generally, the impacts of ongoing climate change on pollinators and pollination services to agriculture may not be fully apparent for several decades, owing to a delayed response in ecological systems. Adaptive responses to climate change include increasing crop diversity and regional farm diversity, and targeted habitat conservation, management or restoration. The effectiveness of adaptation efforts at securing pollination under climate change is untested. Many actions to support wild and managed pollinators and pollination could be implemented more effectively with improved governance. For example, broad-scale government policy may be too homogenous and not allow for local variation in practices; administration can be fragmented into different levels; and goals can be contradictory between sectors. Coordinated, collaborative action and knowledge-sharing that builds links across sectors (e.g., agriculture and nature conservation), across jurisdictions (e.g., private, government, not-for-profit), and among levels (e.g., local, national, global) can overcome these challenges and lead to long-term changes that benefit pollinators. Establishing effective governance requires habits, motivations and social norms to change over the long term. However, the possibility that contradictions between policy sectors remain even after coordination efforts should be acknowledged and be a point of attention in future studies.

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Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services - IPBES

Biota Neotropica 16(1): e0026, 2016
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
article

Long-distance movement by a great fruit-eating bat, *Artibeus lituratus* (Olfers, 1818), in southeastern Brazil (Chiroptera, Phyllostomidae): evidence for migration in Neotropical bats?

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ARNONE, I.S., TRAJANO, E., PULCHÉRIO-LEITE, A., PASSOS, F.C. **Long-distance movement by a great fruit-eating bat, *Artibeus lituratus* (Olfers, 1818), in southeastern Brazil (Chiroptera, Phyllostomidae): evidence for migration in Neotropical bats?** Biota Neotropica. 16(1): e0026. http://dx.doi.org/10.1590/1676-0611-BN-2015-0026

Abstract: In Brazil, bat migrations have been inferred based on seasonal variations in bat abundances observed for several species, probably as a result of variations in temperature and food availability. However, direct evidence of individual medium to long distance (> 10 km) movements, based on marked specimens, is restricted to large frugivorous bats, genus *Artibeus* (Phyllostomidae). We report the longest bat movement recorded in Brazil, along 113 km in a straight line, difference in altitude of 738 m, from a mixed *Araucaria* forest in Curitiba, PR, to the Atlantic Forest, Alto Ribeira, SP, by a female *Artibeus lituratus* (Olfers, 1818), over a period of 14 months. This data is consistent with the occurrence of migratory movements in Neotropical bats, such as the ecologically flexible *Artibeus* spp., over relatively large areas, probably with short stopover foraging intervals. Implications for the conservation of these bats are clear, as their home ranges may be much larger than their foraging areas, encompassing more than one biome and overcoming political borders.
Keywords: *mark-recapture, use of space, Atlantic forest.*

ARNONE, I.S., TRAJANO, E., PULCHÉRIO-LEITE, A., PASSOS, F.C. **Deslocamento de longa distância por um grande morcego frugívoro, Artibeus lituratus (Olfers, 1818), no sudeste do Brasil (Chiroptera, Phyllostomidae): evidência de migração de morcegos Neotropicais?** Biota Neotropica. 16(1): e0026. http://dx.doi.org/10.1590/1676-0611-BN-2015-0026

Resumo: Migrações em morcegos brasileiros têm sido inferidas a partir de variações sazonais nas abundâncias regionais das populações, provavelmente condicionadas por flutuações na temperatura e na disponibilidade de alimento. No entanto, registros de deslocamentos individuais de média a longa distância, ultrapassando suas áreas domiciliares (> 10 km), comprovados através de marcação e recaptura, são restritos aos grandes morcegos frugívoros do gênero *Artibeus* (Phyllostomidae). Registramos, aqui, o maior deslocamento já publicado, de ca. 113 km em linha reta, entre localidades com diferença de altitude de 738 m, respectivamente em floresta mista de araucárias, região de Curitiba, PR, e em Mata Atlântica, Alto Ribeira, SP, realizado por uma fêmea de *Artibeus lituratus* (Olfers, 1818), em um intervalo máximo de 14 meses. Este dado é consistente com a ocorrência de movimentos migratórios em *Artibeus* spp. ao longo de áreas bastante extensas, provavelmente através de várias etapas de forrageio. As implicações para a conservação desses quirópteros são claras, uma vez que os animais desta espécie podem ter áreas de vida bem maiores que suas áreas domiciliares (de forrageio), abrangendo mais de um bioma e ultrapassando limites geopolíticos.
Palavras-chave: *Marcação-recaptura, uso do espaço, Mata Atlântica.*

Introduction

The key role of bats in tropical ecosystems is widely recognized (Kalko 1998, Muscarella & Fleming 2007), and several studies on the ecology of Neotropical bats, including patterns of space and habitat use, have been published in the last two decades (*e.g.*, Charles-Dominique 1991, Fenton et al. 1992, Gannon & Willig 1997, Kalko et al. 1996, Avila-Cabadilla et al. 2009, Trevelin et al. 2013). Yet little is known about far range dispersal and migrations of these species.

Migration is the movement of animals that follow seasonal availability of resources, whose strategies involve a great variety of schemes; this differs from dispersal, which is generally unidirectional (Krauel & McCracken 2013). It is defined as a seasonal and cyclic population movement, but may not occur in all populations of a species (Alerstam & Hedenström 1998, McCracken et al. 1994).

For Dingle (1996), migrating animals have several characteristics, such as: travelling in a relatively straight line during foraging, displaying special pre-departure or post-arrival behaviors, and storing energy for use during or after the journey. Some authors do not consider shorter spatial movements in bats as migration because they do not require physiological adaptations (Fleming & Eby 2003, McCracken et al. 1994).

In tropical and subtropical areas, long-distance migrants follow transient fruit or nectar resources (Fleming & Eby 2003). Insect-eating bats can migrate in response to seasonally available prey, but these patterns are obscured by the lack of information on seasonal insect availability beyond agricultural pests (Krauel & McCracken 2013). Although regional migrants are assumed to move in search of roost sites (Griffin 1945, 1970, Tuttle 1976), many latitudinal migrants are assumed to be in the pursuit of food, with roosts being a secondary factor (Krauel & McCracken 2013).

In a recent review, Krauel & McCracken (2013) list 88 species (10 families) that are known to migrate or are suspected of being migrants. The great majority are small and medium-sized North American and European vespertilionids, followed by molossids (weight range 10-30 g, forearm range 40–57 mm), characterized by narrow wings with high aspect ratio (Norberg & Rayner 1987) along maximum one-way recorded distances of 140 to 1,905 km. Records of distances travelled by phyllostomids are far less common in the literature; e.g., over 1,000 km for the highly specialized glossophagine *Leptonycteris curasoae* Miller 1900 and *L. nivalis* (Saussure 1860), and a reference to movements less than 200 km long for *Carollia perspicillata* (Krauel & McCracken op. cit.).

In Brazil, indirect evidence of bat migrations has been gathered by authors working on bat communities who consistently observe seasonal variations in the abundance of several species (Trajano 1996, 2003). Seasonal differences in bat abundance have also been found in other Neotropical countries, such as Costa Rica, Nicaragua and Ecuador, as analyzed by McGuire & Boyle (2013) in the context of evidence for altitudinal migrations.

However, data on bat movements based on individual monitoring are sparse, restricted to few species and relatively short distances, on a scale of 10^2 km (e.g., Trajano 1996, Esbérard 2003, Bianconi et al. 2006, Costa et al. 2006, Menezes-Jr. et al. 2008, Mendes et al. 2009, using mark-recapture; Bernard & Fenton, 2003, Mello et al. 2008, Trevelin et al. 2013, using radiotelemetry). This does not allow for the detection of patterns. Moreover, in spite of a growing interest on this subject, the lack of a common database hampers the development of integrated mark-recapture programs that would involve several research teams in different regions of Brazil (Trajano 2003).

In this paper, we report long distance movement of a large *Artibeus lituratus*, as evidence of far range migration or dispersion in these Neotropical frugivorous bats. This was the result of inter-team cooperation, made possible due to personal contacts.

Methods

1. Study sites

The bat was first captured in 2005 during a field study on urban bats at Schaffer Campus (Leite 2008), Universidade Tuiuti do Paraná, in a neighborhood known as Pilarzinho (25°24'2"S 49°17'27"W, 934 m a.s.l.), north-central Curitiba, state of Paraná. The locality is a 2-hectare fragment with heavily disturbed mixed rainforest surrounded by neighborhoods composed of buildings, paved paths and a man-made lake. In the region, there are several other forest remnants; such as Bosque do Alemão (4 hectares), Bosque Zaninelle (3.7 hectares), Bosque da Vista Alegre (5.5 ha) and Parque Tingui (38 ha). According to the classification by Köppen, the climate is Cfb, i.e., mesothermal humid, without a dry season, mild summers, and average air temperature in the warmest month below 22 °C.

This individual was recaptured at the entrance of Alambari de Baixo cave (24°33'24"S 48°39'52"W, 196 m a.s.l.) in 2006, during a study on bat communities from caves and surface habitats in the Alto Ribeira karst area, southeast of São Paulo state (Arnone 2008). The cave is located at Bairro da Serra, a rural district of Iporanga Co. Most of the region rests within a conservation unit — the Parque Estadual Turístico do Alto Ribeira (PETAR) — situated between the towns of Apiaí and Iporanga, with 33,000 hectares mostly covered by dense rainforest. More than 400 caves are known in the area. The region is inserted in the largest continuum of Brazilian Atlantic rainforest, encompassing other state conservation units that total approximately 275,000 hectares: Mosaico de Unidades de Conservação do Jacupiranga, Parque Estadual Carlos Botelho, Parque Estadual de Intervales, and Reserva Ecológica do Xitué. The climate of the region is classified as Cfa, i.e., humid mesothermal, without a defined dry season and having warm summers, the average air temperature in the warmest month being above 22 °C.

2. Capture and marking

In both studies, bats were captured in mist-nets, and those that were not euthanized for identification were marked for individual recognition with metal bands on the forearm. These bands were attached to the forearm using long-nosed pliers. The bands used in both studies had individual codes with identifications engraved in the metal, consisting of the last name of the bat researcher plus a number. In Curitiba, bats were marked using bands signed PULCH LEITE plus a number, and in PETAR with bands signed ARNONE plus a number. Sex and reproductive condition was noted and the bats were then released at the same place of capture.

Results

On March 26, 2006, Arnone (2008) captured a marked *A. lituratus* female at Alambari de Baixo cave wearing a band used in a study other than his own. Two species of large *Artibeus* were previously recorded in the Alto Ribeira karst area (Trajano 1996), which are difficult to distinguish in the field. Moreover, the band was partially damaged, hampering a conclusive identification of its provenance. Therefore, the specimen was kept in order to confirm the species identification and to trace the origin of the band code. Afterwards, the code of the bat band was identified as PULCH LEITE 212, the last name of a bat researcher who was conducting a study in Curitiba. This individual was marked 14 months earlier on January 9, 2005. At first capture, the female was lactating; during recapture there was no sign of reproductive activity.

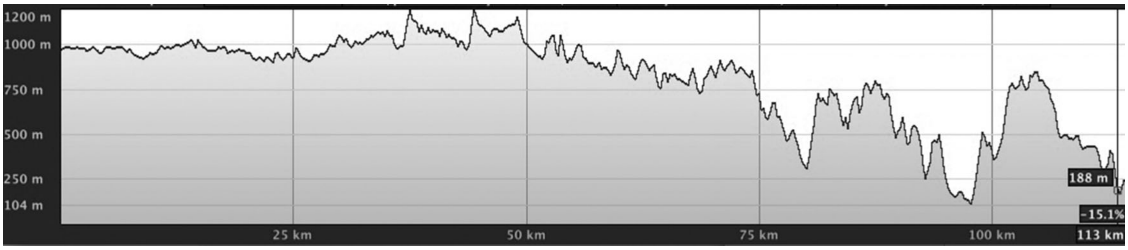

Figure 1. Elevation profile from point of capture to point of recapture of the female *Artibeus lituratus*.

The specimen was then euthanized and deposited as a voucher specimen in the collection of the Museu de Zoologia, Universidade de São Paulo (MZ33972).

The distance in straight line between the two localities, obtained with a line drawn by the ruler tool in the program Google Earth from point of capture to point of recapture, is ca. 113 km, with a difference in altitude of 738 m (Figure 1).

Discussion

The longest bat movement previously recorded in Brazil was also of a female *A. lituratus*, which was first captured in a locality in the state of Pará (northern Brazil) and then recaptured 210 days later, 60 km away (Bernard & Saldanha 2004). Movements covering dozens of kilometers between forest remnants, parks and urban areas, all of large *Artibeus* spp., have been reported in eastern Brazil. Esbérard (2003) recorded a movement of 21 km for a specimen of *A. lituratus*, and 25 km for a specimen of *A. fimbriatus* Gray, 1838 (author does not inform the sexes), both in Rio de Janeiro. In the same state, Costa et al. (2006) recorded a movement of 21.7 km after 20 days of a male *A. fimbriatus* between Ilha Grande, an island, and Mangaratiba, the mainland, with a minimum distance of 5 km over sea. Menezes-Jr et al. (2008) recorded a 34.8 km long movement for an *A. lituratus* female, with 97 days between captures between Parque Natural Municipal Serra da Medanha and Itacuruçá Island, implying flight with a minimum distance of 500 m over sea. In Espírito Santo state, Mendes et al. (2009) recorded a movement of 35.9 km for a male of *A. lituratus.*

Morrison (1979), using radiotelemetry, described that individuals of *Artibeus jamaicensis* Leach 1821 usually forage within a radius of 10 to 15 km away from their day roost. The distance between feeding roosts and fruiting trees utilized by radio-tagged *A. jamaicensis* ranged from 25 to 400 m, and the number of feeding sites visited was influenced by moon phase; day roosts tended to be further away and might have been frequently changed, possibly in order to decrease the risks of predation (Morrison 1980). In a more recent study, Albrecht et al. (2007) showed that the home range size for *Artibeus watsonii* Thomas 1901 was highly variable among the five animals tracked, ranging from 1.8 to 17.9 ha with a mean of about 9 ha.

Larger mammals establish extensive home ranges (MacNab 1963, Lindstedt et al. 1986, Swihart et al. 1988). The same would be expected for large bat species. According to Fleming (1982), because large bats are able to fly faster, their foraging areas should be more extensive than those of small bats. However, the broad wings with low aspect ratio of Stenodermatinae bats are not well-suited for long-distance migrations (Noberg and Rayner 1987). Hence, the movement presently recorded of 100 km by a female of *A. lituratus* may be considered as long-distance movement, and is therefore biologically significant data for stenodermatins.

As aforementioned, several authors raised the hypothesis of inter-regional migrations among Neotropical bats based on seasonal variation in the abundance of different species. Trajano (1985, 1996) observed a decline in the total abundance of cave bats in the Alto Ribeira karst area during the cooler, less rainy months (May to September). This was more evident for some common species, such as the frugivorous *Carollia perspicillata* (Linnaeus, 1758) and *Artibeus fimbriatus* Gray, 1838, and the nectarivorous/polinivorous *Anoura caudifer* (E. Geoffroy, 1818). The author suggests that during winter when nighttime temperature outside of caves may drop considerably (to a few degrees above 0°C in June to August), many bats would migrate to lower, warmer regions, possibly near the coast. This is consistent with data by Passos et al. (2003) for Parque Estadual Intervales (PEI), contiguous to PETAR, but occurring in higher altitudes (860 m a.s.l.) in which no *Artibeus* spp. was captured in the cooler months. During this time, fruits eaten by those bats (Cecropiacea) would be scarce. The same tendency of accentuated population decrease during the winter in PEI was observed by Mello et al. (2009) for *S. lilium*, also fruit-eating bats that are usually abundant throughout the year in lowlands (Giannini 1999, Aguiar and Marinho-Filho 2004).

Furthermore, Fazzolari-Corrêa (1995), studying the bat community in Parque Estadual da Ilha do Cardoso (PEIC), an estuary island situated on the coast of southern São Paulo state (minimum distance to the continent in a straight line being ca. 200 m), observed that the three *Artibeus* spp., the large *A. fimbriatus* and *A. lituratus*, and the medium-sized *A. obscurus* (Schinz, 1821), among others, were captured more frequently during the warmer rainy season (November to April); whereas some other fruit-eating bats, such as *C. perspicillata* and *Platyrrhinus lineatus* (E. Geoffroy, 1810), were more abundant in cooler months. In a continental area near the Cardoso region, Geraldes (1999) obtained similar results for the three *Artibeus* spp., whereas *Anoura geoffroyi* Gray, 1838 bats were more frequently captured in the cooler months. On the other hand, Rosa (2004) found an increase in the capture frequency of *A. lituratus* bats at the beginning of the cooler season (April and May 2003) in Parque Estadual Rio da Onça, Matinhos, on the coast of Paraná at 3 m a.s.l. In the coolest season (June, July and August), average temperature was around 16-17 °C. This author suggested that the increase was caused by migration of some individuals to the region, because in this season temperature was warmer in lower altitudes and more food would be available when compared to highlands.

Some years ago, Esberard et al. (2011) gathered data on extensive year-round sampling at multiple elevations to test for evidence of altitudinal migration in Ipanema broad-nosed bats, *Pygoderma bilabiatum* (Wagner, 1843). *P. bilabiatum* was absent in regions where the temperature varied seasonally, and less common during cooler seasons at higher elevations. The authors concluded that these bats migrate altitudinally in response to seasonal variations, a conclusion supported by the constant abundance in regions where climate did not vary substantially.

In Costa Rica, long-term capture records at a montane site generated by Timm & Laval (2000), revealed that several species were either completely absent during part of the year or showed substantial seasonal changes in abundance: *A. lituratus*, *Artibeus toltecus* (Saussure, 1860), *Carollia brevicauda* (Schinz, 1821), *S. lilium* and *Hylonycteris underwoodi* Thomas, 1903. These authors suggested that seasonal changes in abundance might represent altitudinal migration. Similarly, altitudinal migrations have been proposed to explain variations in seasonal abundances of *S. lilium* and *Sturnira erythromos* (Tschudi, 1844) in the Argentinian Andes (Giannini 1999).

Not unexpectedly, migratory movements were suggested for the free-tailed bat *Tadarida brasiliensis* (I.Geoffroy Saint-Hilaire 1824) in the city of Porto Alegre, southern Brazil, based on the decrease in number of individuals found in the colonies during winter (Marques 2003). North American populations of this nominal species are known to migrate seasonally between the USA and Mexico (Marques op. cit.), and similar ecological patterns are expected in South American areas with subtropical to temperate climate.

Direct and indirect evidence of bat migrations are also available for fully tropical regions of Brazil. For instance, in Reserva do Panga, Uberlândia area, Minas Gerais state, eastern Brazil, bats of most species were more frequently captured during the rainy season, including the fruit-eating *P. lineatus*, the nectarivorous *Glossophaga soricina* (Pallas, 1766), and *Anoura caudifer* (Pedro & Taddei 2002). According to these authors, migrations of at least part of the *P. lineatus* population in the area would be associated with seasonal variations in fruit availability, as is the case of *Cecropia* sp. Long-distance bat movements in Amazonia, as recorded by Bernard & Saldanha (2004) (discussed above), are probably also related to seasonal and/or inter-annual fluctuations in food resources.

It is noteworthy that, although able to sustain flight over distances of at least 5 km, on the scale of their daily activities large *Artibeus* spp. are not particularly mobile, especially when compared to other plant-eating bats. Based on recapture rates and stability of colonies inside caves, Trajano (1996) concluded that in the Alto Ribeira karst area, *A. fimbriatus* bats are more sedentary than the smaller *C. perspicilllata* and *A. caudifer* bats. Likewise, in Pará state, Amazonia, the percentage of recaptures and mean distance between recaptures recorded by Bernard & Fenton (2003) were similar for *C. perspicillata* and the large *A. jamaicensis* bats. Therefore, long distance movements by large *Artibeus* spp., just as those presently recorded, would be carried out in several steps, along some still unknown route(s). In fact, in all reported cases the time interval between recaptures was quite long, lasting several weeks.

We did not demonstrate cyclical two-way migratory movement *sensu* Krauel & McCracken (2013) because the marked individual was collected as a voucher. However, the fact that it was a fully grown, reproductively active female (dispersal is more common among young individuals), associated with strong evidence of seasonal, thus migratory, movements in *Artibeus* spp., makes it reasonable to hypothesize that the 113 km-long movement hereby recorded is part of an altitudinal migratory movement. Altitudinal migrations to lower areas would be the best solution to the problem of fruit shortage considering the following: 1) the significant altitudinal gradients over relatively short distances in Serra do Mar; 2) the high energetic demands throughout the year of non-hibernating bats; and 3) the generally positive correlation between temperature and fruit availability (as observed in the study areas), at least in the south-southeastern Brazilian countryside where winter may be very cold. The alternative, predominantly latitudinal migration, implies flying much longer distances, thus expending more energy.

Frugivorous bats, such as *C. perspicillata* and large and small-sized *Artibeus* species, may cross matrix areas in fragmented landscapes, flying over relatively long distances (up to 13 km – Bianconi 2009), connecting these elements and promoting forest regeneration by seed dispersion. However, these bats seem to be dependent on forest-structured areas (natural or restored) for day roosting (Trevelin et al. 2013, Ripperger et al. 2015). Riparian forests may be important routes for crossing degraded areas (Medina et al. 2007).

Implications for conservation are clear. The home range of these species, i.e., area required by individuals to complete their life cycle, must include forest-structured habitats and may be quite large, trespassing political borders and encompassing more than one biome. Investigating regional, latitudinal and altitudinal movements is necessary in order to understand temporal variations in the abundance of populations. Bat home ranges may be much larger than study areas viable for academic work, especially in the present academic climate ruled by the "publish or perish" philosophy, which imposes urgency, superficiality and fragmented science. In such a scenario, inter-team cooperation allowing data integration is of paramount importance for conservation, adding relevance to initiatives such as the one suggested by Trajano (2003), of a national program in Brazil using standardized permanent marks identifying the institution and/or researcher, with a centralized reference data system.

Acknowledgements

The authors are grateful to the administration of the Parque Estadual Turístico do Alto Ribeira (PETAR) for authorizing the collection of bats and use of the Park facilities. Park employees Sebastião Lopes, Cláudio Gomes and Gilberto Dalla Libera, helped us during fieldwork. Mary Andriani, native speaker, revised the English of the manuscript. This study was supported by the Conselho Nacional de Pesquisas - CNPq (IA M. Sc. scholarship n. 134385/2005-5; ET fellowship n. 302956/2010-7, FCP fellowship n. 303757/2012-4). NOG IDEA-WILD supplied equipment, such as mist nets, headlamps, calipers and dynamometers, which were used during the study.

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Received 12/03/2015
Revised 4/11/2015
Accepted 18/11/2015

Biota Neotropica 16(1): e20150062, 2016
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)

short communication

Dangerous neighborhood: saurophagy between syntopic *Tropidurus* lizards

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PASSOS, D.C., MONTEIRO, F.A.C., NOGUEIRA, C.H.O. **Dangerous neighborhood: saurophagy between syntopic *Tropidurus* lizards.** Biota Neotropica. 16(1): e20150062. http://dx.doi.org/10.1590/1676-0611-BN-2015-0062

Abstract: Saurophagy constitutes an important source of mortality among lizards and has been reported for the genus *Tropidurus*. However, the extension of this behavior remains unknown. Herein, we record the predation of *T. jaguaribanus* by its congener *T. hispidus*. This is the first report of saurophagy among different species of syntopic *Tropidurus*. Furthermore, whereas published records of saurophagy tend to be directed against juveniles, this case involved two adult individuals.

Keywords: *Predation, mortality, agonistic interactions, Tropiduridae, Caatinga.*

PASSOS, D.C., MONTEIRO, F.A.C., NOGUEIRA, C.H.O. **Vizinhança perigosa: saurofagia entre lagartos *Tropidurus* sintópicos.** Biota Neotropica. 16(1): e20150062. http://dx.doi.org/10.1590/1676-0611-BN-2015-0062

Resumo: A saurofagia constitui uma importante fonte de mortalidade entre lagartos e tem sido reportada para o gênero *Tropidurus*. Contudo, a extensão deste comportamento permanece desconhecida. Neste estudo registramos a predação de *T. jaguaribanus* por seu congênere *T. hispidus*. Este é o primeiro caso de saurofagia entre diferentes espécies de *Tropidurus* sintópicos. Além disso, embora a saurofagia tenda a ser direcionada contra jovens, este caso envolveu dois indivíduos adultos.

Palavras-chave: *Predação, mortalidade, interações agonísticas, Tropiduridae, Caatinga.*

Introduction

Predation constitutes one of the major pressures negatively affecting natural populations. In context of lizards, the predation by a sympatric lizard and even by the same species represent two important sources of mortality (Vitt 2000, Siqueira & Rocha 2008). At first glance, the incidence of these kind of predatory events appeared to be infrequent, but cases of saurophagy and cannibalism among lizards are increasingly documented (Pincheira-Donoso 2012, Robbins et al. 2013).

Lizards of the genus *Tropidurus* are known to be ambush foragers with opportunistic feeding habits. Although their diet is primarily composed of arthropods, several species also feed on plant itens as well small vertebrates (Faria & Araújo 2004, Van Sluys et al. 2004, Kolodiuk et al. 2010). Among the vertebrate preys of *Tropidurus*, there are consumption records of mammals (Gasparini & Peloso 2007), frogs (Vitt et al. 1996, Kiefer et al. 2006, Ribeiro & Freire 2009, Costa et al., 2010), but mainly of lizards. For instance, saurophagy was reported for *T. hispidus* (Spix, 1825) (Rojas-Runjaic et al. 2006, Costa et al. 2010, Zanchi et al. 2012), *T. itambere* Rodrigues, 1987 (Faria & Araújo 2004), *T. montanus* Rodrigues, 1987 (Kiefer 1998), and *T. torquatus* (Wied, 1820) (Teixeira & Giovanelli 1999, Galdino & Van Sluys 2004, Kokubum & Lemos 2004, Kiefer et al. 2006, Peloso & Pavan 2007). Moreover, cannibalism was recorded in *T. hispidus* (Sales et al. 2011), *T. hygomi* Reinhardt & Lütken, 1861 (Dias & Rocha 2004, Kohlsdorf et al. 2004), *T. montanus* (Kiefer & Sazima 2002), *T. oreadicus* Rodrigues, 1987 (Araujo 1987), and *T. torquatus* (Kiefer et al. 2006).

Despite saurophagic and cannibalistic behaviors had been relatively well documented for *Tropidurus* lizards, the extent of these events remains misunderstood. Furthermore, of all saurophagic records involving *Tropidurus* lizards as predators, none included syntopic congeners as prey. Herein, we expand the knowledge on saurophagy by providing the first record of predation of *T. jaguaribanus* Passos, Lima & Borges-Nojosa, 2011 by *T. hispidus*.

Material and Methods

The observations were made during a field study on the geographical distribution of the species of the *Tropidurus semitaeniatus* group, at the vicinity of the Instituto Federal de Ciência, Educação e Tecnologia do Estado do Ceará – IFCE (5°52'59" S, 38°36'13" W, 137 m a.s.l., Datum: WGS 1984), Jaguaribe municipality, Ceará state, northeastern Brazil. The study area is located in a depression region between residual massifs along the middle course of the Jaguaribe River, where there are many rocky outcrops. This location is covered by secondary vegetation composed mainly of xerophytic shrubs and an ephemeral herbaceous stratum during the rainy season. The climate is semiarid and the environment is highly susceptible to desertification (Guerra et al. 2010).

Predatory event was video and photographically recorded in detail by two of us (DCP and FACM) about 5 meters from the lizards. After the end of the observations, both prey and predator were collected, fixed in 10% formalin, preserved in 70% ethanol, and deposited in the Coleção Herpetológica da Universidade Federal do Ceará (CHUFC L 5996 - *T. jaguaribanus* and

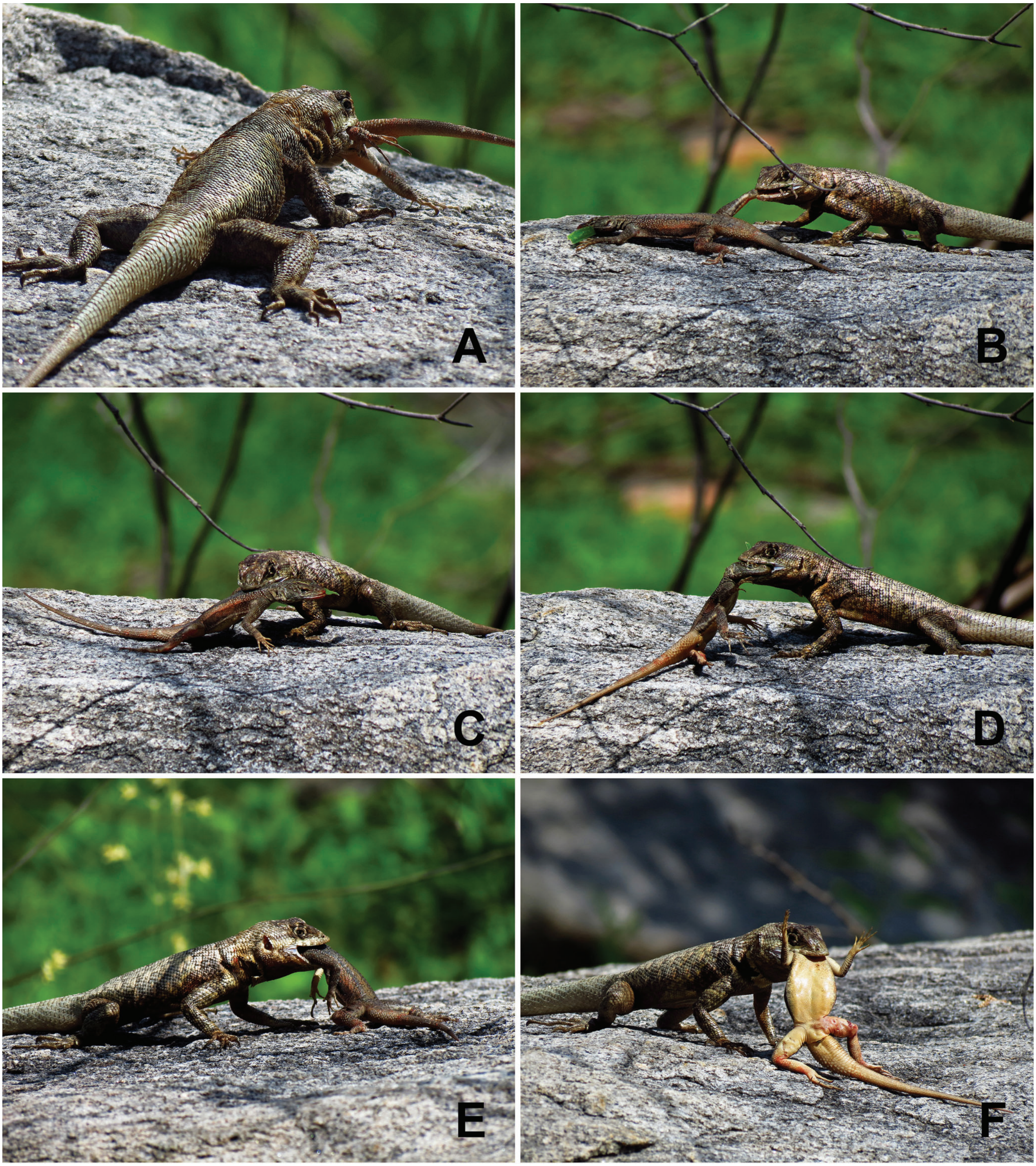

Figure 1. Saurophagic behavior of *Tropidurus hispidus* on *Tropidurus jaguaribanus*. (A) prey capture by the left hindlimb; (B) prey recapture by the right hind limb; (C) prey recapture by the thorax; (D) prey recapture by the head; (E) dorsal attempt to swallow the prey; (F) ventral attempt to swallow the prey.

CHUFC L 5997 - *T. hispidus*) . In the lab, the snout–vent length (SVL) of lizards was measured with calipers (to nearest 0.01 mm). An X-ray was made of the *T. jaguaribanus* specimen (VMI-Philips Compacto Plus 500 – 32 kV / 0.03 mAs / mA 100) to evaluate its bone injuries. It was then dissected to diagnose its cause of death by one of us (CHON), at the radiology sector at the Veterinary Hospital of the Universidade Estadual do Norte Fluminense Darcy Ribeiro.

Results

On the morning of 23 April 2015 at 09:14 a.m. an adult male *Tropidurus hispidus* (112.5 mm SVL) chased and caught an adult female of *T. jaguaribanus* (76.4 mm SVL) by its left hind limb (Figure 1A). After a few seconds, the predator vigorously shook the prey still firmly held between its jaws, while the prey writhed and bit its head in unsuccessful attempts to escape. Thereafter, the predator briefly released the prey triggering its escape, but soon pursued and recaptured it again. This process involving release, pursuit and recapture happened several times, differing only in the part of the prey's body (e.g., right hindlimb, thorax, and head, respectively) bitten by the predator (Figure 1B-D). Only 26 minutes after the beginning of the observations we assumed the death of the prey, due to the absence of any reaction to the last release event. On that occasion, the predator kept right off and gently touched the prey. Prey manipulation and observation lasted some minutes, afterwards the predator began to swallow it. There were two attemps to swallow the prey, both head-first. Initially, the predator tried to swallow the prey dorsally (Figure 1E), but failed. Then, it turned the prey with belly up and tried to swallow it again (Figure 1F). However, the predator was not able to swallow entirely the prey. At 10:16 a.m., after almost an hour, the predator started to lose interest for the prey, and we shot it down with an airgun. Then, both lizards were collected, taken to the lab and deposited at the scientific collection of the Universidade Federal do Ceará.

The radiography showed multiple bone fractures throughout the prey's body (Figure 2) as follows: jaw (complete fracture of the left mandibular bone), right forelimb (luxation of the radioulnar and radiocarpal joints), left hind limb (transversal fracture of the femur), right hind limb (spiral fracture of the fibula). The necropsy also revealed several tegumentary perforations at the bite sites, lacerations and edemas in vicinity of the fractured bones, as well hemorrhagic areas in the femoral region of the left hind limb and in the tibial region of the right hind limb. In addition, the lizard's skull was smashed, estimated about 12% by comparing the photographic records of the beginning and end of the predatory event (head height 7.0 and 6.1 mm, respectively). However, although the hypovolemic shock might be generally the cause of death in severely injured animals (Fighera et al. 2008), we were not able to accurately evaluate the seriousness of the cranial trauma due to the small body size of the prey, and so the *causa mortis* of the specimen could not be precisely determined.

Discussion

The Neotropical lizard *Tropidurus hispidus* has a wide geographical distribution, occurring in Caatinga semiarid and coastal areas in northeastern Brazil as well as in Amazonian savanna enclaves in northern South America (Carvalho 2013). As is know for most *Tropidurus*, this species feeds mainly on arthropods, but leaves, flowers and fruits also may compose its diet (Vitt 1995, Van Sluys 2004, Kolodiuk et al. 2010). Moreover, small vertebrates

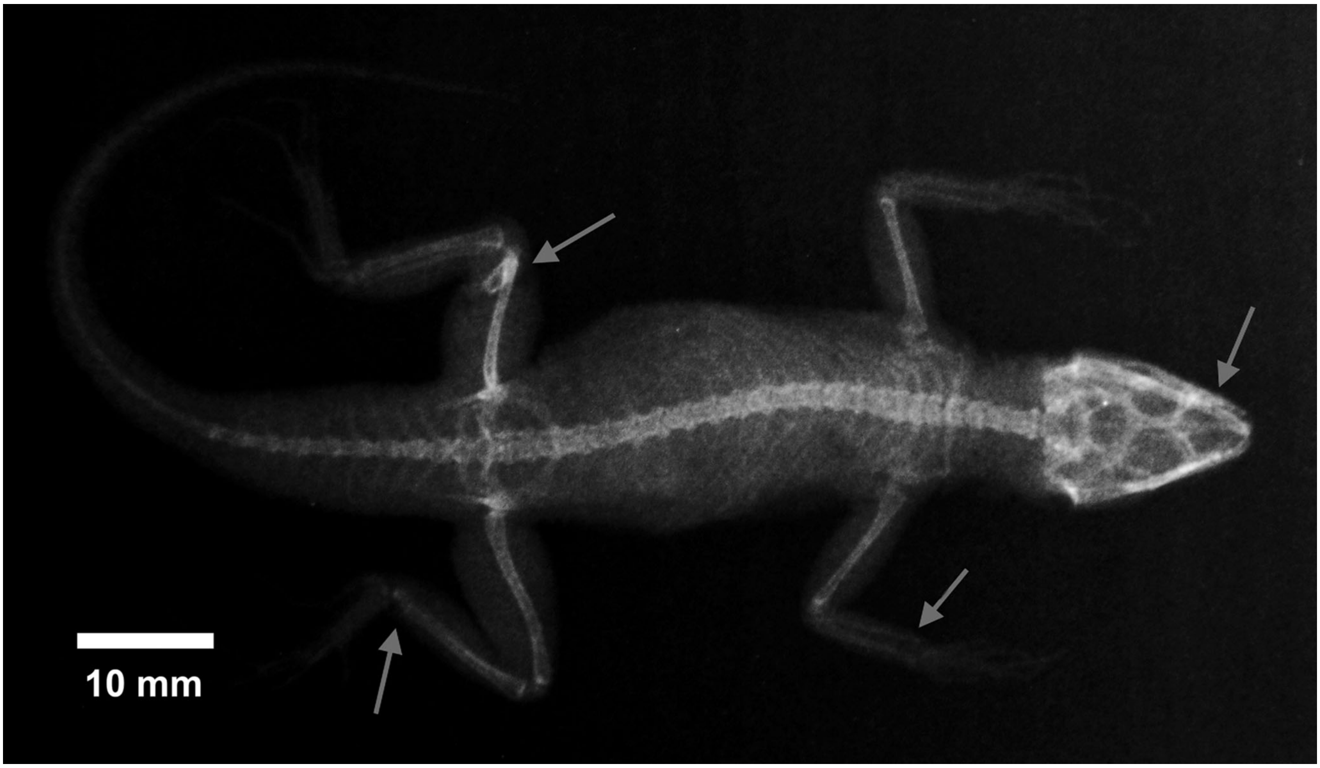

Figure 2. Radiography of an adult female *Tropidurus jaguaribanus.* The arrows indicate the multiple bone fractures.

have been also reported among its prey, such as the frogs *Elachistocleis ovalis* (Schneider, 1799) (Vitt et al. 1996) and *Scinax x-signatus* (Spix, 1824) (Ribeiro & Freire 2009), beyond the lizards *Colobosaura modesta* (Reinhardt and Lütken, 1862) (Costa et al. 2010), *Cnemidophorus ocellifer* (Spix, 1825) (Zanchi et al. 2012) and *Norops auratus* (Daudin, 1802) (Costa-Campos & Souza 2013). Although *T. hispidus* is commonly found in sympatry with other congeners, as *T. erythrocephalus* Rodrigues 1987, *T. hygomi* and *T. montanus* (Rodrigues 1987), to our knowledge there is no record of congeneric saurophagy between syntopic *Tropidurus* species. *Tropidurus hispidus* and *T. jaguaribanus* live in syntopy on rocky outcrops along the Jaguaribe Valley in the state of Ceará (Passos et al. 2011) and although agonistic encounters between the species eventually occur, they usually tolerate the proximity to each other (Passos *pers. obs.*). Thus, this is the first record of *T. jaguaribanus* as prey of *T. hispidus* and the first report of congeneric saurophagy among different species of syntopic *Tropidurus*.

Tropidurus hispidus is one of the largest species of the *torquatus* group (Rodrigues 1987, Freitas & Silva 2005), whilst *T. jaguaribanus* is the largest one of the *semitaeniatus* group (Passos et al. 2011, Passos et al. 2013). In general, juvenile lizards are more susceptible to predation in both saurophagic and cannibalistic interactions (Siqueira & Rocha 2008). Their smaller relative size compared to adults, their higher relative abundance as well the lack of experience in avoid predators may explain this trend (Vitt 2000). In fact, the majority of records of saurophagy and cannibalism in *T. hispidus* were directed against juveniles (e.g. Sales et al. 2011) or species of smaller body size (e.g. Zanchi et al. 2012). However, the case reported herein involved adult individuals of two of the largest species of the genus *Tropidurus*. This itself would already be noteworthy, even more if added to the complex hunting behavior performed repeatedly by *T. hispidus*.

Acknowledgements

We thank Izamaro Araújo, director of the Instituto Federal de Ciência, Educação e Tecnologia do Estado do Ceará – Campus Jaguaribe, for the opportunity to work on the IFCE's property, and Jean Nixon for fieldwork assistance. We also thank Helena Hokamura, head of radiology sector from Veterinary Hospital of Universidade Estadual do Norte Fluminense Darcy Ribeiro, for logistical support and the radiological analysis. We are grateful to Daniel Cassiano Lima and Laís Feitosa Machado for the critical review of a previous version of this manuscript. We are also grateful to Gunther Köhler and an anonymous referee for the valuable suggestions to this paper. DCP is funded by a Doctor's degree scholarship from the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES. The collecting permit 42552-4 was granted by the Instituto Chico Mendes de Conservação da Biodiversidade – ICMBio.

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Received 29/05/2015
Revised 27/01/2016
Accepted 9/02/2016

Biota Neotropica 16(1): e0069, 2016
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
short communication

Annual changes in a bird assembly on artificial perches: Implications for ecological restoration in a subtropical agroecosystem

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VOGEL, H.F., SPOTSWOOD E., CAMPOS, J.B., BECHARA, F.C. **Annual changes in a bird assembly on artificial perches: Implications for ecological restoration in a subtropical agroecosystem.** Biota Neotropica. 16(1): e0069. http://dx.doi.org/10.1590/1676-0611-BN-2015-0069

Abstract: Artificial perches are used in tropical forest restoration projects to increase the dispersal of seeds into restored areas. The ability of perches to enhance seed deposition depends on their ability to attract seed dispersing birds, as well as the correlation between the season of bird visits to perches and the phenology of fruit production in adjacent forests. Using data collected from a large-scale restoration project, we characterized the community of birds that utilize artificial perches over the course of one year. We hypothesized that the structure of a bird assemblage that uses artificial perches is affected by seasonal variation. We aimed to describe the richness, abundance and diversity of a bird assemblage on artificial perches in a subtropical Atlantic forest restoration experiment in Southern Brazil. Richness and abundance estimates of the avian fauna were obtained from eight artificial perches placed in four experimental plots (~2 y-old). Parameters of richness and abundance were compared using ANOVA. The bird assemblage was described using SHE analysis [richness (S), diversity (H') and evenness (E)], with additional estimates of occurrence and dominance. In total, 451 records of 32 ± 3.16 SD species were obtained. Thraupidae was the most numerous family (nine species, 28.12% of the total). Richness and abundance varied seasonally and were highest during spring and summer. Five migratory species of flycatchers were recorded between spring and early autumn. Perches were ineffective in attracting specialized frugivorous birds, emphasizing that seed dispersal tends to be carried out primarily by generalist omnivores in the initial phase of forest regeneration.

Keywords: *Avian fauna, ecological restoration, Atlantic forest, nucleation.*

VOGEL, H.F., SPOTSWOOD E., CAMPOS, J.B., BECHARA, F.C. **Variação anual na assembleia de aves em poleiros artificiais: Implicações para a restauração ecológica em agroecossistema subtropical.** Biota Neotropica. 16(1): e0069. http://dx.doi.org/10.1590/1676-0611-BN-2015-0069

Resumo: Poleiros artificiais são usados em projetos de restauração de florestas tropicais para aumentar a dispersão de sementes em áreas restauradas. A capacidade de poleiros para melhorar a deposição de sementes depende da sua capacidade de atrair aves dispersoras, bem como a correspondência entre a estação de visitas de aves nos poleiros e a fenologia da produção de frutos nas florestas adjacentes. Usando dados coletados a partir de um projeto de restauração de grande escala, que caracterizaram a comunidade de aves que utilizam poleiros artificiais ao longo de um ano, foi testada a hipótese que a estrutura da assembleia de aves em poleiros artificiais é afetada por variações sazonais. O objetivo foi descrever a riqueza, abundância e diversidade da assembleia de aves que visitam poleiros artificiais em um experimento de restauração florestal da mata Atlântica subtropical no sul do Brasil. Estimativas de riqueza e abundância da avifauna foram obtidas de oito poleiros artificiais colocados em quatro parcelas experimentais (~2 anos de idade). Parâmetros de riqueza e abundância foram comparados usando ANOVA. A assembleia de aves foi descrita por meio de análise SHE [riqueza (S), diversidade (H') e equitabilidade (E)], com estimativas adicionais de ocorrência e dominância. No total, foram obtidos 451 registos de 32 ± 3,16 DP espécies. Thraupidae foi a família mais abundante (nove espécies, 28.12% do total). Riqueza e abundância variaram sazonalmente, sendo mais elevadas durante a primavera e verão. Foram registradas cinco espécies migratórias de tiranídeos entre a primavera e o início do outono. Poleiros foram ineficazes na atração de aves frugívoras especializados, enfatizando que a dispersão de sementes tende a ser realizada principalmente por onívoros generalistas na fase inicial de regeneração florestal.

Palavras-chave: *Avifauna, restauração ecológica, Mata Atlântica, nucleação.*

Introduction

In diverse tropical forests, restoration has emerged as a tool for promoting the recovery of forests after deforestation and agricultural abandonment (Reis et al. 2010). However, recovery in diverse tropical forests can be notoriously slow (Rey-Benayas et al. 2008). The use of bird perches within restoration projects can aid the recovery process by increasing the dispersal of forest seeds into restored areas (Shiels & Walker 2003), the connectivity between forest remnants and the genetic variability of degraded habitats (Wuderle Jr. 1997, Holl 1998). In addition to seed dispersal, perches may also increase the diversity of avian fauna from non-seed dispersal guilds, which could assist with the recovery of other ecosystem functions (Bocchese et al. 2008). Moreover, artificial perches can complement other common techniques such as the high-diversity planting of trees (Rodrigues et al. 2011, Carnevale & Montagnini 2002), assisted regeneration (Shono et al. 2007) and nucleation (Reis et al. 2010, Corbin & Holl 2012).

Quantifying the use of artificial perches is a critical first step in understanding how perches affect avifaunal diversity and ecosystem function in restored areas. For example, in some tropical areas dominated by exotic invasive grasses, perches have not been effective at increasing the recruitment of primary forest seeds in restored areas (Holl et al. 2000, César et al. 2014). However, perches may serve other functions, including furnishing hunting and resting areas for raptorial species, which may act in the population control of granivorous and herbivorous animals such as insects and rodents (Hall et al. 1981, Pias et al. 2012). They may also attract pollinator (Shiels & Walker 2003, Lindell & Thurston 2013), generalist insectivorous and omnivorous birds (Bocchese et al. 2008, Morrison & Lindell 2012). These trophic groups may act as occasional dispersers of forest fruit, thus substituting some of the ecosystem functions performed by specialized frugivorous birds, which are generally rare or absent in degraded environments (Sekercioglu 2006, Pizo 2007).

Dispersal into restored areas may not occur either because frugivores may be absent (Staggemeier & Galetti 2007, Caves et al. 2013), or because the seasonality of perch use does not match the seasonality of fruit production. Furthermore, in some subtropical regions, there is evidence that many birds contribute only seasonally to seed dispersal. Thus, seasonal matching between perch use by dispersers and the phenological cycle of vegetation is key to the effectiveness of perches in promoting the dispersal of forest seeds (Zanini & Ganade 2005). Little attention has been given to the relationship between annual variation in the deposition of seeds and the resulting changes in the composition of the bird assemblage (Vicente et al. 2010, Hartz et al. 2012). For example, one-third of the austral migrants are the Tyrannidae family (Chesser 1994, Alves 2007) and their strong preference for perches (Holl et al. 1998, Vicente et al. 2010) and migratory behavior could be reflected in the seasonal changes in the use of artificial perches. Moreover, most studies involving birds on artificial perches provide little emphasis on quantitative parameters of the avian fauna.

Here, we characterize an avifaunal assembly that uses artificial perches within a large-scale restoration experiment that uses nucleation techniques to accelerate restoration in a subtropical agroecosystem (Reis et al. 2010). Using data collected over two years through multiple seasons, we estimate richness, abundance and diversity of species using perches. To understand what ecosystem functions may be provided by birds using perches, we also identify the trophic position and dominance of all species. We ask whether the avian community changes throughout the year and whether annual migration patterns affect how perches are used. Lastly, we ask whether seasonal changes in seed-dispersing species match the seasonal production of forest fruit. We expected higher richness and abundance of birds using perches in the spring and summer, when most austral migrants occur in Southern Brazil (Belton 1985, Stotz et al. 1996, Ridgely & Tudor 2001).

Materials and Methods

1. *Study area*

This study was developed on a research farm of the Federal Technological University of Paraná (Universidade Tecnológica Federal do Paraná; 25°41’43.35”S; 53°6’12.27”W) in the municipality of Dois Vizinhos (Paraná state, Southern Brazil; Figure 1). The area is approximately 50 m from a stream, 495-504 m above sea level. Climate in the region is *Cfa*, according to Köppen, with a mean temperature of 19.2°C and annual frost (Maack 2002). Precipitation is 2,044 mm/year, with no hydric deficit. Vegetation is classified as Atlantic subtropical forest in an ecotone between Araucaria moist forest and seasonal semideciduous forest. The experimental area was historically used for agriculture and pasture until October 2010, when a restoration experiment began. Four randomized plots were established at a distance of ~13 m from one another using a set of nucleation techniques (see next item).

2. *Nucleation techniques*

Four out of twelve batches (40 x 54 m) were randomly selected for implementation of the nucleation techniques (Figure 1). A set of seven nucleation techniques was used in each plot (developed and implanted by F.C. Bechara in an adaption from Reis et al. 2010) in six 3 x 40 m strips, occupying 1/3 of the plot (2/3 have no intervention to promote natural regeneration). The seven techniques were: (1) six artificial shelters for the fauna (1 m x 1 m x 1 m pile of firewood); (2) two tripods: artificial perches made from the trunk plus the dry crown of eucalyptus trees (10 m high and a diameter of 15 to 20 cm at soil level). The sweet passion fruit (*Passiflora alata* Curtis), native to the region, was cultivated on the perches; (3) transfer of topsoil seed bank (collected in a conserved forest remnant) in six 1-m^2 nuclei; (4) seed rain (captured in 30 seed traps for 12 months in a conserved forest remnant) in six 1-m^2 nuclei; (5) nuclei of cover crop composed of pigeon pea (*Cajanus cajan* (L.) Millsp.; Fabaceae) in 12 3 x 4 m nuclei; (6) islets of native trees (Anderson, 1953) composed of five seedlings spaced 1 m apart and arranged in a “+” shape, with four seedlings of the same rapid-growth pioneer species at the edges and one non-pioneer species in the center (we used 12 pioneer species and 24 non-pioneer species in a density of 24 islets); (7) islets of terrestrial epiphytes composed of five bromeliad (*Bromelia antiacantha* Bertol) saplings spaced 0.5 m apart in a “+” shape (Anderson, 1953).

3. *Data collection*

A census of the birds was undertaken from January to December 2012 (in the second year after the start of restoration). Richness and abundance was obtained by direct counting (Bibby et al. 2000) at a single site in the center of each experimental plot between the two perches (Figure 1 in the

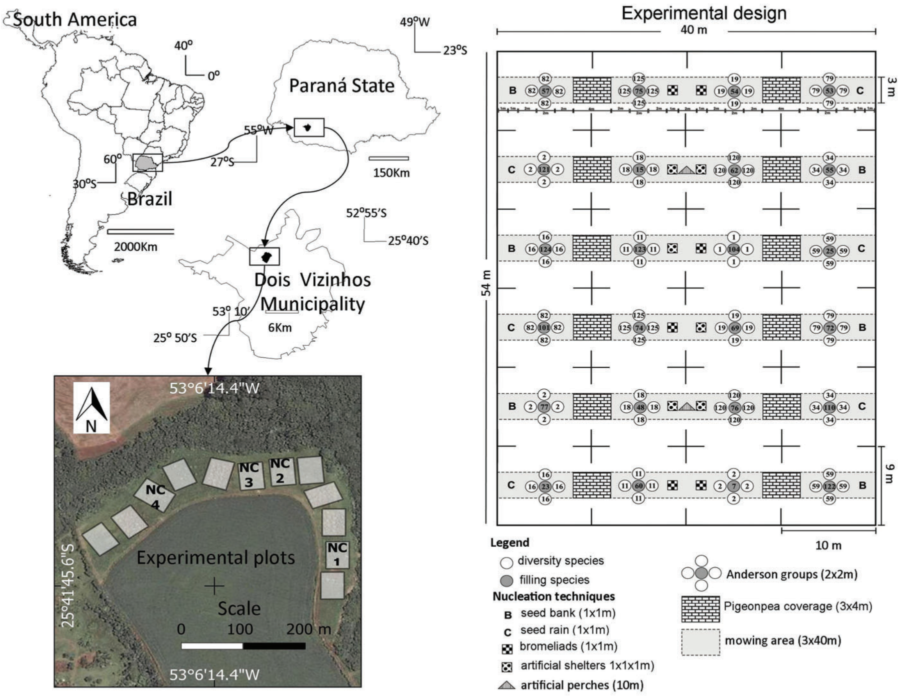

Figure 1. Area of study and distribution of the experimental plots. In detail, experimental design containing nucleation techniques. In the experiment there are twelve experimental plots but only four (NC 1, 2, 3 & 4) were restored by nucleation techniques.

experimental design). Sampling took place twice a month on two successive days of observation. Two 10-minute point counts (separated by about eight hours) were conducted each day in the morning ~06h40 to ~08h40 -3GMT and in the afternoon ~16h30 to ~18h30. The plot at the start of sampling was chosen at random, and the sequence was always from the first to the last plot. Six counts were conducted at each site per season, for a total of 24 counts per site, with a sampling effort of 8 h per plot or 32 h of total effort. Only individuals specifically resting on perches were recorded and the nomenclature used to identify the birds was taken from the Brazilian Committee of Ornithological Records (CBRO 2014).

4. Statistical analyses

In order to describe the diversity of the bird assemblage that used the perches, richness estimates were obtained using rarefaction with the estimators Jackknife 1 and Bootstrap (10,000 randomizations). Rarefaction estimates both the true diversity of a system and the sampling effort required to obtain a reasonable approximation of species diversity. The technique is appropriate when the true diversity of a system is unknown, and when the sampled populations are composed of several unidentified subpopulations (Colwell et al. 2004). Diversity was estimated using SHE analysis (Buzas & Hayek 1998), which examines the relationship between S (species richness), H' (Shannon-Wiener diversity index) and LnE (evenness, measure using the Pielou index – J'). This approach is an alternative to evaluating general tendencies of the parameters that compose diversity over the increase in the sampling effort. Exponential function for the species accumulation curve and linear functions (Ln) of evenness and diversity were also obtained.

Species abundance was interpreted based on Berger-Parker – D dominance (Krebs 1999, Melo 2008). Dominance classes were later grouped according to Palissa et al. (1977): eudominant (> 10%); dominant (10 ⊢ 5%); subdominant (2 ⊢ 5%); recessive (1 ⊢ 2%), rare (< 1%). We obtained the frequency of occurrence index (Linsdale & Rodgers 1937), expressed by the number of samples in which the species was present in relation to the sampling total. Categories used to form the frequency of occurrence classes were based on Dajoz (1983): constant (> 50%); accessory (25% to 50%); accidental (< 25%). The indices of dominance (%) and frequency (%) were related through a linear regression analysis (PAST® ver. 2.17; Hammer et al. 2001), where dominance acts as a dependent variable, with the objective of verifying if it could predict perch use occurrence parameters.

In order to quantify the trophic position of birds using artificial perches, we used the guild proposed by Almeida et al. (2003). Each species was categorized as either a migrant (M) or a resident (R), based on Bencke (2001). The proportions of species categorized by dominance, frequency of occurrence, trophic categories and status of occurrence were compared using a chi-square test, with $\alpha = 0.05$ statistical acceptance. To compare bird community composition between seasons, we used detrended correspondence analysis (DCA), with greater weight given to low-abundance species, enabling the obtainment of Pearson correlation measurements between species and axes (PC-ORD™ ver. 6; McCune & Mefford 2011). Mean scores of the axes between seasons were later tested through Kruskal-Wallis non-parametric variance analysis (PAST® ver.2.17; Hammer et al. 2001).

In order to quantify how seasonal variation in the use of perches could affect the dispersal of seeds under perches, birds were evaluated based on their known dispersal capacity from the literature. Each species was either a probable disperser (P-dispersers), or a likely non-disperser (N-dispersers), based on Pineschi (1990), Pizo (2004), Fonseca & Antunes (2007) and Athiê & Dias (2012). Disperser categories were used to evaluate

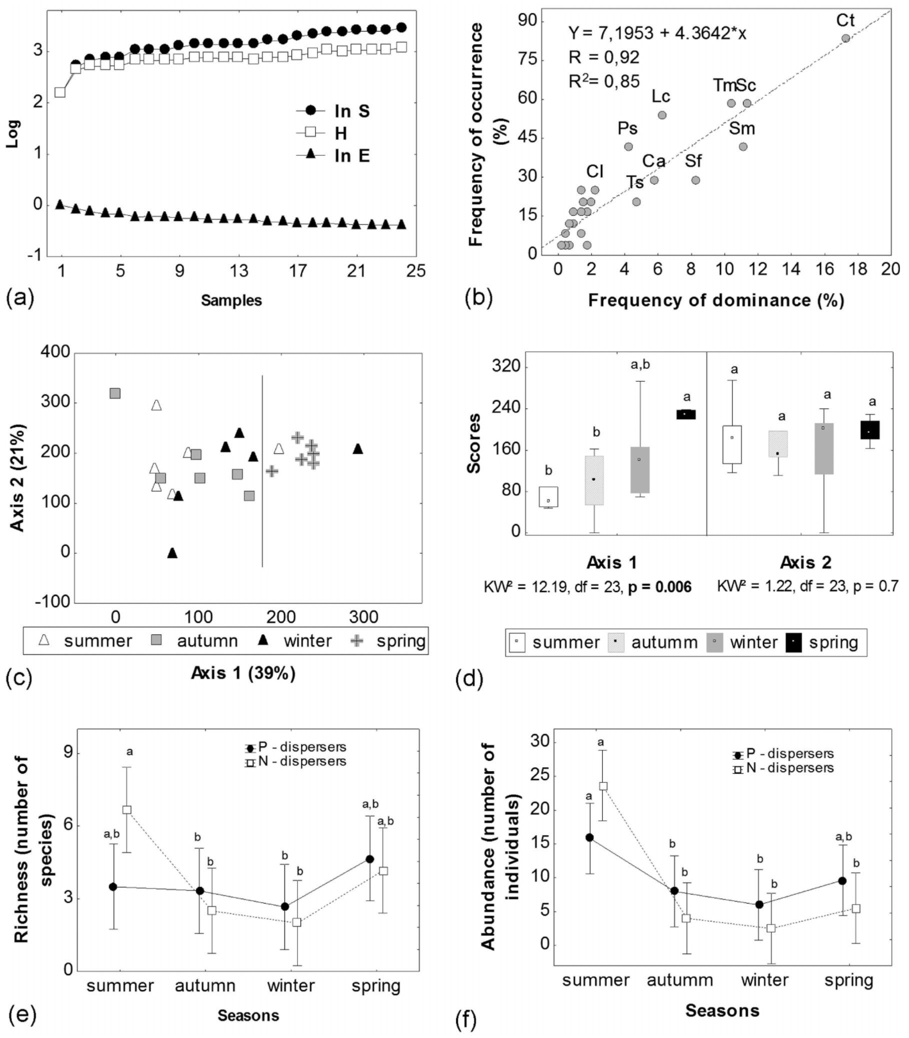

Figure 2. (a) Analysis of species richness (S), diversity (H') and Evenness (E) of birds using perches across all seasons; (b) Regression analysis between the frequency of dominance and the frequency of occurrence of birds that use artificial perches. The codes represent: (Ct) *Columbina talpacoti*, (Sc) *Sporophila caerulescens*, (Tm) *Tyrannus melancholicus*, (Sm) *Sporagra magellanica*, (Lc) *Lanio cucullatus*, (Sf) *Sicalis flaveola*, (Ps) *Pitangus sulphuratus*, (Ca) *Crotophaga ani*, (Ts) *Tyrannus savanna* and (Cl) *Chlorostibon lucidus*. The letters represent the genera and species, respectively; (c) Detrended Correspondence Analysis (DCA); (d) DCA with respective Kruskal-Wallis test for scores of axes; (e) Richness test; (f) Abundance of potential disperser species that used artificial perches (ANOVA; where the means followed by the same letters do not differ by means of the Tukey test, with minimum acceptance of $P < 0.05$).

how the abundance and richness of likely disperser and non-disperser birds varied between seasons by the comparing seasonal richness and abundance in each category, using analysis of variance [factorial ANOVA (two groups *vs.* four seasons)]. The Bartlett and the Shapiro-Wilk tests were used to check the homogeneity of the variances and normality of the data, respectively (Quinn & Keough 2002).

Results

A total of 451 records of 32 ± 3.16 species belonging to 14 families (Appendix 1) were obtained using the following richness estimates: 48.11 ± 6.17 (Jackknife 1) and 30.49 ± 2.63 (Bootstrap). Thraupidae was the most numerous family, with nine species represented (28.12%), followed by Tyrannidae ($n = 6$ or 18%). The species accumulation curve obeyed the logarithmic model expressed by the function $y = 8.2793 \ln(x) + 5.2989$ and $R^2 = 0.997$. The linear models obtained from evenness ($y = -0.0141x - 0.0881$; $R^2 = 0.8964$) and diversity ($y = 0.0213x + 2.5905$; $R^2 = 0.699$) show a tendency of decrease in evenness, contrary to the increase in diversity.

There were relatively few dominant species, and most species were rarely seen on perches. Dominance categories were not evenly distributed ($\chi^2 = 13.93$, df = 4; $P = 0.007$), with a predominance of rare species ($n = 14$; 43.75%), followed by recessive species (25%). Only *Columbina talpacoti*, *Sporophila caerulescens*, *Sporagra magellanica* and *Tyrannus melancholicus* were eudominant. Species occurrence analysis showed that only four (12.5%) species (*C. talpacoti*, *Lanio cucullatus*, *S. caerulescens* and *T. melancholicus*) were constant on the artificial perches. Most species fell into the accidental category ($n = 24$; 75%; $\chi^2 = 25$, df = 3; $P < 0.001$). Regression analysis allows the diagnosis that the frequency of dominance can predict the frequency of occurrence ($y = 7.1955 + 4.3642*x$), with adjusted $R^2 = 0.85$ (Figure 2b).

Five trophic groups represented the species visiting perches, most of which were granivorous ($n = 11$; 34.37%; $\chi^2 = 13.31$, df = 4; $P < 0.05$), omnivorous ($n = 10$), insectivorous ($n = 8$) or carnivorous ($n = 2$). Only a single nectarivorous species (*Chlorostilbon lucidus*) was found, and no exclusively frugivorous birds were seen. DCA (Figure 2c) separated the bird assemblage between spring, and autumn and summer (Figure 2d). In general, the species were weakly correlated with the first two retained axes, which together explained 60% of the variance (Appendix 1).

Seasonal variation in both richness ($F_{[3.40]} = 14.79$; $P < 0.01$) and abundance ($F_{[3.40]} = 4.33$; $P = 0.01$; Table 1 and Figure 2e and f) was significant, supporting our hypothesis of finding greater species richness and abundance in spring and summer. There was no effect of seasonality on the groups or interaction of the factors. However, a Tukey HSD test showed that the richness of the N-disperser group was higher only during summer (6.66 ± 1.96 SD species); whereas the abundance of individuals was higher in summer for both groups (P-dispersers 15.83 ± 5.11 SD and N-dispersers 23.66 ± 12.58 SD; Figure 2e and f).

Discussion

We found that artificial perches were used by a diverse assemblage of species occupying different trophic positions. Birds that used perches are capable of performing a number of ecosystem functions, including reducing seed predation by rodents (carnivores), and consuming insects (insectivores) and grains (granivores). However, specialist frugivores were absent from perches, and omnivorous species capable of dispersing seeds varied seasonally in richness and abundance. Our main conclusion is that while ecosystem functions may be enhanced by artificial perches, the capacity of perches to increase seed input from adjacent forest may be limited, i.e. dispersal tends to be carried out primarily by generalist omnivores in the initial phase of forest regeneration.

The richness found in this work (32 species) was near what was obtained by the Bootstrap estimator, showing a satisfactory sampling effort. Based on the function of the species accumulation rate, five years of sampling would be necessary to reach the richness estimated by the Jackknife 1 method (48 spp.). However, the branches of the artificial perches began to break after two years, reducing the landing area. This may explain the tendency of a decrease in evenness during sampling, because some aggressive species (e.g. flycatchers) tend to defend landing or territorial sites (Tomaz & Alves 2009), excluding other species. The gradual increase in diversity (H') is due to the arrival of migrant individuals in the spring.

Other studies have found variable numbers of species using artificial perches, with values between seven species in Guedes et al. (1997) and 35 in Bechara et al. (2007). Such variation can be attributed to several factors, including perch type (Silva et al. 2010), structure and degree of habitat and landscape alteration (Staggemeier & Galetti 2007, Pillatt et al. 2010), and variations in the sampling effort and methodology. Another factor that deserves more attention is the optimum density of perches in the landscape. Few perches can concentrate the birds at a single site; whereas many perches can dilute abundance, giving a false interpretation of efficiency (Silva et al. 2010).

We found that the species that used perches most frequently were also dominant. Among the most abundant species, only *T. melancholicus* is an effective disperser, ingesting fruits from forest edges and depositing the seeds in open environments (Fonseca & Antunes 2007, Athiê & Dias 2012). Other dominant species (including *C. talpacoti*, *L. cucullatus*, *Zenaida auriculata* and *Volatinia jacarina*) are granivorous and feed on seeds of Poaceae and Asteraceae (Belton 1985, Azpiroz et al. 2012), which are abundant in the area. The presence of granivorous birds on artificial perches is common. These species may occasionally consume fruit and are potential dispersers. However, granivores may also limit seed deposition under perches, due to the predation of seeds already dispersed by other birds (Christianini & Galetti 2007). The role of birds as dispersers or predators of seeds deserves greater study, because many granivorous birds have been recorded carrying out frugivory and dispersal. *Z. auriculata* and *V. jacarina* (Vieira & Silva 1997, Bucher & Bocco 2009) are examples.

We found a structural change in the bird assemblage visiting perches during the spring, corresponding to the arrival of the first austral migrants (Joseph 1996, Alves 2007). Many species in the Neotropical region contain both migratory and non-migratory individuals (Belton 1985, Sick 1997). Thus, as more migrants return from wintering sites to reproduce, the abundance of certain species can increase during summer. In the DCA of our study, *Turdus amaurochalinus* it primarily responsible for the spring separating in the axis 1 in relation mostly autumn and winter.

Both migratory and non-migratory individuals were present at our study site during the reproductive season, and this was reflected in an increase in the abundance of this species on perches during the summer (Capllonch et al. 2008, Vogel et al. 2012). *T. amaurochalinus* is omnivorous (Gasperin & Pizo 2012) and one of the most important dispersers in agricultural areas or near agroecosystems (Pizo 2004).

Notably, specialized dispersers were never seen using perches in our study. Thus, generalist dispersers, and seasonal variations in their occurrence, are key to understanding the potential for perches to enhance seed dispersal. Other studies

Table 1. Result of the factorial analysis of variance between N-disperser and P-disperser groups. The abbreviations SS, DF, MS, F and P represent the sum of squares, degrees of freedom, mean square, ANOVA test value and statistical significance.

	Effect	SS	DF	MS	F	P
Abundance	Groups	11	1	11	0.27	0.60
	Seasons	1782	3	594	14.79	**0.00**
	Interaction	310	3	103.30	2.57	0.06
	Error	1606.50	40	40.15	-	-
Richness	Groups	1.02	1	1.02	0.22	0.63
	Seasons	58.90	3	19.63	4.33	**0.01**
	Interaction	33.23	3	11.08	2.44	0.07
	Error	181.16	40	4.52	-	-

including perches have also found similar results (e.g. Shiels & Walker 2003, Pillatt 2010, Vicente et al. 2010). The absence of frugivorous species was probably caused by the defaunation brought about by site degradation (Gomes et al. 2008). Regenerating environments also furnish few food and reproductive resources for specialized frugivores, including cavities for nests and availability of fruits during the whole year (Sekercioglu 2006, Pizo 2007, Pillat et al. 2010).

Five migratory bird species were recorded, all from Tyrannidae (*Elaenia flavogaster*, *Megarynchus pitangua*, *Tyrannus melancholicus*, *Tyrannus savanna* and *Empidonomus varius*). This bird group has an insectivorous diet (Ridgely & Tudor 2001, Gabriel & Pizo 2005, Martins-Oliveira et al. 2012), which may be useful in the control of forest pests (Strong et al. 2000). Insectivory is likely to be highest during the reproductive period for birds in Southern Brazil, which occurs between spring and autumn (Belton 1985, Sick 1997), when many species require a large quantity of insects to feed their chicks (Argel-de-Oliveira et al. 1998, Marini et al. 2009). A second benefit brought about by the presence of flycatchers on perches is the capacity to promote seed dispersal in pastures and open areas (Fonseca & Antunes 2007, Gabriel & Pizo 2005). On the other hand, flycatchers are the main species responsible for mobbing, a behavior that consists of defending territory against other birds (Cunha & Fontenelle 2014). When flycatchers are present on perches during their reproductive period, they tend to chase away other species that can exercise important ecosystem functions in restoration, including seed dispersal by toucans (Galetti et al. 2000) and the predation of rodents by hawks (Hall et al. 1981, Pias et al. 2012).

For both the seasonal semideciduous forest and the mixed ombrophilous forest (Araucaria moist forest) of Southern Brazil, the greatest availability of fruits occurs between spring and summer (Mikich & Silva 2001, Liebsch & Mikich 2009), when our study found the abundance and richness of potential dispersers to be highest. This synchrony between peak fruit availability and peak disperser abundance in this agroecosystem emphasizes the importance of this mutualism (Zanini & Ganade 2005, Jordano et al. 2006, Carlo et al. 2007, Hartz et al. 2012). In summary, we found seasonal variation in the richness and abundance of the avian fauna using the artificial perches in the early stages of forest regeneration (~2 years of age) within a restoration experiment. Fifty percent of the birds that used the perches (representing five trophic groups) were possible dispersers. The use of perches was ineffective in attracting specialist frugivorous birds, emphasizing that seed dispersal in fragmented landscapes tends to be carried out mainly by generalist omnivores and insectivores, among which migratory or partially migratory species also occur. Seasonal variation in the richness and abundance of birds using perches corresponded to the peak fruiting season for most of the zoochoric species that occurred in the adjacent forest, highlighting the potential for artificial perches to increase seed deposition into restoration areas. Future studies are recommended to evaluate the dispersal capacity of granivores, which were the most frequent and abundant in this study.

Acknowledgments

We thank CNPq (Conselho de Desenvolvimento Científico Tecnológico) for financing the project (process no. 575081/2008-2) and COPEL-GET, especially Murilo L. Barddal, for the implantation and forest maintenance. We also thank forest technician Gilmar Poser Brizola for help in the field. We are grateful to the Programa em Ecologia de Ambientes Aquáticos Continentais (PEA) and the Universidade Tecnológica Federal do Paraná for logistical support. HFV thanks CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) for the scholarship.

Appendix 1. Species. FD% = frequency of dominance percentage and (CD) categories of dominance. FO% = frequency of occurrence percentage, (FC) frequency categories. Correlation (r) values of species between the axes of Detrended Correspondence Analysis (DCA) carried out to ordain according to the sampling seasons. Categories of dominance: eu = eudominant, do = dominant, su = subdominant, re = recessive and ra = rare. Categories of frequency of occurrence: con = constant, ace = accessory and aci = accidental. Tags: (•) = potential dispersers and (☐) species without efficiency for dispersal.

Species	**Diet**	**Seasons**				**Dominance**		**Constancy**		**DCA (r)**		**Migratory status (dispersive group)**
		summer	**autumn**	**winter**	**spring**	**FD%**	**CD**	**FO%**	**FC**	**Axis 1**	**Axis 2**	
Elanus leucurus (Vieillot, 1818)	carnivorous	+	-	+	+	0.67	ra	12.50	aci	0.28	0	resident (☐)
Rupornis magnirostris (Gmelin, 1788)	carnivorous	+	+	-	-	0.89	ra	12.50	aci	0.28	-0.23	resident (☐)
Columbina talpacoti (Temminck, 1811)	granivorous	+	+	+	+	17.29	eu	83.33	con	-0.49	-0.33	resident (•)
Zenaida auriculata (Des Murs, 1847)	granivorous	+	+	-	-	2.00	re	20.83	aci	-0.42	0.26	resident (•)
*Crotophaga ani*Linnaeus, 1758	insectivorous	+	+	+	-	5.76	do	29.17	ace	-0.42	-0.13	resident (☐)
Guira guira (Gmelin, 1788)	insectivorous	-	-	-	-	0.44	ra	4.17	aci	0.23	0.02	resident (☐)
Chlorostilbon lucidus (Shaw, 1812)	nectarivorous	+	-	-	+	2.22	su	25.00	aci	0.07	-0.01	resident (☐)
Colaptes melanochloros (Gmelin, 1788)	insectivorous	-	-	-	+	0.22	ra	4.17	aci	0.23	0.02	resident (☐)
Furnarius rufus (Gmelin, 1788)	insectivorous	+	+	-	-	1.33	re	16.67	aci	0.12	-0.03	resident (☐)
Elaenia flavogaster (Thunberg, 1822)	insectivorous	-	-	+	-	0.22	ra	4.17	aci	0	0.1	migratory (•)
Pitangus sulphuratus (Linnaeus, 1766)	omnivorous	+	+	+	+	4.21	su	41.67	ace	0.26	-0.01	resident (•)
Megarynchus pitangua (Linnaeus, 1766)	omnivorous	-	+	-	+	0.44	ra	8.33	aci	0.13	-0.03	migratory (•)
*Tyrannus melancholicus*Vieillot, 1819	omnivorous	+	-	+	+	10.42	eu	58.33	con	0.01	0.13	migratory (•)
*Tyrannus savanna*Vieillot, 1808	omnivorous	+	-	+	+	4.66	su	20.83	aci	0.42	0.09	migratory (•)
Empidonomus varius (Vieillot, 1818)	omnivorous	-	-	+	+	0.89	ra	16.67	aci	0.43	0.21	migratory (•)
*Troglodytes musculus*Naumann, 1823	insectivorous	+	+	-	+	1.33	re	1.00	aci	0.28	0.16	resident (☐)
*Turdus rufiventris*Vieillot, 1818	omnivorous	-	+	-	-	0.22	ra	4.17	aci	-0.1	0.05	resident (•)
*Turdus amaurochalinus*Cabanis, 1850	omnivorous	-	-	-	+	1.77	re	16.67	aci	0.53	0.15	resident (•)
Mimus saturninus (Lichtenstein, 1823)	omnivorous	+	-	-	-	1.77	re	4.17	aci	-0.23	0.38	resident (•)
*Saltator similis*d'Orbigny & Lafresnaye, 1837	omnivorous	-	-	-	+	0.44	ra	8.33	aci	0.37	0.06	resident (•)
Lanio cucullatus (Statius Muller, 1776)	granivorous	+	+	+	+	6.21	do	54.17	con	-0.28	0.15	resident (•)
Tangara sayaca (Linnaeus, 1766)	omnivorous	-	-	+	-	0.22	ra	4.17	aci	0.44	0.21	resident (•)
Conirostrum speciosum (Temminck, 1824)	insectivorous	-	-	+	-	0.44	ra	4.17	aci	0	0.04	resident (•)
Sicalis flaveola (Linnaeus, 1766)	granivorous	+	+	-	-	8.20	do	29.17	ace	-0.45	-0.21	resident (☐)
Sicalis luteola (Sparrman, 1789)	granivorous	+	-	-	-	0.22	ra	4.17	aci	-0.22	0.38	resident (☐)
Embernagra platensis (Gmelin, 1789)	granivorous	+	+	-	-	1.33	re	8.33	aci	-0.25	0.38	resident (☐)
Volatinia jacarina (Linnaeus, 1766)	granivorous	+		+	-	1.33	re	16.67	aci	-0.26	-0.49	resident (•)
Sporophila caerulescens (Vieillot, 1823)	granivorous	+	+	+	+	11.31	eu	58.33	con	-0.08	0.38	resident (☐)
Geothlypis aequinoctialis (Gmelin, 1789)	insectivorous	-	-	+	-	0.22	ra	4.17	aci	0.04	0.2	resident (☐)
Agelaioides badius (Vieillot, 1819)	granivorous	+	-	-	-	0.67	ra	4.17	aci	-0.23	-0.15	resident (☐)
Molothrus bonariensis (Gmelin, 1789)	granivorous	+	-	+	+	1.55	re	20.83	aci	0.45	0.15	resident (☐)
Sporagra magellanica (Vieillot, 1805)	granivorous	+	-	+	+	11.09	eu	41.67	ace	-0.44	0.43	resident (☐)

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Received 7/06/2015
Revised 25/11/2015
Accepted 18/12/2015

Biota Neotropica 16(1): e20150028, 2016
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
inventory

The genus *Pinnularia* (Bacillariophyta, Pinnulariaceae) from Lago dos Tigres, Britânia, Goiás, Brazil

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DA SILVA, W.J., RUWER, D., NOGUEIRA, I., DUNCK, B. **The genus *Pinnularia* (Bacillariophyta, Pinnulariaceae) from Lago dos Tigres, Britânia, Goiás, Brazil.** Biota Neotropica. 16(1): e20150028. http://dx.doi.org/10.1590/1676-0611-BN-2015-0028

Abstract: Studies of the genus *Pinnularia* Ehrenb. are only incipient in central-western Brazil, especially in Goiás. Only 20 of the 170 taxa known from Brazil were recorded in this state until now. A taxonomic study of *Pinnularia* from Lago dos Tigres (Tocantins-Araguaia River Basin) recorded 20 specific and infraspecific taxa, distributed in 17 species, including *P. instabilis* whose lectotype is designated here. Only *P. meridiana* var. *meridiana* was previously recorded in aquatic systems of the state. Eighteen taxa are newly recorded for Goiás, and one is the first record in Brazil. The *Pinnularia* flora from Lago dos Tigres contains nine taxa in common with the Amazon River Basin flora, and seven other taxa that occur elsewhere in the Paraná River Basin.

Keywords: *blocked river valley, Pinnularia meridian, Pinnularia instabilis, lectotypification, central-western Brazil.*

DA SILVA, W.J., RUWER, D., NOGUEIRA, I., DUNCK, B. **O gênero *Pinnularia* (Bacillariophyta, Pinnulariaceae) do Lago dos Tigres, Britânia, Goiás, Brasil.** Biota Neotropica. 16(1): e20150028. http://dx.doi.org/10.1590/1676-0611-BN-2015-0028

Resumo: O gênero *Pinnularia* Ehrenb. é incipientemente estudado na região Centro-Oeste brasileira, especialmente em Goiás. Somente 20 de 170 táxons conhecidos no Brasil foram registrados nesse estado até agora. Nesse estudo, objetivou-se a realização de estudos taxonômicos de *Pinnularia* do Lago dos Tigres (Bacia Tocantins-Araguaia). Vinte táxons em nível específico e infraespecífico, distribuídos em 17 espécies, foram observados e caracterizados aqui, incluindo *P. instabilis* cujo lectótipo foi designado aqui. Somente *P. meridiana* var. *meridiana* foi primeiramente registrada em sistemas aquáticos do estado. Dezoito táxons constituíram citações pioneiras para o estado de Goiás e um foi o primeiro registro de ocorrência para o Brasil. A flora de *Pinnularia* do Lago dos Tigres apresentou nove táxons comuns com a Bacia Amazônica e outras sete foram comuns à Bacia do Paraná.

Palavras-chave: *vale bloqueado, Pinnularia meridian, Pinnularia instabilis, lecotipificação, Centro-Oeste.*

Introduction

The taxon name *Pinnularia* was proposed by Ehrenberg (1840a, 1840b) as a subgenus of *Navicula* Bory. Later, Ehrenberg (1843a, 1843b) used the name at generic level. However, the name *Pinnularia* was earlier used by Lindley & Hutton (1835) for a genus of fossil high plants. *Pinnularia* Lindley & Hutton was lesser used than *Pinnularia* Ehrenb., which was conserved against the first one and it is the correct name to generic level according the International Code for Nomenclature of algae, fungi and plants (ICN, McNeill et al. 2012).

Pinnularia is a genus of naviculoid diatoms characterized by valves linear, lanceolate or elliptic, with plane or undulate surfaces (Krammer 2000). Members of this genus usually presented different courses of the internal and external fissure of the raphe; transapically, the valves bear alveolated costal systems, which are simple or partially recovered (Krammer 2000). This genus occurs predominantly in oligotrophic continental waters, with low electrolyte concentration and low pH values (Uherkovich 1984, Metzeltin & Lange-Bertalot 1998, Krammer 2000).

The genus *Pinnularia* comprises more than 2,700 species specific and infraspecific combinations, of which about 674 are currently accepted (Guiry & Guiry 2015). In Brazil, studies about *Pinnularia* recorded approximately 215 taxa (Pereira et al. 2014, Eskinazi-Leça et al. 2016). These studies were mainly concentrated in the regions South (Torgan et al. 1999, Tremarin et al. 2009, 2010), Southeast (Menezes & Dias 2001, Rocha & Bicudo 2008) and North (Hustedt 1965, Metzeltin & Lange-Bertalot 1998, 2007, Pereira et al. 2012, 2013, 2014).

In Central-West Region only 20 taxa were registered until now (Delgado & Souza 2007, da Silva et al. 2011). These studies comprised small areas, such as Distrito Federal, the regions Central, Northeast, and Southwest from Goiás, and a small city in Mato Grosso. The Central-West, Brazil, bears sources from the main hydrographic regions from the country. Three of these are present in the State of Goiás (i.e., São Francisco, Paraná, and Tocantins-Araguaia). Nowadays, this region has undergoing to deforestation and biocide effects because agricultural practices, which have been listed as one of the main reasons of aquatic biodiversity loss (Tundisi 2003). This impels a race against time in order to know the diversity of algal organisms from areas in similar conditions.

Phylocogical studies in the Western region from Goiás are still scarce. The Lago dos Tigres is localized in this area and it has four studies that approaching the algal biodiversity (i.e., Nabout & Nogueira 2007, Dunck et al. 2012, Oliveira et al. 2012a, 2012b), but none of them recorded species of *Pinnularia*. We aimed here to inventory the species of *Pinnularia* from Lago dos Tigres, Britânia, Goiás, Brazil.

Material and methods

Lago dos Tigres is localized in Britânia, in the West Region from the State of Goiás, Brazil (Figure 1). Commonly called lake, the Lago dos Tigres is, actually, characterized as blocked valley (Nabout & Nogueira 2007), also called drowned valley. Drowned valleys can be originated from the natural damming of water volumes of receptor rivers or by deposition of sediments, creating a barrier to the water (Kalff 2002). In the Lago dos Tigres, the Água Limpa River dammed by the water of the Vermelho River and sediments deposited at the confluence of these two rivers, resulting in a lentic body 50 km^2 of superficial area (Nabout & Nogueira 2007). These systems constitute affluents of the Tocantins-Araguaia River Basin.

This Lago dos Tigres System has acid to neutral waters, which reach temperatures higher than 21 °C. These waters are characterized as oligomesotrophic to mesotrophic, with high oxygen concentration (Nabout & Nogueira 2007). Physical and chemical variables were measured and values of averages and standard deviations ($n = 11$) are provided in Table 1. Depth and water transparency were measured by means measuring tape and Secchi disk, respectively. Water temperature, conductivity, oxygen saturation and pH were determined through a water multi-analyzer (HORIBA U-21). Total nitrogen (TN) and total phosphorus (TP) were inferred according to APHA (2005).

Phytoplankton samples were obtained using 25 µm plankton net. Periphytic material was scraped from artificial substrates (rocks) using toothbrush. These substrates were sampled after the 21st day of colonization. The material examined was collected from the 11 sites along Lago dos Tigres system (Britânia, Goiás), monthly, from June 2004 to November 2004, and from June 2008 and January 2009, totalizing 178 samples (Table 2). All the samples were fixed with Transeau solution (Bicudo & Menezes 2006) and deposited in the Herbarium of the Universidade Federal de Goiás (UFG), with numbers between UFG29864 and UFG29973, and between UFG43636 and UFG43724 (Table 2).

The samples were oxidized according to Simonsen (1974), modified by Moreira-Filho & Valente-Moreira (1981) and permanent slides were mounted using Naphrax®. The material was examined with Zeiss Axioscop 40 microscope and images were captured with an Axiovison system for observation of morphological characteristics of each taxa. A part of oxidized material was deposited under stubs and sputtered with a layer of 150-200 Å of gold in Sputter Coater Desk V (Denton Vacuum, LLC). The preparations were analyzed in a Jeol

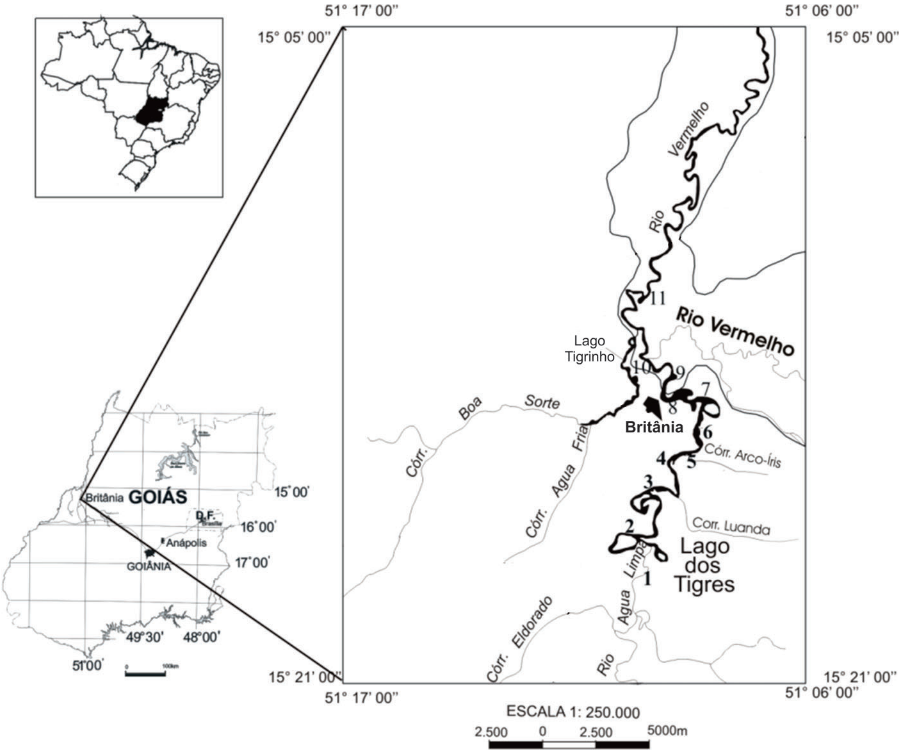

Figure 1. Lago dos Tigres System, Britânia, Goiás, and sampling sites in the study area.

Table 1. Physical and chemical characterization of Lago dos Tigres System from June/2004 to January/2009 (*n* = 11; Sd: standard deviation; TN: total nitrogen; TP: total phosphorus).

Variables		**Jun/04**	**Jul/04**	**Aug/04**	**Sep/04**	**Oct/04**	**Nov/04**	**Jul/08**	**Aug/08**	**Sep/08**	**Oct/08**	**Nov/08**	**Dec/08**	**Jan/09**
Depth (m)	Mean	3.93	3.02	2.75	2.24	2.21	2.7	2.45	1.95	1.85	1.77	2.19	2.85	4.28
	Sd	1.23	1.07	0.99	1.02	1.21	1.10	1.27	1.05	1.10	1.3	1.34	1.15	1.05
Transparency (m)	Mean	0.49	0.52	0.51	0.4	0.45	0.32	0.53	0.46	0.41	0.43	0.35	0.37	0.48
	Sd	0.13	0.10	0.16	0.06	0.07	0.07	0.08	0.11	0.09	0.10	0.12	0.10	0.16
Water temperature (°C)	Mean	25.32	25.94	26.19	28.17	30.45	32.01	23.90	27.60	30.50	29.90	30.90	29.50	29.50
	Sd	0.88	0.70	2.05	1.84	1.38	2.22	1.70	2.20	2.20	1.40	1.90	0.70	0.70
Conductivity (µS.s^{-1})	Mean	46.25	31.82	22.62	28.64	46.21	30.91	-	21.63	20.1	6.91	4.18	5.36	7.37
	Sd	14.07	7.51	5.84	9.21	13.74	8.86	-	9.77	10.19	3.75	1.78	1.75	5.96
Oxygen saturation (%)	Mean	100.88	111.00	131.64	168.91	134.54	155.82	-	-	-	8.90	8.50	6.70	5.80
	Sd	6.19	6.86	7.98	29.12	9.93	12.18	-	-	-	0.60	0.50	0.800	0.80
TN (µg.L^{-1})	Mean	230.00	148.18	94.55	68.18	81.36	139.89	121.60	148.10	234.70	374.90	195.00	129.00	-
	Sd	99.87	69.97	68.76	68.67	35.07	54.24	73.90	68.60	166.00	205.90	108.20	72.80	-
TP (µg.L^{-1})	Mean	52.5	52.27	58.18	50	37.73	29.95	20.40	14.30	92.80	19.80	18.50	17.60	-
	Sd	46.60	57.67	76.65	48.78	53.73	25.19	22.5	22.5	144.9	16.6	18.9	23.5	-
pH	Mean	7.30	7.51	6.95	6.81	7.61	7.2	6.22	6.71	6.39	6.38	6.53	6.35	6.35
	Sd	0.46	0.66	0.25	0.40	0.61	0.28	0.51	0.40	0.40	0.32	0.29	0.90	0.88

JSM-6610 scanning electron microscope (Jeol, USA), with an electrical potential of 6 kV, spot size 25–40.

The identification of the taxa at infrageneric level was based on specific bibliography and, as well as possible, based on original material (e.g., Metzeltin & Lange-Bertalot 1998, 2007, Krammer 2000, Metzeltin et al. 2005). The standardization of the author names were made according to IPNI (http://www.ipni.org/).

The frequency of occurrence of each species in the samples was based on Guille (1970), according to which taxa with frequencies up to 10% were considered rare, between 10% and 50%, inclusive, were considered common, and higher than 50% were considered constant.

Results and discussion

Twenty taxa of *Pinnularia* were recorded in this study (Table 3), all of them were considered rare according to the criteria proposed by Guille (1970) because occurred in 0.56% to 5.61% of the 178 samples analyzed in this study. The most frequent were *P. meridiana* var. *meridiana* Metzeltin & Krammer and *P. rumrichiae* Krammer, which occurred in nine and ten samples, respectively. Only *P. meridiana* var. *meridiana* was recorded early in other diatomoflora study from the State of Goiás (Souza & Oliveira 2007, da Silva et al. 2011). Other 18 taxa were firstly recorded in this State from this study, and *Pinnularia microstauron* var. *rostrata* constituted the first report for Brazil. Among the 18 taxa already recorded in Brazil, nine were common to environments from the Amazonas River Basin (Hustedt 1965, Simonsen 1987, Metzeltin & Lange-Bertalot 1998, 2007, Pereira et al. 2012, 2013); seven occurred in states of São Paulo and or Paraná, from the Paraná River Basin (Rocha & Bicudo 2008, Souza & Senna 2009, Moresco et al. 2011); six taxa were common to the Guaraguaçu River Basin, in the State of Paraná (Tremarin et al. 2009, 2010, Santos et al. 2011); and one taxon were common to the Guaíba River Basin, in Rio Grande do Sul (Metzeltin & Lange-Bertalot 1998). The only that already was recorded in Goiás also belongs to the Tocantins-Araguaia River Basin, to which run the waters of the Lago dos Tigres System (Souza & Oliveira 2007, da Silva et al. 2011).

Pinnularia acrosphaeria var. *tumidula*

Krammer, Diatoms of Europe, vol. 1, p. 55, 214, Fig. 21: 8, 9, 2000. (Figure 2)

Holotype. Preparation 1792 MR, Collection Mayer in Regensburgische Botanische Gesellschaft (REG), Regensburg, Germany.

Type locality. Nelubium pond, in the botanical garden from Munich, Germany.

Valves linear, tumid at the middle part; broadly rounded apices; length: 79–82 µm, breadth: 12.5–12.66 µm, length/breadth ratio: 6.32–6.57; axial area broad, linear, presenting granulations; raphe lateral, one terminal end abruptly curve and other sickle-shaped, proximal ends slightly curved to the same direction; striae parallel, becoming slightly radiate towards to the ends of the valves; striae: 12/10 µm.

Material examined. Brazil, State of Goiás, Britânia, Lago dos Tigres, plankton, Nogueira et al. Site 01, 19/10/2008, P01M10, ISN1265 (UFG 43675); Site 4, 04/06/2004, ISN877 (UFG 29866); Rio Vermelho, plankton, Nogueira et al. Site 11, 14/07/2004, ISN907 (UFG 29890).

Table 2. Samples collected in the Lago dos Tigres Systems

Herbarium number	**Locality**	**Date**	**Coordinates**	**Collector number**	**Collectors**	**Habitat**
UFG29864	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	04/06/2004	15°18'58" S; 51°9'56" W	ISN874	Nogueira, I.S., Martins, L. L., da Silva, W.J., Nabout, J.C.	Phytoplankton
UFG29865	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	04/06/2004	15°17'57" S; 51°10'7" W	ISN876	Nogueira, I.S., Martins, L. L., da Silva, W.J., Nabout, J.C.	Phytoplankton
UFG29866	Brazil, State of Goiás, Britânia, Lago dos Tigres, Santo Antônio Farm, Site 4	04/06/2004	15°16'17" S; 51°9'10" W	ISN877	Nogueira, I.S., Martins, L. L., da Silva, W.J., Nabout, J.C.	Phytoplankton
UFG29867	Brazil, State of Goiás, Britânia, Lago dos Tigres, harbor ferry, Site 6	04/06/2004	15°15'12" S; 51°8'33" W	ISN878	Nogueira, I.S., Martins, L. L., da Silva, W.J., Nabout, J.C.	Phytoplankton
UFG29868	Brazil, State of Goiás, Britânia, Lago dos Tigres, Lago dos Tigres Farm, Site 7	04/06/2004	15°14'17" S; 51°8'59" W	ISN879	Nogueira, I.S., Martins, L. L., da Silva, W.J., Nabout, J.C.	Phytoplankton
UFG29869	Brazil, State of Goiás, Britânia, Lago dos Tigres, city in front of the Christ, Site 8	04/06/2004	15°14'9" S; 51°9'27" W	ISN869	Nogueira, I.S., Martins, L. L., da Silva, W.J., Nabout, J.C.	Phytoplankton
UFG29870	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of the "lake" in Vermelho River, Site 10	04/06/2004	15°13'18" S; 51°10'6" W	ISN881	Nogueira, I.S., Martins, L. L., da Silva, W.J., Nabout, J.C.	Phytoplankton
UFG29871	Brazil, State of Goiás, Britânia, Lago dos Tigres, new channel of the Vermelho River, Site 11	04/06/2004	15°11'47" S; 51°9'57" W	ISN882	Nogueira, I.S., Martins, L. L., da Silva, W.J., Nabout, J.C.	Phytoplankton
UFG29872	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1, under macrophytes	04/06/2004	15°18'58" S; 51°9'56" W	ISN889	Nogueira, I.S., Martins, L.L., da Silva, W.J., Nabout, J.C.	Periphyton
UFG29873	Brazil, State of Goiás, Britânia, Lago dos Tigres, harbor ferry, Site 6	04/06/2004	15°15'12" S; 51°8'33" W	ISN875	Nogueira, I.S., Martins, L.L., da Silva, W.J., Nabout, J.C.	Periphyton
UFG29875	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Arco-Íris Stream, Site 5	05/06/2004	15°15'46" S; 51°8'41" W	ISN891	Nogueira, I.S., Martins, L.L., da Silva, W.J., Nabout, J.C.	Periphyton
UFG29876	Brazil, State of Goiás, Britânia, Lago dos Tigres, city in front of the Christ, Site 8	05/06/2004	15°14'9" S; 51°9'27" W	ISN892	Nogueira, I.S., Martins, L.L., da Silva, W.J., Nabout, J.C.	Periphyton
UFG29877	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of the "lake" in Vermelho River, Site 10	05/06/2004	15°13'18" S; 51°10'6" W	ISN893	Nogueira, I.S., Martins, L.L., da Silva, W.J., Nabout, J.C.	Periphyton
UFG29878	Brazil, State of Goiás, Britânia, Lago dos Tigres, new channel of the Vermelho River, Site 11	05/06/2004	15°11'47" S; 51°9'57" W	ISN894	Nogueira, I.S., Martins, L.L., da Silva, W.J., Nabout, J.C.	Periphyton
UFG29880	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	13/07/2004	15°18'58" S; 51°9'56" W	ISN898	Nogueira, I.S., da Silva, W.J., Nabout, J.C., Oliveira, J.E., Jorge, V.A.	Phytoplankton
UFG29881	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	13/07/2004	15°17'57" S; 51°10'7" W	ISN899	Nogueira, I.S., da Silva, W.J., Nabout, J.C., Oliveira, J.E., Jorge, V.A.	Phytoplankton

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Table 2. Continued.

Herbarium number	Locality	Date	Coordinates	Collector number	Collectors	Habitat
UFG29882	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Luanda Stream, Santo Antônio Farm, Site 3	13/07/2004	15°16'47" S; 51°9'44" W	ISN900	Nogueira, I.S., da Silva, W.J., Nabout, J.C., Oliveira, J.E., Jorge, V.A.	Phytoplankton
UFG29883	Brazil, State of Goiás, Britânia, Lago dos Tigres, Santo Antônio Farm, Site 4	13/07/2004	15°16'17" S; 51°9'10" W	ISN901	Nogueira, I.S., da Silva, W.J., Nabout, J.C., Oliveira, J.E., Jorge, V.A.	Phytoplankton
UFG29884	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Arco-Íris Stream, Site 5	13/07/2004	15°15'46" S; 51°8'41" W	ISN902	Nogueira, I.S., da Silva, W.J., Nabout, J.C., Oliveira, J.E., Jorge, V.A.	Phytoplankton
UFG29885	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of the "lake" in Vermelho River, Site 9	13/07/2004	15°15'46" S; 51°8'41" W	ISN913	Nogueira, I.S., da Silva, W.J., Nabout, J.C., Oliveira, J.E., Jorge, V.A.	Phytoplankton
UFG29886	Brazil, State of Goiás, Britânia, Lago dos Tigres, harbor ferry, Site 6	13/07/2004	15°15'12" S; 51°8'33" W	ISN903	Nogueira, I.S., da Silva, W.J., Nabout, J.C., Oliveira, J.E., Jorge, V.A.	Phytoplankton
UFG29887	Brazil, State of Goiás, Britânia, Lago dos Tigres, Lago dos Tigres Farm, Site 7	13/07/2004	15°14'17" S; 51°8'59" W	ISN904	Nogueira, I.S., da Silva, W.J., Nabout, J.C., Oliveira, J.E., Jorge, V.A.	Phytoplankton
UFG29888	Brazil, State of Goiás, Britânia, Lago dos Tigres, city in front of the Christ, Site 8	13/07/2004	15°14'9" S; 51°9'27" W	ISN905	Nogueira, I.S., da Silva, W.J., Nabout, J.C., Oliveira, J.E., Jorge, V.A.	Phytoplankton
UFG29889	Brazil, State of Goiás, Britânia, Lago dos Tigres, downstream of the "lake", Lago dos Tigres Farm, Site 9	14/07/2004	15°13'43" S; 51°9'14" W	ISN906	Nogueira, I.S., da Silva, W.J., Nabout, J.C., Oliveira, J.E., Jorge, V.A.	Phytoplankton
UFG29890	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of the "lake" in Vermelho River, Site 10	14/07/2004	15°13'18" S; 51°10'6" W	ISN907	Nogueira, I.S., da Silva, W.J., Nabout, J.C., Oliveira, J.E., Jorge, V.A.	Phytoplankton
UFG29891	Brazil, State of Goiás, Britânia, Lago dos Tigres, new channel of the Vermelho River, Site 11	14/07/2004	15°11'47" S; 51°9'57" W	ISN908	Nogueira, I.S., da Silva, W.J., Nabout, J.C., Oliveira, J.E., Jorge, V.A.	Phytoplankton
UFG29895	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	19/08/2004	15°18'58" S; 51°9'56" W	ISN945	Nogueira, I.S., da Silva, W.J., Nabout, J.C., Oliveira, J.E., Jorge, V.A.	Phytoplankton
UFG29896	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	19/08/2004	15°17'57" S; 51°10'7" W	ISN946	Nogueira, I.S., Martins, L. L., Uto, F.N., Nabout, J.C.	Phytoplankton
UFG29897	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Luanda Stream, Santo Antônio Farm, Site 3	19/08/2004	15°16'47" S; 51°9'44" W	ISN947	Nogueira, I.S., Martins, L. L., Uto, F.N., Nabout, J.C.	Phytoplankton
UFG29898	Brazil, State of Goiás, Britânia, Lago dos Tigres, Santo Antônio Farm, Site 4	19/08/2004	15°16'17" S; 51°9'10" W	ISN948	Nogueira, I.S., Martins, L. L., Uto, F.N., Nabout, J.C.	Phytoplankton

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Table 2. Continued.

Herbarium number	Locality	Date	Coordinates	Collector number	Collectors	Habitat
UFG29899	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Arco-Íris Stream, Site 5	19/08/2004	15°15'46" S; 51°8'41" W	ISN949	Nogueira, I.S., Martins, L. L., Uto, F.N., Nabout, J.C.	Phytoplankton
UFG29900	Brazil, State of Goiás, Britânia, Lago dos Tigres, harbor ferry, Site 6	19/08/2004	15°15'12" S; 51°8'33" W	ISN950	Nogueira, I.S., Martins, L. L., Uto, F.N., Nabout, J.C.	Phytoplankton
UFG29901	Brazil, State of Goiás, Britânia, Lago dos Tigres, Lago dos Tigres Farm, Site 7	19/08/2004	15°14'17" S; 51°8'59" W	ISN951	Nogueira, I.S., Martins, L. L., Uto, F.N., Nabout, J.C.	Phytoplankton
UFG29902	Brazil, State of Goiás, Britânia, Lago dos Tigres, city in front of the Christ, Site 8	19/08/2004	15°14'9" S; 51°9'27" W	ISN952	Nogueira, I.S., Martins, L. L., Uto, F.N., Nabout, J.C.	Phytoplankton
UFG29903	Brazil, State of Goiás, Britânia, Lago dos Tigres, downstream of the "lake", Lago dos Tigres Farm, Site 9	20/08/2004	15°13'43" S; 51°9'14" W	ISN953	Nogueira, I.S., Martins, L. L., Uto, F.N., Nabout, J.C.	Phytoplankton
UFG29904	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of the "lake" in Vermelho River, Site 10	20/08/2004	15°13'18" S; 51°10'6" W	ISN954	Nogueira, I.S., Martins, L. L., Uto, F.N., Nabout, J.C.	Phytoplankton
UFG29905	Brazil, State of Goiás, Britânia, Lago dos Tigres, new channel of the Vermelho River, Site 11	20/08/2004	15°11'47" S; 51°9'57" W	ISN955	Nogueira, I.S., Martins, L. L., Uto, F.N., Nabout, J.C.	Phytoplankton
UFG29907	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	09/09/2004	15°18'58" S; 51°9'56" W	ISN985	Nogueira, I.S., Martins, L. L., da Silva, W.J., Rodrigues, J.	Phytoplankton
UFG29908	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	09/09/2004	15°17'57" S; 51°10'7" W	ISN986	Nogueira, I.S., Martins, L. L., da Silva, W.J., Rodrigues, J.	Phytoplankton
UFG29909	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Luanda Stream, Santo Antônio Farm, Site 3	09/09/2004	15°16'47" S; 51°9'44" W	ISN987	Nogueira, I.S., Martins, L. L., da Silva, W.J., Rodrigues, J.	Phytoplankton
UFG29910	Brazil, State of Goiás, Britânia, Lago dos Tigres, Santo Antônio Farm, Site 4	09/09/2004	15°16'17" S; 51°9'10" W	ISN988	Nogueira, I.S., Martins, L. L., da Silva, W.J., Rodrigues, J.	Phytoplankton
UFG29911	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Arco-Íris Stream, Site 5	09/09/2004	15°15'46" S; 51°8'41" W	ISN989	Nogueira, I.S., Martins, L. L., da Silva, W.J., Rodrigues, J.	Phytoplankton
UFG29912	Brazil, State of Goiás, Britânia, Lago dos Tigres, harbor ferry, Site 6	09/09/2004	15°15'12" S; 51°8'33" W	ISN990	Nogueira, I.S., Martins, L. L., da Silva, W.J., Rodrigues, J.	Phytoplankton
UFG29913	Brazil, State of Goiás, Britânia, Lago dos Tigres, Lago dos Tigres Farm, Site 7	09/09/2004	15°14'17" S; 51°8'59" W	ISN991	Nogueira, I.S., Martins, L. L., da Silva, W.J., Rodrigues, J.	Phytoplankton

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Table 2. Continued.

Herbarium number	Locality	Date	Coordinates	Collector number	Collectors	Habitat
UFG29914	Brazil, State of Goiás, Britânia, Lago dos Tigres, city in front of the Christ, Site 8	09/09/2004	15°14'9" S; 51°9'27" W	ISN992	Nogueira, I.S., Martins, L. L., da Silva, W.J., Rodrigues, J.	Phytoplankton
UFG29915	Brazil, State of Goiás, Britânia, Lago dos Tigres, downstream of the "lake", Lago dos Tigres Farm, Site 9	10/09/2004	15°13'43" S; 51°9'14" W	ISN993	Nogueira, I.S., Martins, L. L., da Silva, W.J., Rodrigues, J.	Phytoplankton
UFG29916	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of the "lake" in Vermelho River, Site 10	10/09/2004	15°13'18" S; 51°10'6" W	ISN994	Nogueira, I.S., Martins, L. L., da Silva, W.J., Rodrigues, J.	Phytoplankton
UFG29917	Brazil, State of Goiás, Britânia, Lago dos Tigres, new channel of the Vermelho River, Site 11	10/09/2004	15°11'47" S; 51°9'57" W	ISN995	Nogueira, I.S., Martins, L. L., da Silva, W.J., Rodrigues, J.	Phytoplankton
UFG29918	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	16/10/2004	15°18'58" S; 51°9'56" W	ISN1023	Nogueira, I.S., Nabout, J.C., Oliveira, J.E., Valente, C.	Phytoplankton
UFG29919	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	16/10/2004	15°17'57" S; 51°10'7" W	ISN1024	Nogueira, I.S., Nabout, J.C., Oliveira, J.E., Valente, C.	Phytoplankton
UFG29920	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Luanda Stream, Santo Antônio Farm, Site 3	16/10/2004	15°16'47" S; 51°9'44" W	ISN1025	Nogueira, I.S., Nabout, J.C., Oliveira, J.E., Valente, C.	Phytoplankton
UFG29921	Brazil, State of Goiás, Britânia, Lago dos Tigres, Santo Antônio Farm, Site 4	16/10/2004	15°16'17" S; 51°9'10" W	ISN1026	Nogueira, I.S., Nabout, J.C., Oliveira, J.E., Valente, C.	Phytoplankton
UFG29922	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Arco-Íris Stream, Site 5	16/10/2004	15°15'46" S; 51°8'41" W	ISN1027	Nogueira, I.S., Nabout, J.C., Oliveira, J.E., Valente, C.	Phytoplankton
UFG29923	Brazil, State of Goiás, Britânia, Lago dos Tigres, harbor ferry, Site 6	16/10/2004	15°15'12" S; 51°8'33" W	ISN1028	Nogueira, I.S., Nabout, J.C., Oliveira, J.E., Valente, C.	Phytoplankton
UFG29924	Brazil, State of Goiás, Britânia, Lago dos Tigres, Lago dos Tigres Farm, Site 7	16/10/2004	15°14'17" S; 51°8'59" W	ISN1029	Nogueira, I.S., Nabout, J.C., Oliveira, J.E., Valente, C.	Phytoplankton
UFG29925	Brazil, State of Goiás, Britânia, Lago dos Tigres, city in front of the Christ, Site 8	16/10/2004	15°14'9" S; 51°9'27" W	ISN1030	Nogueira, I.S., Nabout, J.C., Oliveira, J.E., Valente, C.	Phytoplankton
UFG29926	Brazil, State of Goiás, Britânia, Lago dos Tigres, downstream of the "lake", Lago dos Tigres Farm, Site 9	17/10/2004	15°13'43" S; 51°9'14" W	ISN1031	Nogueira, I.S., Nabout, J.C., Oliveira, J.E., Valente, C.	Phytoplankton
UFG29927	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of the "lake" in Vermelho River, Site 10	17/10/2004	15°13'18" S; 51°10'6" W	ISN1032	Nogueira, I.S., Nabout, J.C., Oliveira, J.E., Valente, C.	Phytoplankton

Continued on next page

Table 2. Continued.

Herbarium number	Locality	Date	Coordinates	Collector number	Collectors	Habitat
UFG29928	Brazil, State of Goiás, Britânia, Lago dos Tigres, new channel of the Vermelho River, Site 11	17/10/2004	15°11'47" S; 51°9'57" W	ISN1033	Nogueira, I.S., Nabout, J.C., Oliveira, J.E., Valente, C.	Phytoplankton
UFG29929	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	05/11/2004	15°18'58" S; 51°9'56" W	ISN1115	Nogueira, I.S., Martins, L. L., da Silva, W.J., Uto, F.N.	Phytoplankton
UFG29930	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	05/11/2004	15°17'57" S; 51°10'7" W	ISN1116	Nogueira, I.S., Martins, L. L., da Silva, W.J., Uto, F.N.	Phytoplankton
UFG29931	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Luanda Stream, Santo Antônio Farm, Site 3	05/11/2004	15°16'47" S; 51°9'44" W	ISN1117	Nogueira, I.S., Martins, L. L., da Silva, W.J., Uto, F.N.	Phytoplankton
UFG29932	Brazil, State of Goiás, Britânia, Lago dos Tigres, Santo Antônio Farm, Site 4	05/11/2004	15°16'17" S; 51°9'10" W	ISN1118	Nogueira, I.S., Martins, L. L., da Silva, W.J., Uto, F.N.	Phytoplankton
UFG29933	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Arco-Íris Stream, Site 5	05/11/2004	15°15'46" S; 51°8'41" W	ISN1119	Nogueira, I.S., Martins, L. L., da Silva, W.J., Uto, F.N.	Phytoplankton
UFG29934	Brazil, State of Goiás, Britânia, Lago dos Tigres, harbor ferry, Site 6	05/11/2004	15°15'12" S; 51°8'33" W	ISN1120	Nogueira, I.S., Martins, L. L., da Silva, W.J., Uto, F.N.	Phytoplankton
UFG29935	Brazil, State of Goiás, Britânia, Lago dos Tigres, Lago dos Tigres Farm, Site 7	05/11/2004	15°14'17" S; 51°8'59" W	ISN1121	Nogueira, I.S., Martins, L. L., da Silva, W.J., Uto, F.N.	Phytoplankton
UFG29936	Brazil, State of Goiás, Britânia, Lago dos Tigres, city in front of the Christ, Site 8	05/11/2004	15°14'9" S; 51°9'27" W	ISN1122	Nogueira, I.S., Martins, L. L., da Silva, W.J., Uto, F.N.	Phytoplankton
UFG29937	Brazil, State of Goiás, Britânia, Lago dos Tigres, downstream of the "lake", Lago dos Tigres Farm, Site 9	06/11/2004	15°13'43" S; 51°9'14" W	ISN1123	Nogueira, I.S., Martins, L. L., da Silva, W.J., Uto, F.N.	Phytoplankton
UFG29938	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of the "lake" in Vermelho River, Site 10	06/11/2004	15°13'18" S; 51°10'6" W	ISN1124	Nogueira, I.S., Martins, L. L., da Silva, W.J., Uto, F.N.	Phytoplankton
UFG29939	Brazil, State of Goiás, Britânia, Lago dos Tigres, new channel of the Vermelho River, Site 11	06/11/2004	15°11'47" S; 51°9'57" W	ISN1125	Nogueira, I.S., Martins, L. L., da Silva, W.J., Uto, F.N.	Phytoplankton
UFG29940	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	13/07/2004	15°18'58" S; 51°9'56" W	ISN934	Nogueira, I.S., da Silva, W.J., Nabout, J. C., Oliveira, J.E., Jorge, V.A	Periphyton
UFG29941	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	13/07/2004	15°17'57" S; 51°10'7" W	ISN935	Nogueira, I.S., da Silva, W.J., Nabout, J. C., Oliveira, J.E., Jorge, V.A	Periphyton
UFG29942	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	13/07/2004	15°17'57" S; 51°10'7" W	ISN936	Nogueira, I.S., da Silva, W.J., Nabout, J. C., Oliveira, J.E., Jorge, V.A	Periphyton

Continued on next page

Table 2. Continued.

Herbarium number	Locality	Date	Coordinates	Collector number	Collectors	Habitat
UFG29943	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	13/07/2004	15°18'58" S; 51°9'56" W	ISN937	Nogueira, I.S., da Silva, W.J., Nabout, J. C., Oliveira, J.E., Jorge, V.A	Periphyton
UFG29944	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	13/07/2004	15°17'57" S; 51°10'7" W	ISN938	Nogueira, I.S., da Silva, W.J., Nabout, J. C., Oliveira, J.E., Jorge, V.A	Periphyton
UFG29946	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	19/08/2004	15°18'58" S; 51°9'56" W	ISN973	Nogueira, I.S., Martins, L.L., Uto, F. N., Nabout, J.C.	Periphyton
UFG29947	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	19/08/2004	15°18'58" S; 51°9'56" W	ISN974	Nogueira, I.S., Martins, L.L., Uto, F. N., Nabout, J.C.	Periphyton
UFG29948	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	19/08/2004	15°18'58" S; 51°9'56" W	ISN975	Nogueira, I.S., Martins, L.L., Uto, F. N., Nabout, J.C.	Periphyton
UFG29949	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	19/08/2004	15°18'58" S; 51°9'56" W	ISN976	Nogueira, I.S., Martins, L.L., Uto, F. N., Nabout, J.C.	Periphyton
UFG29950	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	19/08/2004	15°17'57" S; 51°10'7" W	ISN977	Nogueira, I.S., Martins, L.L., Uto, F. N., Nabout, J.C.	Periphyton
UFG29951	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	19/08/2004	15°17'57" S; 51°10'7" W	ISN978	Nogueira, I.S., Martins, L.L., Uto, F. N., Nabout, J.C.	Periphyton
UFG29952	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	09/09/2004	15°18'58" S; 51°9'56" W	ISN1013	Nogueira, I.S., Martins, L.L., da Silva, W.J., Rodrigues, J.	Periphyton
UFG29953	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	09/09/2004	15°18'58" S; 51°9'56" W	ISN1014	Nogueira, I.S., Martins, L.L., da Silva, W.J., Rodrigues, J.	Periphyton
UFG29954	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	09/09/2004	15°18'58" S; 51°9'56" W	ISN1015	Nogueira, I.S., Martins, L.L., da Silva, W.J., Rodrigues, J.	Periphyton
UFG29955	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	09/09/2004	15°17'57" S; 51°10'7" W	ISN1016	Nogueira, I.S., Martins, L.L., da Silva, W.J., Rodrigues, J.	Periphyton
UFG29956	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	09/09/2004	15°17'57" S; 51°10'7" W	ISN1017	Nogueira, I.S., Martins, L.L., da Silva, W.J., Rodrigues, J.	Periphyton
UFG29957	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	16/10/2004	15°18'58" S; 51°9'56" W	ISN1126	Nogueira, I.S., Nabout, J.C., Oliveira, J.E., Valente, C.	Periphyton
UFG29958	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	16/10/2004	15°18'58" S; 51°9'56" W	ISN1127	Nogueira, I.S., Nabout, J.C., Oliveira, J.E., Valente, C.	Periphyton

Continued on next page

Table 2. Continued.

Herbarium number	Locality	Date	Coordinates	Collector number	Collectors	Habitat
UFG29959	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	16/10/2004	15°17'57" S; 51°10'7" W	ISN1128	Nogueira, I.S., Nabout, J.C., Oliveira, J.E., Valente, C.	Periphyton
UFG29960	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	16/10/2004	15°17'57" S; 51°10'7" W	ISN1129	Nogueira, I.S., Nabout, J.C., Oliveira, J.E., Valente, C.	Periphyton
UFG29961	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	16/10/2004	15°17'57" S; 51°10'7" W	ISN1130	Nogueira, I.S., Nabout, J.C., Oliveira, J.E., Valente, C.	Periphyton
UFG29962	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	16/10/2004	15°17'57" S; 51°10'7" W	ISN1131	Nogueira, I.S., Nabout, J.C., Oliveira, J.E., Valente, C.	Periphyton
UFG29963	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	05/11/2004	15°18'58" S; 51°9'56" W	ISN1132	Nogueira, I.S., Martins, L.L., da Silva, W.J., Uto, F.N.	Periphyton
UFG29964	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	05/11/2004	15°18'58" S; 51°9'56" W	ISN1133	Nogueira, I.S., Martins, L.L., da Silva, W.J., Uto, F.N.	Periphyton
UFG29965	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	05/11/2004	15°18'58" S; 51°9'56" W	ISN1134	Nogueira, I.S., Martins, L.L., da Silva, W.J., Uto, F.N.	Periphyton
UFG29966	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	05/11/2004	15°18'58" S; 51°9'56" W	ISN1135	Nogueira, I.S., Martins, L.L., da Silva, W.J., Uto, F.N.	Periphyton
UFG29967	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	05/11/2004	15°17'57" S; 51°10'7" W	ISN1136	Nogueira, I.S., Martins, L.L., da Silva, W.J., Uto, F.N.	Periphyton
UFG29968	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	05/11/2004	15°17'57" S; 51°10'7" W	ISN1137	Nogueira, I.S., Martins, L.L., da Silva, W.J., Uto, F.N.	Periphyton
UFG29969	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	05/11/2004	15°17'57" S; 51°10'7" W	ISN1138	Nogueira, I.S., Martins, L.L., da Silva, W.J., Uto, F.N.	Periphyton
UFG29970	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	05/11/2004	15°17'57" S; 51°10'7" W	ISN1139	Nogueira, I.S., Martins, L.L., da Silva, W.J., Uto, F.N.	Periphyton
UFG29973	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1, under macrophytes	04/06/2004	15°18'58" S; 51°9'56" W	ISN873	Nogueira, I.S., Martins, L.L., da Silva, W.J., Nabout, J.C.	Periphyton
UFG43636	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	17/07/2008	15°18'58" S; 51°9'56" W	ISN1226	Nogueira, I.S.	Phytoplankton
UFG43637	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	17/07/2008	15°17'57" S; 51°10'7" W	ISN1227	Nogueira, I.S.	Phytoplankton
UFG43638	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Luanda Stream, Santo Antônio Farm, Site 3	17/07/2008	15°16'47" S; 51°9'44" W	ISN1228	Nogueira, I.S.	Phytoplankton

Continued on next page

Table 2. Continued.

Herbarium number	Locality	Date	Coordinates	Collector number	Collectors	Habitat
UFG43639	Brazil, State of Goiás, Britânia, Lago dos Tigres, Santo Antônio Farm, Site 4	17/07/2008	15°16'17" S; 51°9'10" W	ISN1229	Nogueira, I.S.	Phytoplankton
UFG43640	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Arco-Íris Stream, Site 5	17/07/2008	15°15'46" S; 51°8'41" W	ISN1230	Nogueira, I.S.	Phytoplankton
UFG43641	Brazil, State of Goiás, Britânia, Lago dos Tigres, harbor ferry, Site 6	17/07/2008	15°15'12" S; 51°8'33" W	ISN1231	Nogueira, I.S.	Phytoplankton
UFG43642	Brazil, State of Goiás, Britânia, Lago dos Tigres, Lago dos Tigres Farm, Site 7	17/07/2008	15°14'17" S; 51°8'59" W	ISN1232	Nogueira, I.S.	Phytoplankton
UFG43643	Brazil, State of Goiás, Britânia, Lago dos Tigres, city in front of the Christ, Site 8	17/07/2008	15°14'9" S; 51°9'27" W	ISN1233	Nogueira, I.S.	Phytoplankton
UFG43644	Brazil, State of Goiás, Britânia, Lago dos Tigres, downstream of the "lake", Lago dos Tigres Farm, Site 9	18/07/2008	15°13'43" S; 51°9'14" W	ISN1234	Nogueira, I.S.	Phytoplankton
UFG43645	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of the "lake" in Vermelho River, Site 10	18/07/2008	15°13'18" S; 51°10'6" W	ISN1235	Nogueira, I.S.	Phytoplankton
UFG43646	Brazil, State of Goiás, Britânia, Lago dos Tigres, new channel of the Vermelho River, Site 11	18/07/2008	15°11'47" S; 51°9'57" W	ISN1236	Nogueira, I.S.	Phytoplankton
UFG43649	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	19/08/2008	15°18'58" S; 51°9'56" W	ISN1239	Nogueira, I.S.	Phytoplankton
UFG43650	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	19/08/2008	15°17'57" S; 51°10'7" W	ISN1240	Nogueira, I.S.	Phytoplankton
UFG43651	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Luanda Stream, Santo Antônio Farm, Site 3	19/08/2008	15°16'47" S; 51°9'44" W	ISN1241	Nogueira, I.S.	Phytoplankton
UFG43652	Brazil, State of Goiás, Britânia, Lago dos Tigres, Santo Antônio Farm, Site 4	19/08/2008	15°16'17" S; 51°9'10" W	ISN1242	Nogueira, I.S.	Phytoplankton
UFG43653	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Arco-Íris Stream, Site 5	19/08/2008	15°15'46" S; 51°8'41" W	ISN1243	Nogueira, I.S.	Phytoplankton
UFG43654	Brazil, State of Goiás, Britânia, Lago dos Tigres, harbor ferry, Site 6	19/08/2008	15°15'12" S; 51°8'33" W	ISN1244	Nogueira, I.S.	Phytoplankton
UFG43655	Brazil, State of Goiás, Britânia, Lago dos Tigres, Lago dos Tigres Farm, Site 7	19/08/2008	15°14'17" S; 51°8'59" W	ISN1245	Nogueira, I.S.	Phytoplankton
UFG43656	Brazil, State of Goiás, Britânia, Lago dos Tigres, city in front of the Christ, Site 8	19/08/2008	15°14'9" S; 51°9'27" W	ISN1246	Nogueira, I.S.	Phytoplankton

Continued on next page

Table 2. Continued.

Herbarium number	Locality	Date	Coordinates	Collector number	Collectors	Habitat
UFG43657	Brazil, State of Goiás, Britânia, Lago dos Tigres, downstream of the "lake", Lago dos Tigres Farm, Site 9	20/08/2008	15°13'43" S; 51°9'14" W	ISN1247	Nogueira, I.S.	Phytoplankton
UFG43658	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of the "lake" in Vermelho River, Site 10	20/08/2008	15°13'18" S; 51°10'6" W	ISN1248	Nogueira, I.S.	Phytoplankton
UFG43659	Brazil, State of Goiás, Britânia, Lago dos Tigres, new channel of the Vermelho River, Site 11	20/08/2008	15°11'47" S; 51°9'57" W	ISN1249	Nogueira, I.S.	Phytoplankton
UFG43662	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	16/09/2008	15°18'58" S; 51°9'56" W	ISN1252	Nogueira, I.S.	Phytoplankton
UFG43663	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	16/09/2008	15°17'57" S; 51°10'7" W	ISN1253	Nogueira, I.S.	Phytoplankton
UFG43664	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Luanda Stream, Santo Antônio Farm, Site 3	16/09/2008	15°16'47" S; 51°9'44" W	ISN1254	Nogueira, I.S.	Phytoplankton
UFG43665	Brazil, State of Goiás, Britânia, Lago dos Tigres, Santo Antônio Farm, Site 4	16/09/2008	15°16'17" S; 51°9'10" W	ISN1255	Nogueira, I.S.	Phytoplankton
UFG43666	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Arco-Íris Stream, Site 5	16/09/2008	15°15'46" S; 51°8'41" W	ISN1256	Nogueira, I.S.	Phytoplankton
UFG43667	Brazil, State of Goiás, Britânia, Lago dos Tigres, harbor ferry, Site 6	16/09/2008	15°15'12" S; 51°8'33" W	ISN1257	Nogueira, I.S.	Phytoplankton
UFG43668	Brazil, State of Goiás, Britânia, Lago dos Tigres, Lago dos Tigres Farm, Site 7	16/09/2008	15°14'17" S; 51°8'59" W	ISN1258	Nogueira, I.S.	Phytoplankton
UFG43669	Brazil, State of Goiás, Britânia, Lago dos Tigres, city in front of the Christ, Site 8	16/09/2008	15°14'9" S; 51°9'27" W	ISN1259	Nogueira, I.S.	Phytoplankton
UFG43670	Brazil, State of Goiás, Britânia, Lago dos Tigres, downstream of the "lake", Lago dos Tigres Farm, Site 9	17/09/2008	15°13'43" S; 51°9'14" W	ISN1260	Nogueira, I.S.	Phytoplankton
UFG43671	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of the "lake" in Vermelho River, Site 10	17/09/2008	15°13'18" S; 51°10'6" W	ISN1261	Nogueira, I.S.	Phytoplankton
UFG43672	Brazil, State of Goiás, Britânia, Lago dos Tigres, new channel of the Vermelho River, Site 11	17/09/2008	15°11'47" S; 51°9'57" W	ISN1262	Nogueira, I.S.	Phytoplankton
UFG43675	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	19/10/2008	15°18'58" S; 51°9'56" W	ISN1265	Nogueira, I.S.	Phytoplankton
UFG43676	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	19/10/2008	15°17'57" S; 51°10'7" W	ISN1266	Nogueira, I.S.	Phytoplankton

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http://dx.doi.org/10.1590/1676-0611-BN-2015-0028

Table 2. Continued.

Herbarium number	Locality	Date	Coordinates	Collector number	Collectors	Habitat
UFG43677	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Luanda Stream, Santo Antônio Farm, Site 3	19/10/2008	15°16'47" S; 51°9'44" W	ISN1267	Nogueira, I.S.	Phytoplankton
UFG43678	Brazil, State of Goiás, Britânia, Lago dos Tigres, Santo Antônio Farm, Site 4	19/10/2008	15°16'17" S; 51°9'10" W	ISN1268	Nogueira, I.S.	Phytoplankton
UFG43679	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Arco-Íris Stream, Site 5	19/10/2008	15°15'46" S; 51°8'41" W	ISN1269	Nogueira, I.S.	Phytoplankton
UFG43680	Brazil, State of Goiás, Britânia, Lago dos Tigres, harbor ferry, Site 6	19/10/2008	15°15'12" S; 51°8'33" W	ISN1270	Nogueira, I.S.	Phytoplankton
UFG43681	Brazil, State of Goiás, Britânia, Lago dos Tigres, Lago dos Tigres Farm, Site 7	19/10/2008	15°14'17" S; 51°8'59" W	ISN1271	Nogueira, I.S.	Phytoplankton
UFG43682	Brazil, State of Goiás, Britânia, Lago dos Tigres, city in front of the Christ, Site 8	19/10/2008	15°14'9" S; 51°9'27" W	ISN1272	Nogueira, I.S.	Phytoplankton
UFG43683	Brazil, State of Goiás, Britânia, Lago dos Tigres, downstream of the "lake", Lago dos Tigres Farm, Site 9	20/10/2008	15°13'43" S; 51°9'14" W	ISN1273	Nogueira, I.S.	Phytoplankton
UFG43684	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of the "lake" in Vermelho River, Site 10	20/10/2008	15°13'18" S; 51°10'6" W	ISN1274	Nogueira, I.S.	Phytoplankton
UFG43685	Brazil, State of Goiás, Britânia, Lago dos Tigres, new channel of the Vermelho River, Site 11	20/10/2008	15°11'47" S; 51°9'57" W	ISN1275	Nogueira, I.S.	Phytoplankton
UFG43688	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	15/11/2008	15°18'58" S; 51°9'56" W	ISN1278	Nogueira, I.S.	Phytoplankton
UFG43689	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	15/11/2008	15°17'57" S; 51°10'7" W	ISN1279	Nogueira, I.S.	Phytoplankton
UFG43690	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Luanda Stream, Santo Antônio Farm, Site 3	15/11/2008	15°16'47" S; 51°9'44" W	ISN1280	Nogueira, I.S.	Phytoplankton
UFG43691	Brazil, State of Goiás, Britânia, Lago dos Tigres, Santo Antônio Farm, Site 4	15/11/2008	15°16'17" S; 51°9'10" W	ISN1281	Nogueira, I.S.	Phytoplankton
UFG43692	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Arco-Íris Stream, Site 5	15/11/2008	15°15'46" S; 51°8'41" W	ISN1282	Nogueira, I.S.	Phytoplankton
UFG43693	Brazil, State of Goiás, Britânia, Lago dos Tigres, harbor ferry, Site 6	15/11/2008	15°15'12" S; 51°8'33" W	ISN1283	Nogueira, I.S.	Phytoplankton
UFG43694	Brazil, State of Goiás, Britânia, Lago dos Tigres, Lago dos Tigres Farm, Site 7	15/11/2008	15°14'17" S; 51°8'59" W	ISN1284	Nogueira, I.S.	Phytoplankton

Continued on next page

Table 2. Continued.

Herbarium number	Locality	Date	Coordinates	Collector number	Collectors	Habitat
UFG43695	Brazil, State of Goiás, Britânia, Lago dos Tigres, city in front of the Christ, Site 8	15/11/2008	15°14'9" S; 51°9'27" W	ISN1285	Nogueira, I.S.	Phytoplankton
UFG43696	Brazil, State of Goiás, Britânia, Lago dos Tigres, downstream of the "lake", Lago dos Tigres Farm, Site 9	16/11/2008	15°13'43" S; 51°9'14" W	ISN1286	Nogueira, I.S.	Phytoplankton
UFG43697	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of the "lake" in Vermelho River, Site 10	16/11/2008	15°13'18" S; 51°10'6" W	ISN1287	Nogueira, I.S.	Phytoplankton
UFG43698	Brazil, State of Goiás, Britânia, Lago dos Tigres, new channel of the Vermelho River, Site 11	16/11/2008	15°11'47" S; 51°9'57" W	ISN1288	Nogueira, I.S.	Phytoplankton
UFG43701	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	11/12/2008	15°18'58" S; 51°9'56" W	ISN1291	Nogueira, I.S.	Phytoplankton
UFG43702	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	11/12/2008	15°17'57" S; 51°10'7" W	ISN1292	Nogueira, I.S.	Phytoplankton
UFG43703	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Luanda Stream, Santo Antônio Farm, Site 3	11/12/2008	15°16'47" S; 51°9'44" W	ISN1293	Nogueira, I.S.	Phytoplankton
UFG43704	Brazil, State of Goiás, Britânia, Lago dos Tigres, Santo Antônio Farm, Site 4	11/12/2008	15°16'17" S; 51°9'10" W	ISN1294	Nogueira, I.S.	Phytoplankton
UFG43705	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Arco-Íris Stream, Site 5	11/12/2008	15°15'46" S; 51°8'41" W	ISN1295	Nogueira, I.S.	Phytoplankton
UFG43706	Brazil, State of Goiás, Britânia, Lago dos Tigres, harbor ferry, Site 6	11/12/2008	15°15'12" S; 51°8'33" W	ISN1296	Nogueira, I.S.	Phytoplankton
UFG43707	Brazil, State of Goiás, Britânia, Lago dos Tigres, Lago dos Tigres Farm, Site 7	11/12/2008	15°14'17" S; 51°8'59" W	ISN1297	Nogueira, I.S.	Phytoplankton
UFG43708	Brazil, State of Goiás, Britânia, Lago dos Tigres, city in front of the Christ, Site 8	11/12/2008	15°14'9" S; 51°9'27" W	ISN1298	Nogueira, I.S.	Phytoplankton
UFG43709	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of the "lake" in Vermelho River, Site 9	12/12/2008	15°13'43" S; 51°9'14" W	ISN1299	Nogueira, I.S.	Phytoplankton
UFG43710	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of the "lake" in Vermelho River, Site 10	12/12/2008	15°13'18" S; 51°10'6" W	ISN1300	Nogueira, I.S.	Phytoplankton
UFG43711	Brazil, State of Goiás, Britânia, Lago dos Tigres, new channel of the Vermelho River, Site 11	12/12/2008	15°11'47" S; 51°9'57" W	ISN1301	Nogueira, I.S.	Phytoplankton
UFG43714	Brazil, State of Goiás, Britânia, Água Limpa River, Água Limpa Farm, Site 1	21/01/2009	15°18'58" S; 51°9'56" W	ISN1304	Nogueira, I.S.	Phytoplankton

Continued on next page

Table 2. Continued.

Herbarium number	Locality	Date	Coordinates	Collector number	Collectors	Habitat
UFG43715	Brazil, State of Goiás, Britânia, Lago dos Tigres, Perdidas Island, Site 2	21/01/2009	15°17'57" S; 51°10'7" W	ISN1305	Nogueira, I.S.	Phytoplankton
UFG43716	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Luanda Stream, Santo Antônio Farm, Site 3	21/01/2009	15°16'47" S; 51°9'44" W	ISN1306	Nogueira, I.S.	Phytoplankton
UFG43717	Brazil, State of Goiás, Britânia, Lago dos Tigres, Santo Antônio Farm, Site 4	21/01/2009	15°16'17" S; 51°9'10" W	ISN1307	Nogueira, I.S.	Phytoplankton
UFG43718	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of Arco-Íris Stream, Site 5	21/01/2009	15°15'46" S; 51°8'41" W	ISN1308	Nogueira, I.S.	Phytoplankton
UFG43719	Brazil, State of Goiás, Britânia, Lago dos Tigres, harbor ferry, Site 6	21/01/2009	15°15'12" S; 51°8'33" W	ISN1309	Nogueira, I.S.	Phytoplankton
UFG43720	Brazil, State of Goiás, Britânia, Lago dos Tigres, Lago dos Tigres Farm, Site 7	21/01/2009	15°14'17" S; 51°8'59" W	ISN1310	Nogueira, I.S.	Phytoplankton
UFG43721	Brazil, State of Goiás, Britânia, Lago dos Tigres, city in front of the Christ, Site 8	21/01/2009	15°14'9" S; 51°9'27" W	ISN1311	Nogueira, I.S.	Phytoplankton
UFG43722	Brazil, State of Goiás, Britânia, Lago dos Tigres, downstream of the "lake", Lago dos Tigres Farm, Site 9	22/01/2009	15°13'43" S; 51°9'14" W	ISN1312	Nogueira, I.S.	Phytoplankton
UFG43723	Brazil, State of Goiás, Britânia, Lago dos Tigres, outfall of the "lake" in Vermelho River, Site 10	22/01/2009	15°13'18" S; 51°10'6" W	ISN1313	Nogueira, I.S.	Phytoplankton
UFG43724	Brazil, State of Goiás, Britânia, Lago dos Tigres, new channel of the Vermelho River, Site 11	22/01/2009	15°11'47" S; 51°9'57" W	ISN1314	Nogueira, I.S.	Phytoplankton

Distribution. Brazil, State of São Paulo, São Paulo, Parque Estadual das Fontes do Ipiranga (Rocha & Bicudo 2008); Pioneer citation for the State of Goiás.

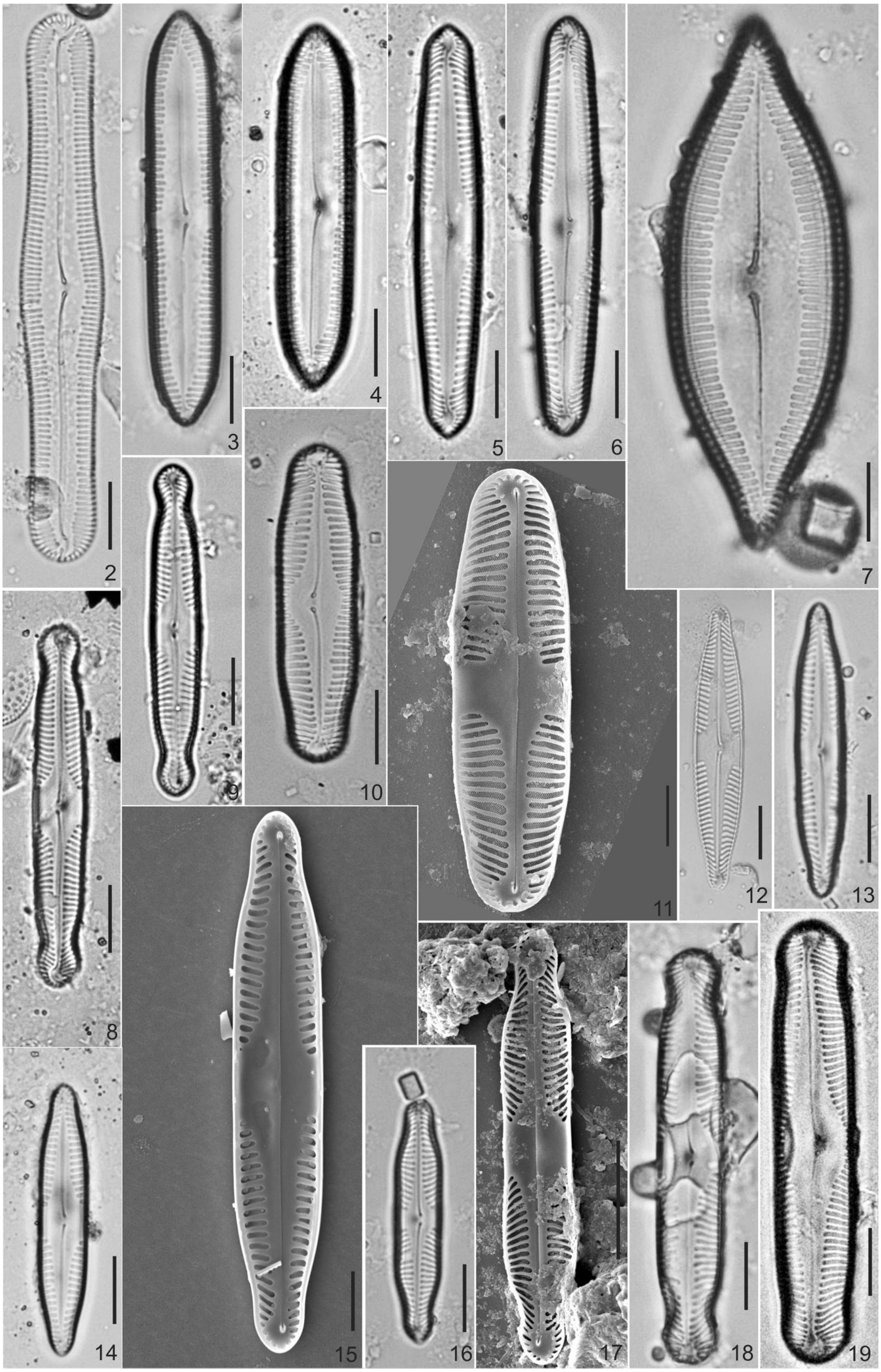
Remarks. Krammer (2000, p. 55, 214) cited in the original description the specimens recorded on “Figs. 21: 8, 9” as representatives of *P. acrophaeria* var. *tumidula*. However, in the legend of these figures, Krammer (2000, p. 300) cited “Figs. 8, 9. *Pinnularia acrosphaeria* var. *turgidula* Grunow ex Cleve (p. 55)”. Krammer (2000, p. 300) still described the specimens recorded on the figures 8 and 9 originally from “Nelubium pond in the botanical garden Munich, slide 1792 MR) which corresponds to the type and type locality of *P. acrosphaeria* var. *tumidula* (and not *P. acrosphaeria* var. *turgidula*), i.e., “Nelubium pond in the botanical garden Munich, slide 1792 MR” (see Krammer 2000, p. 55, 214). Because the agreement with the type and type locality and with the original description of the taxa, we concluded that the description of the legend is, actually, a typographic error that can be corrected. In contrast, if it was not accepted as typographic error, the taxon would not be valid because was published without an illustration as required by Art. 44.2 of the ICN (McNeill et al., 2012). Similarly, other authors seem to consider the legend of the Krammer (2000, figures 21: 8, 9) as a typographical error since has adopted the name as validly proposed (e.g., Rocha & Bicudo 2008, Montoya-Moreno et al. 2013).

The diacritical characteristic of this taxon from the nominated variety is the prominent intumescence at the middle part of the valve (Krammer 2000). The specimens found in Lago dos Tigres agreed with the original description and is very similar to the type material illustrated by Krammer (2000, figure 21: 9). Rocha & Bicudo (2008) also found *P. acrosphaeria* var. *tumidula* in the State of São Paulo, which the specimens of the Lagos dos Tigres were similar.

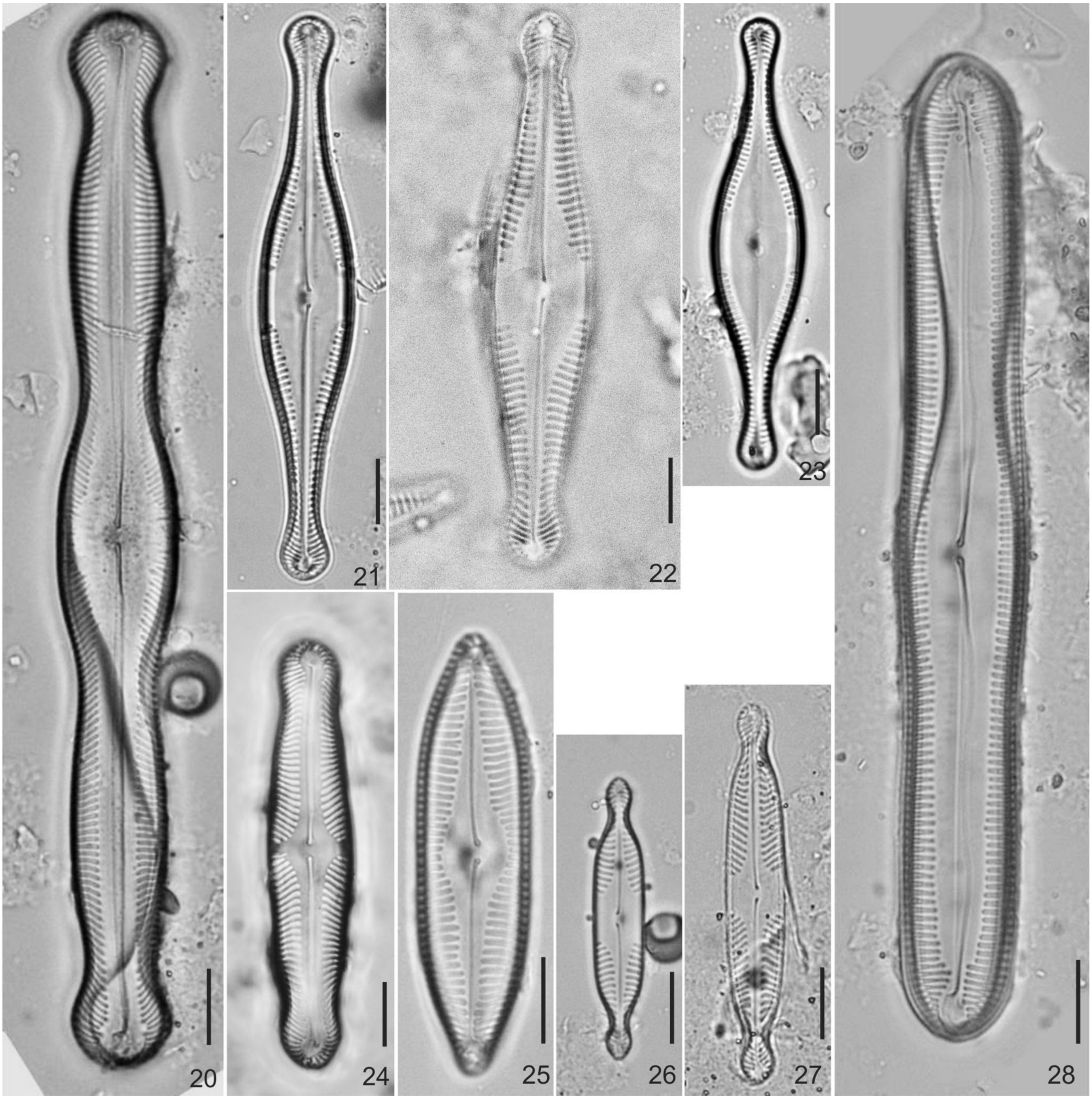
All the taxa subscribed to *P. acrophaeria* present axial area with granulations (Krammer 2000). Although this feature was observed in the representatives of *P. acrophaeria* var. *tumidula* from Lago dos Tigres, it seems to be inconspicuous during the process of microphotography (Figure 2). This seems to be the case of the representatives recorded by Rocha & Bicudo (2008, Figures 43, 44), in which the granulations were little evident in the pictures but this data was provided in the characterization of the species.

Table 3. Morphometric characteristics of the representatives of *Pinnularia* found in Lago dos Tigres System

Species	Length (µm)	Breadth (µm)	Length/breadth ratio	Striae in 10 µm	Valves	Axial area
Pinnularia acrosphaeria var. *tumidula*	79–82	12.5–12.66	6.32–6.57	12	linear, tumid at the middle part	broad, linear
Pinnularia brauniana var. *sanctipaulensis*	49.12–53.93	7.68–8.37	6.15–6.91	10–12	linear-lanceolate	somewhat rhomboid, with large fascia reaching the margins
Pinnularia certa	48–60	7–9	5.97–7.92	10–11	linear-lanceolate	lanceolate
Pinnularia cf. *acuminata*	45–61	10.5–12	4.01–5.79	10–11	linear	wide, linear-lanceolate
Pinnularia divergens var. *mesoleptiformis*	64.24–72.81	12.04–13.78	4.82–5.25	10–11	lanceolate, triundulate margins	linear
Pinnularia hudsonii	61.81–67.64	10–11	5.6–6.6	10–11	lanceolate	lanceolate, broad
Pinnularia instabilis	53.71–83.11	17.7–21.3	3.03–4.54	10	lanceolate, wide	lanceolate, broad
Pinnularia latarea	45.69–62.6	7.91–10.38	5.77–6.03	11–12	linear, with slightly undulated margins	narrowly lanceolate
Pinnularia mayeri	52	7	7.42	10–11	linear-lanceolate	linear-lanceolate
Pinnularia meridiana var. *meridiana*	43.81–62.79	8.22–11.37	4.01–6.16	11	linear, with bi-undulate margins	rhomboid
Pinnularia microstauron var. *brasiliensis*	41.14–45.79	7.22–8.6	5.37–6.57	10–11	linear, with bi-undulated margins	rhomboide
Pinnularia microstauron var. *rostrata*	35.2–36.49	6.23–7.32	4.89–5.41	10–13	linear	rhomboid
Pinnularia perumbrosa	105.49–148.22	11.13–17.88	7.78–8.78	10–12	linear, triundulate and inflamade at the middle part	linear-lanceolate
Pinnularia rostratissima f. *subundulata*	81.85–91.22	12.47–15.43	5.83–6.53	8–10	rhomboid-lanceolate, inflated at the middle part and slightly undulated margins	broad, rhomboid
Pinnularia rostratissima var. *rostratissima*	81.27–88.12	13.78–15.63	5.63–5.89	10–11	fusiform-lanceolate, strongly inflated at the middle part	broad, lanceolate
Pinnularia rostratissima var. *ventricosa*	70	15	4.66	12	fusiform-lanceolate, inflated at the middle part	fusiform
Pinnularia rumrichiae	38.17–43.24	7.12–8.01	4.81–5.92	10–12	linear	lanceolate
Pinnularia silviasalae	58.71–69.52	11.32–12.76	4.98–5.95	10–12	linear, with slightly undulated margins	indistinct from the axial area to broadly circular, almost reaching the margins
Pinnularia superpaulensis	123.2–126.7	17.14–19.33	6.41–7.01	10–11	linear, slightly tumid at middle part	lanceolate
Pinnularia variarae	49.32–54.27	13.65–15.13	3.59–3.81	9–11	linear-lanceolate, with straight margins	circular to elliptical, sometimes indistinct from the axial area



Figures 2–19. Species of *Pinnularia* from Lago dos Tigres (Figures 2–10, 12–14, 16, 18, 19: light microscopy; Figures 11, 15, 17: scanning electron microscopy); Figure 2. *Pinnularia acrosphaeria* var. *tumidula*; Figures 3, 4. *Pinnularia acuminata*; Figures 5, 6. *Pinnularia hudsonii*; Figure 7. *Pinnularia instabilis*; Figures 8, 9. *Pinnularia mayeri*, Figures 10, 11. *Pinnularia meridiana* var. *meridiana*; Figure 12. *Pinnularia certa*; Figure 13–15. *Pinnularia microstauron* var. *brasiliensis*; Figures 16–17. *Pinnularia microstauron* var. *rostrata*; Figure 18. *Pinnularia latarea*; Figure 19. *Pinnularia silviasalae*. Scale bar: Figures 2–10, 12–14, 16–19: 10 µm; Figures 11, 15: 5 µm.



Figures 20–28. Species of *Pinnularia* from Lago dos Tigres (light microscopy); Figure 20. *Pinnularia perumbrosa*; Figure 21. *Pinnularia rostratissima* var. *rostratissima*; Figure 22. *Pinnularia rostratissima* f. *subundulata*; Figure 23. *Pinnularia rostratissima* var. *ventricosa*; Figure 24. *Pinnularia divergens* var. *mesoleptiformis*; Figure 25. *Pinnularia variarae*; Figure 26. *Pinnularia rumrichiae*; Figure 27. *Pinnularia brauniana* var. *sanctipaulensis*; Figure 28. *Pinnularia superpaulensis*. Scale bar: 10 μm.

Pinnularia brauniana var. *sanctipaulensis*

A.C.R. Rocha, Hoehnea, vol. 35, n. 4, p. 603, Figs. 21–25, 2008. (Figure 27)

Holotype. Preparation SP255743 in Herbário "Maria Eneyda P. Kauffmann Fidalgo" (SP) do Instituto de Botânica da Secretaria do Meio Ambiente do Estado de São Paulo.

Type locality. Lago das Ninféias, Parque Estadual das Fontes do Ipiranga, São Paulo, State of São Paulo, Brazil.

Valves linear-lanceolate; capitate apices; length: 49.12–53.93 μm, breadth: 7.68–8.37 μm, length/breadth ratio: 6.15–6.91; axial area linear to linear-lanceolate; axial area somewhat rhomboid, with large fascia reaching the margins; raphe lateral, terminal fissures hooked, proximal fissures curved to the same side; striae radiated, becoming convergent towards to the ends of the valves; striae: 10–12/10 μm.

Material examined

Brazil, Goiás, Britânia, Lago dos Tigres, plankton, Nogueira et al., Site 11, 20/10/2008, P11M10, ISN1275 (UFG 43685).

Distribution

Brazil, State of São Paulo, São Paulo, Parque Estadual das Fontes do Ipiranga (Rocha & Bicudo 2008); Pioneer citation for the State.

Pinnularia certa

Krammer & Metzeltin, Iconogr. Diatomol., vol. 5, p. 166, Figs. 178: 12–17, 1998. (Figure 12)

Holotype. Preparation 2607c KASSEL, Collection Krasske in Naturkundemuseum im Ottoneum (KASSEL), Kassel, Germany.

Type locality. Demerara River, Guyana.

Valves linear-lanceolate; narrowly rounded apices; length: 48–60 μm, breadth: 7–9 μm, length/breadth ratio: 5.97–7.92; axial area lanceolate; central area rectangular, reaching the valvae margins; raphe lateral, proximal raphe fissures unilaterally deflected; striae short, radiate, becoming convergent towards to the ends of the valves; striae: 10–11/10 μm.

Material examined. Brazil, State of Goiás, Britânia, Lago dos Tigres, Baía das Perdidas, periphyton, Nogueira *et al.* Site 2, 13/07/2004, ISN939 (UFG 29945); Água Limpa River, plankton, Nogueira *et al.* Site 1, 09/09/2004, ISN985 (UFG 29907).

Distribution. Brazil, State of Amazonas, Lago Calado; State of Pará, Tapajós River (Metzeltin & Lange-Bertalot 1998); Pioneer citation for the State of Goiás.

Remarks. Pinnularia *certa* is very similar to *P. microstauron* var. *brasiliensis* Krammer & Metzeltin (see below), including metric characteristics as recorded in their original descriptions (Metzeltin & Lange-Bertalot 1998). However, *P. certa* presents wider central margin reaching the margins than in *P. microstauron* var. *brasiliensis*. Moreover, *P. microstauron* var. *brasiliensis* has straight and parallel margins while in *P. certa* the margins are slightly convex.

The outline of the individuals found in Lago dos Tigres was similar to *P. certa*. However, some of these representatives were longer (48–60 μm against 43–54 μm) and or narrower (7–9 μm against 8.4–9.4 μm) than the type population characterized by Metzeltin & Lange-Bertalot (1998).

Pinnularia cf. *acuminata*

W.Sm., Syn. British. Diat., vol. 1, p. 55, Fig. 18: 164, 1853. (Figures 3, 4)

Lectotype. Preparation IX-38-A7 VH, Collection Van Heurck in the Dr. Henri Van Heurck Museum (AWH), Antwerp, Belgium, designated by Krammer (2000, p. 159).

Isolectotype. Preparation 20600 BM, Collection Natural History Museum in the Natural History Museum (BM), London, England, designated by Krammer (2000, p. 159).

Type locality. Premmay Peat, Aberdeenshire, Scotland.

Valves linear, sometimes with slightly concave margins at the middle part; cuneate apices; length: 45–61 μm, breadth: 10.5–12 μm, length/breadth ratio: 4.01–5.79; axial area wide, linear-lanceolate, reaching $\frac{1}{2}$ of the breadth of the valvae; central area with thin fascia, reaching the valves margins; raphe lateral, proximal ends slightly curved to the same side; striae short, parallel, becoming slightly convergent towards to the ends of the valves; striae: 10–11/10 μm.

Material examined. Brazil, State of Goiás, Britânia, Lago dos Tigres, Baía das Perdidas, periphyton, Nogueira et al., Site 2, 13/07/2004, ISN939 (UFG 29945); Água Limpa River, plankton, Nogueira et al., Site 1, 09/09/2004, ISN985 (UFG 29907); Lago dos Tigres, plankton, Nogueira et al., Site 10, 18/07/2008, P10M07, ISN1235 (UFG 43645), Site 01, 15/11/2008, P01M11, ISN1278 (UFG 43688).

Distribution. Brazil, State of Amazonas, Negro River (Metzeltin & Lange-Bertalot 2007); State of Paraná, Guaraguaçu River (Tremarin et al. 2010); Pioneer citation for the State of Goiás.

Remarks. *P. acuminata* and *P. inconstans* Mayer presents similar outlines, but the first one has acuminate apices, wider axial area and an inconspicuous to small fascia (Krammer 2000, figures 144: 7–9). On the other hand, the neotype specimens of *P. inconstans* have more rounded ends of the valvae, narrower axial area, and a conspicuous fascia (Krammer 2000, figures 143:3–5, 11, 12). Such similarities lead to confusions concerning the identification of the two taxa in some studies of diatom flora.

Pinnularia inconstans sensu Krammer (2000, Fig 143: 10), from Demerara River, Guyana, and *P. inconstans* sensu Tremarin et al. (2010), from the State of Paraná, Brazil, for example, present more similar characteristics to the complex *P. acuminata*, specially *P. acuminata* var. *guyanensis* Metzeltin & Lange-Bert. (Metzeltin & Lange-Bertalot 2007). This taxa differs from the nominated variety because breather (9.5–10 against 12–16 μm) and smaller valves (36–42 against 40–84 μm), and higher density of striae (10–11 against 8–10 striae per 10 μm) (Metzeltin & Lange-Bertalot 2007).

The representatives of *Pinnularia* cf. *acuminata* from Lago dos Tigres were similar to *P. inconstans* sensu Krammer (2000, Fig 143: 10) and *P. inconstans* sensu Tremarin et al. (2010), and, concomitantly, to *P. acuminata* var. *guyanensis*, but presented breadth values intergrading with those of the nominated variety. The densities of striae of the specimens from Lago dos Tigres were slightly higher than *P. acuminata* var. *acuminata* but agreed with *P. acuminata* var. *guyanensis*. However, *Pinnularia* cf. *acuminata* presented a wider axial area and more cuneated valvar ends than the type of *P. acuminata*.

The outline, including valvar ends, and axial area of *Pinnularia* cf. *acuminata* was similar to *P. acuminata* var. *novaezealandica* Krammer sensu Tremarin et al. (2010). However, the representatives found in Lago dos Tigres were smaller (45–61 μm against 86.1–133.3 μm), and narrower (10.5–12 μm against 13.3–14.1 μm) than the specimens in Tremarin et al. (2010). Similarly to our representatives, *P. acuminata* var. *novaezealandica* sensu Tremarin et al. (2010, figure 9) differs from the type specimens of this taxon as illustrated by Krammer (2000, figures 148: 1–5) because presents wider axial area and more cuneated valvar ends, although agreed partially with *P. acuminata* var. *novaezealandica* [*novazealandica*] sensu Metzeltin & Lange-Bertalot (2007, Figures 262: 1–3).

The individuals from Lago dos Tigres present outline to *P. subacuminata* Krammer & Metzeltin, but still here the axial area of *Pinnularia* cf. *acuminata* was slightly narrower, the valvar ends were cuneate instead cuneate-rounded, as observed in *P. subacuminata*. Moreover, *P. subacuminata* is larger (45–61 μm against 95–115 μm) than the specimens from Lago dos Tigres.

Compared to *P. angustivalva* Krammer & Metzeltin, *Pinnularia* cf. *acuminata* present axial area slightly wider, smaller central area, margins slightly convex, and valvar ends cunead-obtuse against cuneate in the representatives os Lago dos Tigres. Some representatives of *Pinnularia* cf. *acuminata* were larger (38–54 µm against 45–61 µm) and all were wider (6.7–8 µm against 10.5–12 µm), and less densely striated (13–14/10 µm against 10–11/10µm) than *P. angustivalva*.

Other similar species is *P. instabiliformis* Krammer & Metzeltin, which also present wide axial area but the valvar ends cuneate-subrostrate (Metzeltin & Lange-Bertalot 1998, figures 8–11) or cuneate- rounded (Metzeltin & Lange-Bertalot 1998, Figures 8–12) comparing to the simply cuneate valvar ends of *Pinnularia* cf. *acuminata*. Some representatives of *Pinnularia* cf. *acuminata* were larger (36–52 µm against 45–61 µm) or slightly wider (10.4 – 11.7 µm against 10.5–12 µm) than *P. instabiliformis*.

Since Lago dos Tigres presented intermediate specimens between several taxa compared here, we identified the taxon as *Pinnularia* cf. *acuminata*, the oldest epithet and the most similar taxon of this complex. More accurate studies should be carried out in order to verify the limits and circumscription among the taxa of this complex.

Pinnularia divergens var. *mesoleptiformis*

Metzeltin e Lange-Bert., Iconogr. Diatomol, vol. 5, p. 170, Figs. 173: 1–4, 1998. (Figure 24)

Holotype. Preparation AmS-521, Collection Lange-Bertalot in Botanisches Institüt der J. W. Goethe Universität, Frankfurt/Main, Germany.

Type locality. Kaieteur-Falss, Potaro River, Guyana.

Valves lanceolate, triundulate margins; rounded apices; length: 64.24–72.81 µm, breadth: 12.04–13.78 µm, length/breadth ratio: 4.82–5.25; axial area linear; central area rhomboid, with fascia reaching the margins; raphe lateral, terminal fissures bayonet-shapes, proximal fissures curved to the same side; striae radiated, becoming convergent towards to the ends of the valves; striae: 10–11/10 µm.

Material examined. Brazil, State of Goiás, Britânia, Lago dos Tigres, plankton, Nogueira *et al.* Site 5, 04/07/2004, ISN878 (UFG 29867); Site 4, 04/06/2004, ISN877 (UFG 29866); Site 11, 17/10/2004, ISN1033 (UFG 29928);

Distribution. Brazil, State of Paraná, Guaraguaçu River (Tremarin et al. 2009, 2010); State of São Paulo, São Paulo, Parque Estadual das Fontes do Ipiranga (Rocha & Bicudo 2008); Pioneer citation for the State of Goiás.

Remarks. The specimens from Lago dos Tigres agreed with the description provided by Metzeltin & Lange-Bertalot (1998). They also were similar but smaller than those illustrated by Rocha & Bicudo (2008) and Tremarin et al. (2010).

Pinnularia hudsonii

Metzeltin, Lange-Bert. & García-Rodríguez, Iconogr. Diatomol., vol. 15, p. 156, Figs 177:1–11, 2005. (Figures 5, 6)

Holotype. Preparation Uru 2002-2, Collection Lange-Bertalot in Botanisches Institüt der J. W. Goethe Universität, Frankfurt/Main, Germany.

Type locality. Rio de La Plata, near Colonia Del Sacramento, Uruguay.

Valves lanceolate; rostrate-cuneate apices; length: 61.81–67.64 µm, breadth: 10–11 µm, length/breadth ratio: 5.6–6.6; axial area lanceolate, broad; central area with fascia, reaching the valvae margins; raphe lateral, terminal ends hooked, proximal ends slightly curved in the same direction.; striae radiate, becoming convergent towards to the ends of the valves; striae: 10–11/10 µm.

Material examined. Brazil, Goiás, Britânia, Lago dos Tigres, plankton, Nogueira et al., Site 8, 13/07/2004, ISN904 (UFG 29887), Site 7, 17/07/2008, P07M07, ISN1232 (UFG 43642); Site 10, 18/07/2008, P10M07, ISN1235 (UFG 43645), Site 11, 20/10/2008, P11M10, ISN1275 (UFG 43685).

Distribution. Brazil, State of Paraná, Guaraguaçu River (Tremarin et al. 2010); Salto Amazonas River (Santos et al. 2011); Pioneer citation for the State of Goiás.

Remarks. The specimens from Lago dos Tigres agreed with the type material, except by the ends which are slight cuneate in the material from Britânia. Similar ends were observed also in the material from Guaraguaçu River (Tremarin et al. 2010, figure 34), what suggest this characteristic as a possible morphological variation into the species.

Pinnularia instabilis

(A. Schmidt) Metzeltin in Metzeltin & Lange-Bertalot, Iconogr. Diatomol., vol. 5, p. 178, Figs. 194: 1–3, Figs. 205: 4–5, 1998. (Figure 7)

Basionym. *Navicula instabilis* A.Schmidt, A. Schmidt's Atlas, Figures 43: 38–40, non Figures 43: 35–37, 1875.

Lectotype (designated here). One figure in Schmidt (1875, Figure 43: 39) (Figure 7)

Lectotype locality. Demerara River, Guyana.

Valves lanceolate, wide; acuminate or attenuated-peaked apices; length: 53.71–83.11 µm, breadth: 17.7–21.3 µm, length/breadth ratio: 3.03–4.54; axial area lanceolate, broad, reaching $\frac{1}{2}$ of the breadth of the valvae; raphe filiform to slightly lateral, terminal ends hooked and proximal ends curved to the same direction; striae parallel becoming slightly radiate towards to the ends of the valves; striae: 10/10 µm.

Material examined. Brazil, State of Goiás. Britânia, Lago dos Tigres, plankton, Nogueira *et al.*, Site 2, 13/07/2004, ISN898 (UFG 29880); Site 4, 04/06/2004, ISN877 (UFG 29866), Site 7, 17/07/2008, P07M07, ISN1232 (UFG 43642); Site 01, 16/09/2008, P01M09, ISN1252 (UFG 43662); Site 02, 16/09/2008, P02M09, ISN1253 (UFG 43663); Site 11, 20/10/2008, P11M10, ISN1275 (UFG 43685), periphyton, Site 2, 09/09/2004 ISN1014 (UFG 29953).

Distribution. Brazil, State of Amazonas, Tupé Lake (Pereira et al. 2013); Pioneer citation for the State of Goiás.

Remarks. In its original proposal, Schmidt (1875, Figures 43: 35–40) illustrated *P. instabilis.* In the legend of these illustrations, he (Schmidt 1875) highlighted his figures 43: 37 and 43: 39 with the acronym "typ.", indicating there and in other parts of his study, the typical representatives of respective taxa. Based on the outline and measures of these illustrations, Metzeltin in Metzeltin & Lange-Bertalot (1998, p. 178) considered the set of Schmidt's specimens of Figures 43: 35–37 as *P. subacuminata* Krammer & Metzeltin and regarded the name *P. instabilis* to Schmidt's specimens from figures 43: 38–40. Since the preferences of Schmidt (1875, figures 43: 37, 39) proven to be ambiguous and that, among them, only remain the figure 43: 39 as the original sense, we designated it as lectotype. Complementarily, we designated as epitype one specimen in preparation from a sample from Demerara River, Guyana, in Collection Hustedt called "A.S." (A.Schmidt), which the specimens found in Lago dos Tigres agreed.

Pinnularia latarea

Krammer, Diatoms of Europe, vol. 1, p. 110, 224, Figs. 80: 1–6, 84: 13-15, 2000. (Figure 18)

Holotype. Preparations 89, 101 and 102 IOS, Collection Schimanski in Institut für Oberflächenanalyse, Meerbusch, Germany.

Type locality. Mönau-Weiher, near Erlangen, Bavaria, Germany.

Valves linear, with slightly undulated margins; capitates apices; length: 45.69–62.6 µm, breadth: 7.91–10.38 µm, length/breadth ratio: 5.77–6.03; axial area narrowly lanceolate, central area expanded, with fascia until reaching the margins; raphe filiform to slightly lateral; striae radiated, becoming convergent towards to the ends of the valves; striae: 11–12/10 µm.

Material examined. Brazil, State of Goiás. Britânia, Lago dos Tigres, plankton, Nogueira *et al.* Site 1, 16/09/2008, P01M09 (UFG 43662), Site 1, 19/08/2008, P01M08 (UFG 43649); Site 07, 19/08/2008, P07M08 (UFG 43655); Site 1, 19/10/2008, P01M10 (UFG 43675); Site 5, 04/07/2004, ISN878 (UFG 29867); Água Limpa River, plankton, Nogueira *et al.* Site 1, plankton, 09/09/2004, ISN985 (UFG 29907).

Distribution. Brazil, State of São Paulo, São Carlos, Monjolinho River (Souza & Senna 2009); State of Paraná, Maringá, Nazaré Stream (Moresco et al. 2011); Pioneer citation for the State of Goiás;

Remarks. The specimens found in Lago dos Tigres agreed with the original description provided by Krammer (2000), except by some representatives more densely striated (11–12/10 µm against 8–10/10 µm). However, the specimens observed in this study presented more linear outlines than the type specimens (Krammer 2000, figures 84: 13–15). The measures and outlines of the Lago dos Tigres material were also similar to that provided by Metzeltin et al. (2005, figures 168:1–14), from Uruguay material, and to that found by Souza & Senna (2009), in São Paulo, including the slight undulation observed in the margins.

Two representatives of *P. latarea* found by Moresco et al. (2011, figures 40, 41) presented similar outlines the type specimens provided by Krammer (2000). A third individual (Moresco et al, 2011, figure 42), however, had outline linear similarly to the individuals observed in Lago dos Tigres.

Pinnularia mayeri

Krammer, Biblioth. Diatomol., vol. 26, p. 115, Figs. 42: 1–4, 1992. (Figures 8, 9)

Holotype. Preparation 912 MR, Collection Mayer in Regensburgische Botanische Gesellschaft (REG), Regensburg, Germany.

Type locality. Outlet of a fish pond, near Hozheim (Oberpfalz near Kladorf), Bavaria, Germany.

Valves linear-lanceolate; capitate apices; length: 52 µm, breadth: 7 µm, length/breadth apices: 7.42; axial area linear-lanceolate, central area rhomboid, with fascia reaching the margins; raphe filiform, terminal fissures hooked and proximal fissures curved to the same side; striae radiate, becoming convergent toward to the ends of the valves; striae: 10–11/10 µm

Material examined. Brazil, State of Goiás, Britânia, Lago dos Tigres, plankton, Nogueira *et al.* Site 4, 04/06/2004, ISN877 (UFG 29866); Site 11, 06/11/2004, ISN1113 (UFG 29939), Lago dos Tigres, Baía das Perdidas, periphyton, Nogueira *et al.,* Site 2, 13/07/2004, ISN936 (UFG 29942), 13/07/2004, ISN939 (UFG 29945);

Distribution. Brazil, State of São Paulo, São Paulo, Parque Estadual das Fontes do Ipiranga (Rocha & Bicudo 2008); Pioneer citation for the State of Goiás.

Remarks. *Pinnularia mayeri* found in Lago dos Tigres agreed with those found in São Paulo by Rocha & Bicudo (2008) and with the original description provided by Krammer (2000). However, the individuals from type material presented outline more lanceolate than our specimens (see Krammer 2000, Figures 96: 9–13).

The outline and measures of the specimens from Lago dos Tigres are also similar to *Pinnularia pisciculus* var. *angusta* Metzeltin & Krammer in Metzeltin & Lange-Bertalot (1998, figures 175: 6–12, 194: 5, 6), and those illustrated in Metzeltin & Lange-Bertalot (2007, figures 267: 8–12, 273: 1–8), except by the more prominent valvar ends, as well as in *P. mayeri. P. pisciculus* var. *angusta* also presents specimens with outline more linear, such as in the Lago dos Tigres material, to lanceolate specimens such as in *P. mayeri.* This variance can suggest a possible conspecificity of these two taxa.

Pinnularia meridiana var. *meridiana*

Metzeltin & Krammer in Metzeltin & Lange-Bertalot, Iconogr. Diatomol., vol. 5, p. 180, Figs 181: 1, 2, 4, 5, 1998. (Figures 10, 11)

Holotype. Preparation AmS-305, Colletion Lange-Bertalot in Botanisches Institüt der J. W. Goethe Universität, Frankfurt/Main, Germany.

Type locality. Stream in Porto Alegre, State of Rio Grande do Sul, Brazil.

Valves linear, with bi-undulate margins; broad cuneate-rounded apices; length: 43.81–62.79 µm, breadth: 8.22–11.37 µm, length/breadth ratio: 4.01–6.16; axial area rhomboid; central area wide, rhomboid, with fascia not reaching the margins; raphe lateral, terminal fissures hooked, with helictoglossa present (Figure 11), proximal ends curved to the same side; striae parallel to slightly radiated, becoming convergent towards to the ends of the valves; striae: 11/10 µm.

Material examined. Brazil, State of Goiás, Britânia, Lago dos Tigres, plankton, Nogueira *et al.* Site 1, 17/07/2008, P01M07, ISN1226 (UFG 43636), Site 10, 18/07/2008, P10M07, ISN1235 (UFG 43645); Site 4, 11/12/2008, P04M12, ISN1294 (UFG 43704); Site 5, 04/07/2004, ISN878 (UFG 29867); Site 3, 19/08/2004, ISN945 (UFG 29895); Site 5, 09/09/2004, ISN989 (UFG 29911); Vermelho River, plankton, Nogueira *et al.* Site 11, 05/07/2004, ISN881 (UFG 29870); Site 11, 17/10/2004, ISN1033 (UFG 29928); Água Limpa River, plankton, Nogueira *et al.* Site 1, 14/07/2004, ISN908 (UFG 29891).

Distribution. Brazil, State of Goiás, Formosa, Paranã River, site 15; Salobro River, site 16; Crixás River, site 17; Paranã River, site 29; Nova Roma, Forquilha Stream, site 7 (Souza & Oliveira 2007, da Silva et al. 2011); State of São Paulo, São Carlos, Monjolinho River (Souza & Senna 2009); State of Paraná, Matinhos, Guaraguaçu River; Pontal do Paraná, Guaraguaçu River; General Carneiro, Salto do Amazonas River; Lagoa da Fazenda São Pedro; Araucárias Reservoir; Neno Stream (Tremarin et al. 2009); State of Rio Grande do Sul, Porto Alegre (from the original material in Metzeltin & Lange-Bertalot 1998).

Pinnularia microstauron var. *brasiliensis*

Krammer & Metzeltin, Iconogr. Diatomol, vol. 5, p. 181, Figs. 179: 9–15, 1998. (Figures 13–15)

Holotype. Preparation AmS-562, Colletion Lange-Bertalot in Botanisches Institüt der J. W. Goethe Universität, Frankfurt/ Main, Germany.

Type locality. Tapajós River, State of Amazonas, Brazil.

Valves linear, with bi-undulated margins; cuneate-rostrate apices; length: 41.14–45.79 µm, breadth: 7.22–8.6 µm, length/ breadth ratio: 5.37–6.57; axial area rhomboide; central area rhomboidal, with fascia reaching the margins; raphe lateral, terminal fissures hooked, proximal fissures curved to the same side; striae short, parallel to radiate, becoming convergent towards to the ends of the valves; striae: 10–11/10 µm

Material examined. Brazil. Goiás. Britânia. Lago dos Tigres, plankton, Nogueira *et al.* Site 1, 16/09/2008, P01M09, ISN1252 (UFG 43662), Site 01, 15/11/2008, P01M11, ISN1278 (UFG 43688), Site 5, 19/08/2008, P05M08, ISN1243 (UFG 43653).

Distribution. Brazil, State of Pará, Tapajós River (from the original material in Metzeltin & Lange-Bertalot 1998); Pioneer citation for the State of Goiás.

Remarks. See comments above, in *P. certa.*

Pinnularia microstauron var. *rostrata*

Krammer, Diatoms of Europe, vol. 1, p. 74, 217, Figs. 51: 8–18, 2000. (Figures 16, 17)

Holotype. Preparation 18B, Collection Krammer in Alfred-Wegener-Institut für Polar- und Meeresforschung (BRM), Bremerhaven, Germany.

Type locality. Hesepertywist near Nordhorn, Emsland, Germany.

Valves linear; rostrate apices; length: 35.2–36.49 µm, breadth 6.23–7.32 µm, length/breadth ratio: 4.89–5.41; axial area rhomboid; central area romphoid, with fascia reaching the margins; raphe filifom, terminal fissures hooked, proximal fissures curved to the same side; striae radiate, becoming convergent towards to the ends of the valves; striae: 10–13/10 µm

Material examined. Brazil, State of Goiás, Britânia, Lago dos Tigres, plankton, Nogueira *et al.* Site 1, 19/08/2008, P01M08, ISN1239 (UFG 43649).

Distribution. Pioneer citation for the country.

Remarks. *Pinnularia microstauron* var. *rostrata* distinguish from the nominate variety because is narrower (6–7 µm against 10–12.4 µm) and presents rostrate apices (Krammer 2000). This taxon is somewhat similar to *P. microstauron* var. *brasiliensis* considering the dimensions, the valvar outline and axial and central areas, but presents clear differences respect to the shape of the apices, which is narrower in the variety *brasiliensis* than in the variety *rostrata* (Figures 13–17).

The specimens observed in Lago dos Tigres were very similar to the material type of *P. microstauron* var. *rostrata* described by Krammer (2000), with some individuals more densely striated than the type population (10–13/10 µm against 10–11/10 µm). The representatives from Lago dos Tigres were also similar to the specimens illustrated by Metzeltin *et al.* (2005, Figures 164: 7, 8, 23), which, however, presented less prominent apices compared to those.

The specimens of the Lago dos Tigres were also similar to *Pinnularia* cf. *microstauron* var. *rostrata* observed by Canani et al. (2011), from Minas Gerais. Nevertheless, the only one specimen recorded by Canani et al. (2011) was larger than the type of *P. microstauron* var. *rostrata* and our specimens (9.8 µm against 6–8 µm), and it can belong to another taxa, closed to this group.

Pinnularia perumbrosa

Metzeltin & Lange-Bert., Iconogr. Diatomol, v. 18, p. 215, Figs. 269: 1, 2, 270: **1–3, 2007. (Figure 20)**

Basionym. *Pinnularia umbrosa* var. *tropica* Metzeltin & Krammer in Metzeltin & Lange-Bertalot, Iconogr. Diatomol, v. 5, p. 194, Figs. 182: 7–9, 1998.

Holotype. Preparation AmS-597, Collection Lange-Bertalot in Botanisches Institüt der J. W. Goethe Universität, Frankfurt/ Main, Germany.

Type locality. State of Amazonas, Brazil.

Valves linear, triundulate and inflamade at the middle part; broad capitates apices; length: 105.49–148.22 µm, breadth: 11.13–17.88 µm, length/breadth ratio: 7.78–8.78; axial area linear-lanceolate, reaching 1/3 of the breadth of the valvae; central area rhomboid, with fascia reaching the margins; raphe lateral, terminal fissures sickle-shaped, proximal fissures slightly curved to the same side; striae radiate, becoming convergent towards the ends of the valves; striae: 10–12/10 µm.

Material examined. Brazil, State of Goiás, Britânia, Lago dos Tigres, plankton, Nogueira *et al.* Site 05, 17/07/2008, P05M07, ISN1230 (UFG 43640); Site 01, 19/10/2008, P01M10, ISN1265 (UFG 43675).

Distribution. Brazil, State of Amazonas, Calado Lake (from the original material in Metzeltin & Lange-Bertalot 1998, 2007); Negro River (Pereira et al. 2012); Pioneer citation for the State of Goiás.

Remarks. *Pinnularia umbrosa* var. *tropica* was initially described from fossil material. The type material presented 87–100 µm length, 13.4–14.7 µm breadth, 6.59–7.3 length/ breadth ratio, and 10–12 striae in 10 µm (Metzeltin & Lange-Bertalot 1998). Metzeltin & Lange-Bertalot (2007) considered the morphometric differences between *P. umbrosa* var. *tropica* and the nominated variety as enough to rising that taxon at specific level, under the new name *P. perumbrosa*, since the combination with epithet *tropica* would not be possible into the genus *Pinnularia*. In this study, Metzeltin & Lange-Bertalot (2007) identified other fossil specimens from Amazonas as *P. perumbrosa.* These specimens presented 98.46–113.0 µm length, 12.31–13.85 µm breadth, length/ breadth ratio 7.33–8.65, amplifying the metric characteristics of this species. Moreover, both group of specimens illustrated by Metzeltin & Lange-Bertalot (1998) and Metzeltin & Lange-Bertalot (2007) have margins conspicuously undulated and breath values that decrease from the middle part towards the ends of the valvae.

Live specimens of *P. perumbrosa* were recorded by Pereira et al. (2012). These specimens presented similar outlines compared to the Metzeltin & Lange-Bertalot's (1998, 2007) material. Although the *P. perumbrosa sensu* Pereira et al. (2012) was larger than the type population, this agreed with those specimens illustrated by Metzeltin & Lange-Bertalot (2007).

Metzeltin & Lange-Bertalot (2007) also described *P. diandae* Metzeltin & Lange-Bert. with undulated margins and similar structure to *P. perumbrosa*, highlighting metric characters as diacritic. *Pinnularia diandae* reach 260 µm length, and about 20 µm breadth.

The material observed in Lago dos Tigres presented larger specimens than any material of *P. perumbrosa* but it could metrically agree with *P. diandae*. Nevertheless, the smallest length values of our material interbreed with measures of *P. perumbrosa* (Metzeltin & Lange-Bertalot 2007, Pereira et al. 2012). Moreover, our material presented also a decrease of the breadth values from the middle part towards to the ends of the valvae, similarly to *P. perumbrosa*, what is not observed in *P. diandae*.

Pinnularia rostratissima f. *subundulata*

Hust., Int. Rev. Hydrobiol., vol. 50, p. 397, Fig. 27, 1965. (Figure 22)

Holotype. Specimen marked in preparation P5/17, Finder 582.4–7, Collection Hustedt in Alfred-Wegener-Institut für Polar- und Meeresforschung (BRM), Bremerhaven, Germany (Simonsen 1987, Figure 754: 2).

Type locality. Tapajoz River, State of Pará, Brazil.

Valves rhomboid-lanceolate, inflated at the middle part and slightly undulated margins; prominent capitate apices; length: 81.85–91.22 µm, breadth: 12.47–15.43 µm, length/breadth ratio: 5.83–6.53; axial area broad, rhomboid; central area rhomboid, reaching the margins; raphe lateral, terminal fissures hooked, proximal fissures curved to the same side; striae short, radiate, becoming convergent towards the ends of the valves; striae: 8–10 /10 µm.

Material examined. Brazil, State of Goiás, Britânia, Lago dos Tigres, plankton, Nogueira *et al.* Site 5, 04/07/2004, ISN878 (UFG 29867); Site 4, 04/06/2004, ISN877 (UFG 29866); Site 1, 09/09/2004, ISN985 (UFG 29907); Site 6, 16/10/2004, ISN1028 (UFG 29923); Site 8, 16/10/2004, ISN1030 (UFG 29925), Lago dos Tigres, Baía das Perdidas, periphyton, Nogueira *et al.* Site 2, 13/07/2004, ISN939 (UFG 29945).

Distribution. Brazil, State of Amazonas (Metzeltin & Lange-Bertalot 1998); State of Pará, Tapajós River, Arapiuns River (Hustedt 1965, Simonsen 1987); Pioneer citation for the State of Goiás.

Remarks. see remarks in *P. rostratissima* var. *rostratissima.*

Pinnularia rostratissima var. *rostratissima*

Hustedt, Int. Rev. Hydrobiol., vol. 50, p. 397, Fig. 26, 1965. (Figure 21)

Holotype. Specimen marked in preparation P5/16, Finder 354.16, Collection Hustedt in Alfred-Wegener-Institüt für Polar- und Meeresforschung (BRM), Bremerhaven, Germany (Simonsen 1987, Figure 754: 1).

Type locality. Tapajós River, State of Pará, Brazil.

Valves fusiform-lanceolate, strongly inflated at the middle part; capitates apices; length: 81.27–88.12 µm, breadth: 13.78–15.63; length/breadth ratio: 5.63–5.89; axial area broad, lanceolate; central area lanceolate, with fascia reaching the margins; raphe lateral, terminal fissures hooked, proximal fissures curved to the same side; striae short, radiate, becoming convergent towards to the ends of the valves; striae: 10–11/10 µm.

Material examined. Brazil, State of Goiás, Britânia, Lago dos Tigres, plankton, Nogueira *et al.* Site 11, 20/10/2008, P11M10, ISN1275 (UFG 43685).

Distribution. Brazil, State of Amazonas, Jaú River (Díaz-Castro et al. 2003); State of Pará, Tapajós River, Arapiuns River (Hustedt 1965, Simonsen 1987, Metzeltin & Lange-Bertalot 1998); Pioneer citation for the State.

Remarks. The original material of *P. rostratissima* presented length 78–93 µm, 11–14 µm breadth and 10–11 striae in 10 µm (Hustedt 1965). Hustedt (1965) also described *P. rostradissima* f. *subundulata* Hust. which differed from nominate forma from the ends of the valve and slight undulations on the margins. Moreover, the outline of the forma *subundulata* is some rhomboidal whereas in the forma *rostratissima* is some fusiform.

Simonsen (1987) illustrated the type of *P. rostratissima* which, according to Metzeltin & Lange-Bertalot (1998) presented length 94 µm, breath 13.4, 9.5–10 striae in 10 µm. Based on these estimative, Metzeltin & Lange-Bertalot (1998) proposed *P. rostratissima* var. *parva* Metzeltin & Lange-Bert. and *P. rostratissima* var. *ventricosa.* Metzeltin & Lange-Bert. According these authors, the variety *parva* would have narrower specimens than the nominate variety (10–11 µm), while the variety *ventricosa* would be broader specimens (14–17.5 µm). However, Metzeltin & Lange-Bertalot (1998) did not take into account the range of measures of specimens in the population characterized by Hustedt (1965), which are intersected with the breath values of the varieties *parva* and *ventricosa.* Despite this, the specimens of *P. rostratissima* var. *parva* described by Metzeltin & Lange-Bertalot (1998) are smaller than the nominate variety (59–63 µm against 78–94 µm). *P. rostratissima* var. *ventricosa* may be similarly distinguished from the nominated variety (54–74 µm against 78–94 µm). Moreover, this taxon presents specimens visually more inflated what can be numerically proved by lower length/breadth values [3.86–4.41 (5.28) instead ≥ 5.57].

The specimens of *P. rostratissima* var. *rostratissima* found in Lago dos Tigres are similar to the outline of the type specimen illustrated by Simonsen (1987, Figure 754: 1). The breath values of these specimens intergrading with the values of *P. rostratissima* var. *rostratissima*, as described by Hustedt (1965), and *P. rostratissima* var. *ventricosa.* But they would not match with *P. rostratissima* var. *ventricosa*, because it was larger and not so inflated as the variety *ventricosa* (i.e., length/breadth value higher than 5.57).

Pinnularia rostratissima var. *ventricosa*

Metzeltin e Lange-Bert., Iconogr. Diatomol, vol. 5, p. 186, Figs. 169: 1–5, 203: 1, 4, 1998. (Figure 23)

Holotype. Preparation AmS-526, Collection Lange-Bertalot in Botanisches Institüt der J. W. Goethe Universität, Frankfurt/Main, Germany.

Type locality. Essequibo-River, Guyana.

Valves fusiform-lanceolate, inflated at the middle part; capitate apices; length: 70; breadth: 15, length/breadth ratio: 4.66; axial area fusiform, central area indistinct of the axial area, with fascia reaching the margins; raphe lateral, terminal fissures hooked, proximal fissures curved to the same side; striae short, slightly radiated, becoming convergent towards the ends of the valves; striae: 12/10 µm.

Material examined. Brazil, State of Goiás, Britânia, Lago dos Tigres, plankton, Nogueira *et al.*, Site 8, 13/07/2004, ISN904 (UFG 29887); Vermelho River, plankton, Nogueira *et al.* Site 11, 05/06/2004, ISN881 (UFG 29870), Site 10, 18/07/2008, P10M07, ISN1235 (UFG 43645); Site 01, 16/09/2008, P01M09, ISN1252 (UFG 43662); Site 11, 20/10/2008, P11M10, ISN1275 (UFG 43685).

Distribution. Brazil, State of Amazonas (Metzeltin & Lange-Bertalot 1998), Negro River (Metzeltin & Lange-Bertalot 2007, Pereira *et al.* 2012); Tupé Lake (Pereira *et al.* 2013); Pioneer citation for the State of Goiás.

Remarks. see remarks in *P. rostratissima* var. *rostratissima.*

Pinnularia rumrichiae

Krammer, Diatoms of Europe, vol. 1, p. 110, 223, Figs. 51: 8–18, 2000. (Figure 26)

Holotype. Preparation Eu-SF 117, Collection Lange-Bertalot in Botanisches Institüt der J. W. Goethe Universität, Frankfurt/Main, Germany.

Type locality. Julma, Ölkky near Kuusamo, Finland.

Valves linear; capitates apices, with very narrow necks; length: 38.17–43.24 µm, breadth: 7.12–8.01 µm, length/breadth ratio: 4.81–5.92; axial area lanceolate; central area rhomboid, with fascia reaching the margins; raphe filiform to slightly lateral, terminal fissures hooked, proximal fissures curved to the same side; striae radiated, becoming convergent towards to the ends of the valves; striae: 10–12/10 µm.

Material examined. Brazil, State of Goiás, Britânia, Lago dos Tigres, plankton, Nogueira *et al.* Site 5, 04/07/2004, ISN878 (UFG 29867); Site 4, 04/06/2004, ISN877 (UFG 29866); Site 8, 16/10/2004, ISN1030 (UFG 29925), Site 6, 09/09/2004, ISN989 (UFG 29911); Vermelho River, plankton, Nogueira et al. Site 11, 14/07/2004, ISN907 (UFG 29890); Site 4, 19/08/2008, P04M08, ISN1242 (UFG 43652), Site 01, 16/09/2008, P01M09, ISN1252 (UFG 43662), Site 1, 19/10/2008, P01M10, ISN1265 (UFG 43675), Site 9, 19/08/2008, P09M10, ISN1273 (UFG 43683), Site 01, 15/11/2008, P01M11, ISN1278 (UFG 43688).

Distribution. Brazil, State of Paraná, Guaraguaçu River (Tremarin et al. 2010); Pioneer citation for the State of Goiás.

Remarks. The specimens from Lago dos Tigres agreed with the original description of *P. rumrichiae*, except in cases that some specimens presented lower length/breadth ratio (4.81–5.85 against 5.6–6.8). Our material was also similar to specimens of *P. rumrichiae* observed by Tremarin et al. (2010) [cited as *P.* "*rumrichae"* but correted in this study according to the Article 60.12 and Recommendation 60C.1 of the International Code for Nomenclature of algae, fungi and plants (McNeill et al. 2012)]. In this case, the illustrated specimens also presented lower length/breadth ratio than the type material (4.92–5.26). Metzeltin et al. (2005) recorded *P. rumrichiae* from Uruguay with lower length/breadth ratio than the type material (4.44–5.83), but the specimens illustrated by them presented more prominent apices and not so narrow necks, compared to the type population.

Pinnularia rumrichiae is similar to *P. brauniana* (Grunow) Mills, a taxon also recorded in aquatic systems from Brazil (Metzeltin & Lange-Bertalot 1998). Despite to present very similar measures and conspicuously capitates valves, the outline of *P. brauniana* is lanceolate, differently of *P. rumrichiae* that present valves with more straight margins, i.e., linear valves, what agreed with the material from Lago dos Tigres.

Pinnularia silviasalae

Metzeltin, Lange-Bert. & García-Rodríguez, Iconogr. Diatomol, vol. 15, p. 160, Figs 169: 1–12, 2005. (Figure 19)

Holotype. Preparation Uru, Collection Lange-Bertalot in Botanisches Institüt der J. W. Goethe Universität, Frankfurt/Main, Germany.

Type locality. Creek, Departament of Colonia, Uruguay.

Valves linear, with slightly undulated margins; subcapitate to broadly capitate apices; length: 58.71–69.52 µm, breadth: 11.32–12.76 µm, length/breadth ratio: 4.98–5.95; axial area lanceolate; axial area indistinct from the axial area to broadly circular, almost reaching the margins; raphe lateral, terminal fissures hooked, proximal fissures curved to the same side; striae radiated, becoming convergent towards to the ends of the valves; striae: 10–12/10 µm.

Material examined. Brazil, State of Goiás, Lago dos Tigres, Baía das Perdidas, periphyton, Nogueira et al. Site 2, 13/07/2004, ISN936 (UFG 29942), Lago dos Tigres, plankton, Nogueira et al. Site 10, 18/07/2008, P10M07, ISN1235 (UFG 43645).

Distribution. Brazil, State of Pará, Belterra, Jucuruí Lake (Metzeltin & Lange-Bertalot 2007); Pioneer citation for the State of Goiás.

Remarks. *Pinnularia silviasalae* differs of similar taxa [e.g., *P. rhomborea* var. *brevicapitata* Krammer, *P. microstauron* (Ehrenb.) Cleve, *P. gibba* Ehrenb. Sensu Metzeltin et al. (2005, figures 166: 1–3), *P. parvulissima* Krammer, and *P.* cf. *parvulissima* Metzeltin et al. (2005, figures 166: 4–6)] from outline, shape and dimensions of the apices, and outline and size of the axial area.

The type material of *P. silviasalae* was also similar to *P. doehringii* Frenguelli, but this taxon is larger (58.78–99.32 µm against 43–70 µm) and breather (12.16–14.96 µm instead 11.5–12 µm), presented broad capitate ends, and central area with fascia reaching the margins. In *P. silviasalae*, this last characteristic occurred in only one specimen of the type population.

Among the representatives of *P. silviasalae* recorded by Metzeltin & Lange-Bertalot (2007, figures 263: 1–6), one specimen was larger than the type material [53.07–67.69 (90.0) µm against 43–70 µm], and a population presented few protracted to subcapitate apices and fascia reaching the margins.

The metric characteristics of the valve, and the dimensions and outline of the axial area of the specimens from Lago dos Tigres were similar to the type of *P. silviasalae*. However, we observed only specimens with capitates apices and with some representatives more densely striated than the type population (10–12/10 µm against 8–10/10 µm). This variation in relation to the type material can be filled by *P. silviasalae* sensu Metzeltin & Lange-Bertalot (2007, figures 263: 1–6). This could indicate that the material type is composed by representatives of part of the variability known for the species.

Pinnularia superpaulensis

(Hust.) Metzeltin e Lange-Bert., Iconogr. Diatomol, vol. 18, p. 226, Figs. 257: 1–3, 2007. (Figure 28)

Basionym. *Pinnularia elegantoides* f. *linearis* Hust., Int. Rev. Hydrobiol., vol. 50, p. 398, Fig. 30, 1965.

Holotype. Specimen marked in preparation 318/40, Finder 400.6, Collection Hustedt in Alfred-Wegener-Institut für Polar- und Meeresforschung (BRM), Bremerhaven, Germany (Simonsen 1987, figures 754: 4, 5).

Type locality. Jucuruí Lake, Brazil.

Valves linear, slightly tumid at middle part; rounded apices; length: 123.2–126.7 µm, breadth: 17.14–19.33 µm, length/breadth ratio: 6.41–7.01; axial area lanceolate; axial area indistinct from the axial area to broadly circular, almost reaching the margins; raphe lateral, terminal fissures hooked, proximal fissures curved to the same side; striae radiated, becoming convergent towards to the ends of the valves; striae: 10–11/10 µm.

Material examined. Brazil, State of Goiás, Britânia, Lago dos Tigres, plankton, Nogueira et al., Site 10, 18/07/2008, P10M07, ISN1235 (UFG 43645).

Distribution. Brazil, State Amazonas, Tupé Lake (Pereira et al. 2013); State of Pará, Belterra, Jucuruí Lake; Igarapé do Tento, Arapiuns River (Hustedt 1965, Simonsen 1987, Metzeltin & Lange-Bertalot 2007); Pioneer citation for the State of Goiás.

Remarks. The material observed in Lago dos Tigres was larger than the type material of *P. superpaulensis* (111 µm against 123.2–126.7 µm) (Simonsen 1987, figure 754: 4). On the other hand, Metzeltin & Lange-Bertalot (2007, figures 257: 1–3) presented specimens of this taxon larger than the type and our material (122.30–131.54 µm length).

Pinnularia superpaulensis was recorded in Tupé Lake, Amazonas, Brazil (Pereira et al. 2013). The metric range of the specimens described in this study is wide and match with the type, *P. superpaulensis* sensu Metzeltin & Lange-Bertalot (2007) and our material (89.3–144 µm). However, the illustrated material in Pereira et al. (2013) had distinct outline compared to these others.

The diversity of *Pinnularia* in central-western Brazil is still incipiently known. From twenty taxa recorded in this study, 18 were new occurrences in State of Goiás. This demonstrates the potential of aquatic environments of this region to encompass biological diversity still not known. Because tributaries of the main Hydrographic River Basin from Brazil are present in Goiás and the importance of aquatic biological communities to the maintenance of the quality of this systems, studies about the flora of diatom and other algae groups should be carried out urgently in this State. Thus, these studies could provide important data to the management of aquatic resources of the Country.

Pinnularia variarae

Metzeltin & Lange-Bert., Iconogr. Diatomol, vol. 5., p. 194, Figs. 181: 8–10, 193: 5, 1998. (Figure 25)

Holotype. Preparation AmS-581, Collection Lange-Bertalot in Botanisches Institüt der J. W. Goethe Universität, Frankfurt/Main, Germany.

Type locality. Lago Calado, State of Amazonas, Brazil.

Valves linear-lanceolate, with straight margins; cuneate apices; length: 49.32–54.27, breadth: 13.65–15.13, length/breadth ratio: 3.59–3.81; axial area lanceolate; axial area circular to elliptical, sometimes indistinct from the axial area; raphe lateral, terminal fissures hooked, proximal fissures curved to the same side; striae radiated, becoming convergent towards to the ends of the valves; striae: 9–11/10 µm.

Material examined. Brazil, State of Goiás, Britânia, Lago dos Tigres, plankton, Nogueira *et al.* Site 1, 17/07/2008, P01M07, ISN1226 (UFG 43636), Site 01, 15/11/2008, P01M11, ISN1278 (UFG 43688).

Distribution. Brazil, Amazonas, Lago Calado (Metzeltin & Lange-Bertalot 1998); State of São Paulo, São Carlos, Monjolinho River (Souza & Senna 2009); Pioneer citation for the State of Goiás.

Remarks. Some of the specimens from Lago dos Tigres were slightly narrower and more densely striated valves than the original material of *P. variarea*, what was also observed by Souza & Senna (2009).

Acknowledgments

The authors thank to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Secretaria de Estado de Ciência e Tecnologia (SECTEC) for founds this Project (CNPq/SECTEC Proc. 232340–75). W.J. da Silva thanks to the CNPq for the scholarship (CNPq/ITI 507274/2004-0). W.J. da Silva and B. Dunck thank to Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for doctoral scholarship granted. D.T. Ruwer thanks to the CNPq/UFG for the scholarship.

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Received 11/03/2015
Revised 28/01/2016
Accepted 23/02/2016

Biota Neotropica 16(1): e20150090, 2016
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
article

Sporormiella as a tool for detecting the presence of large herbivores in the Neotropics

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RACZKA, M.F., BUSH, M.B., FOLCIK, A.M., MCMICHAEL, C.H. ***Sporormiella* as a tool for detecting the presence of large herbivores in the Neotropics.** Biota Neotropica. 16(1): e20150090. http://dx.doi.org/10.1590/1676-0611-BN-2015-0090

Abstract: The reliability of using the abundance of *Sporormiella* spores as a proxy for the presence and abundance of megaherbivores was tested in southern Brazil. Mud-water interface samples from nine lakes, in which cattle-use was categorized as high, medium, or low, were assayed for *Sporormiella* representation. The sampling design allowed an analysis of both the influence of the number of animals using the shoreline and the distance of the sampling site from the nearest shoreline. *Sporormiella* was found to be a reliable proxy for the presence of large livestock. The concentration and abundance of spores declined from the edge of the lake toward the center, with the strongest response being in sites with high livestock use. Consistent with prior studies in temperate regions, we find that *Sporormiella* spores are a useful proxy to study the extinction of Pleistocene megafauna or the arrival of European livestock in Neotropical landscapes.

Keywords: *Extinction, fossil pollen, lake sediment, livestock, Pleistocene Megafauna, Sporormiella spores.*

RACZKA, M.F., BUSH, M.B., FOLCIK, A.M., MCMICHAEL, C.H. ***Sporormiella* como ferramenta para detectar a presença de grandes herbívoros na região Neotropical.** Biota Neotropica. 16(1): e20150090. http://dx.doi.org/10.1590/1676-0611-BN-2015-0090

Resumo: A confiabilidade dos valores de *Sporormiella* como um proxy para estimar a presença e abundância de megaherbívoros foi testada na região sudeste do Brasil. Amostras superficiais de nove lagos, categorizados quanto a presença de gados em alto, médio e baixo uso do seu entorno foram coletadas para a análise de abundância de *Sporormiella*. O modelo amostral aplicado permitiu a interpretação tanto da influência do número de animais que usam a margem do lago quanto a distância da margem do lago sobre a quantidade de esporos encontrados. As análises indicam que esporos de *Sporormiella* é um excelente proxy para detectar a presença de grandes herbívoros. A concentração e abundância de esporos reduz em direção ao centro do lago, o que fica mais evidente em locais com alto uso do entorno do lago por esses animais. Consistente com estudos realizados em regiões temperadas, nós concluímos que o uso de *Sporormiella* se mostra de grande valia para entender a extinção da megafauna do Pleistoceno como também a introdução de animais nas paisagens neotropicais.

Palavras-chave: *Extinção, pólen fóssil, sedimentos lacustres, pecuária, Megafauna Pleistocênica, Sporormiella.*

Introduction

The Pleistocene megafauna were animals that exceeded 100 kilograms (Johnson 2002, Martin & Steadman 1999), such as ground sloth, mastodon, and glyptodonts. In South America, the Late Pleistocene extinction resulted in the loss of 57 genera of megafauna (Barnosky & Lindsey 2010, Martin & Klein 1984, Martin & Steadman 1999). With the arrival of Europeans, domesticated megafauna, such as cows, horses and oxen, were introduced to many areas. Both in pre-history and now, megafauna produce a wide range of effects on terrestrial ecosystems that can disturb and alter the functioning of the ecosystem (Ripple & Van Valkenburgh 2010). Some of these effects are direct, for example removal and consumption of vegetation, while other effects are indirect, such as alterations of rates of nutrient cycling (Augustine & McNaughton 1998, Doughty et al. 2013, Johnson 2009, MacFadden & Shockey 1997, McNaughton 1985, Smith et al. 2010).

The extinction of megafauna at the end of the Pleistocene has intrigued researchers for decades (Gill 2014). Environmental change (Grayson & Meltzer 2002, Macphee 1999) combined with human hunting pressure (Blitzkrieg) (Martin 1973, Miller et al. 1999) is the leading hypothesis to explain the extinction. For most of the 20th century, fossilized bones were the only evidence to assess the demise of these unique Quaternary animals (Webb et al. 1984). Fossils are scarce, and in most of the cases only provide descriptive interpretation (Borrero 2009). Because of these limitations, an additional proxy for megafauna is necessary that is common, tightly associated with megafaunal presence, and can be found in temporally intact paleoecological archives (Bakker et al. 2015).

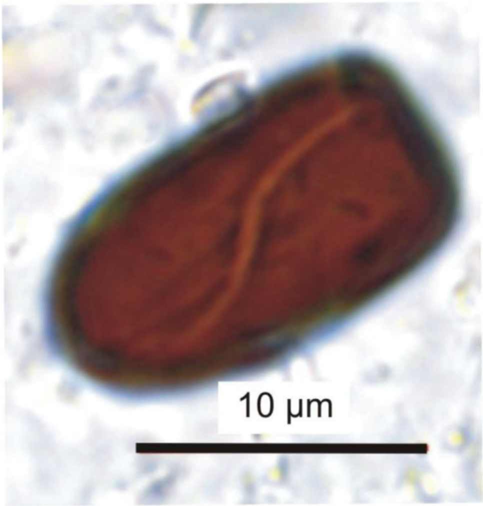

Figure 1. Photomicrograph of a single *Sporormiella* cell (terminal segment) showing the aperture in s-shape that facilitates the identification of the spore.
Figura 1. Fotomicrografia de uma célula única de *Sporormiella* (segmento terminal) mostrando a abertura em forma de 's' que facilita a identidicação do esporo.

Spores of *Sporormiella* (Figure 1), a genus of primarily coprophilous fungi, are now widely used to detect mega herbivore presence and even estimate their abundance in paleoecological reconstructions (Davis & Shafer 2006, Gill et al. 2012, Gill et al. 2009, Robinson et al. 2005). Though pioneered in the Great Plains of the USA (Davis 1987, Davis et al. 1977), *Sporormiella* has been used to reconstruct the presence of Moas in New Zealand (Wood et al. 2011), Giant tortoises in the Galapagos (Froyd et al. 2013), Giant lemurs, elephant birds and the pygmy hippopotamus in Madagascar (Burney et al. 2003).

Despite the growing scientific literature regarding the role of *Sporormiella* in Quaternary sediments, very few studies have been conducted in modern settings to assess the reliability of the spores as a proxy for megafauna (Etienne et al. 2012, Gill et al. 2013, Raper & Bush 2009). Modern megafauna, such as cows, are analogs of Pleistocene megafauna that can be used to calibrate *Sporormiella* signatures in paleoecological studies. According to Raper & Bush (2009), *Sporormiella* can be a common element of lake sediments in localities with modern cattle presence, particularly samples collected near the shoreline. The dispersion of *Sporormiella* into lake sediments is likely affected by the abundance of animals in the region, transportation of the spores by physical agents after defecation, and physical characteristics of the lake basin. Higher concentrations of *Sporormiella* at the shoreline probably result from the relatively heavy spore structure that causes the fungus cell to sink rapidly. An exponential decline in spore concentration with increasing distance from shoreline was suggested by Raper & Bush (2009) for the shallow flat-bottomed lakes of Florida. Parker & Williams (2012) found that in dam and natural lakes in the US Great Plains, Midwestern USA, the decline from shoreline to the center was linear. A study of mountain lakes in the French Alps suggested that the *Sporormiella* concentrations were a function of flows that transported plumes of *Sporormiella* into deep water.

No study of *Sporormiella* occurrence has yet been undertaken in South American systems. The presence of a suite of mid-sized rodents and herbivores that are commonly found around lakes, e.g. capybara, agouti, paca, and deer could complicate the use of *Sporormiella* as a marker of Pleistocene megafauna. Here we aim to: (1) test the association between *Sporormiella* concentrations in modern sediments and the presence of introduced European animals, (2) Determine if the use of livestock has a significant impact on *Sporormiella* concentrations; and (3) test whether *Sporormiella* declines with distance from the shoreline.

Material and Methods

To understand the association between megafauna abundance and *Sporormiella* representation in lake sediment archives, we sampled nine lakes with different cattle use in the adjacent landscape: i) High cattle use (> 40 per day visiting the lake); ii) Medium cattle use (~10 per day visiting the lake), and iii) Low cattle use (<5 per day visiting the lake). We also examined whether the abundance of *Sporormiella* was related to distance from the lake shoreline (Raper & Bush 2009).

1. *Experimental design*

To compare *Sporormiella* signatures along a gradient of cattle densities, we selected nine flat-bottomed lakes across southeastern Brazil (Table 1), in the São Paulo and Minas Gerais (Figure 2). The sampled lakes are situated in the southeastern region of Brazil in the cerrado (Goodland & Pollard 1973), and in the Atlantic rain forest (Morellato & Haddad 2000). Lakes ranged in size from 100 to 150 m in diameter and were classified according to the use by livestock. Due to limited

Table 1. Attributes and characteristics of each lake. Lakes with asterisk are also being analyzed for paleoecological reconstructions.
Tabela 1. Atributos e características de cada lago. Lagos marcados com asterísco também estão sendo analisados para estudos paleoecológcos.

Lake Name	Elev. (m)	Lat./Long.	~Depth (m)	# Samples	Category
Araça/MG	806	19°31'48 S/44°6'28W	1.8	20	High
Maria/SP	760	23°6'41 S/ 46°31'25W	2	8	High
Pedrinha/MG	702	19°33'42 S/44°7'21W	1.5	12	High
Guilto/MG	720	19°28'48 S/44°9'1W	2.4	20	Medium
Fora/MG	700	19°26'48 S/44°11W	2.6	20	Medium
Rocha/SP	645	21°52'40 S/47°5'19W	1.5	8	Low
Serra Negra/MG *	1170	18°53'31 S/ 46°49'29W	1.5	9	Low
Branca/SP *	710	21°54'12 S/ 47° 1'46W	1.8	11	Low
Sumidouro/MG	648	19°32'20 S/ 43°56'32W	0.8	12	Low

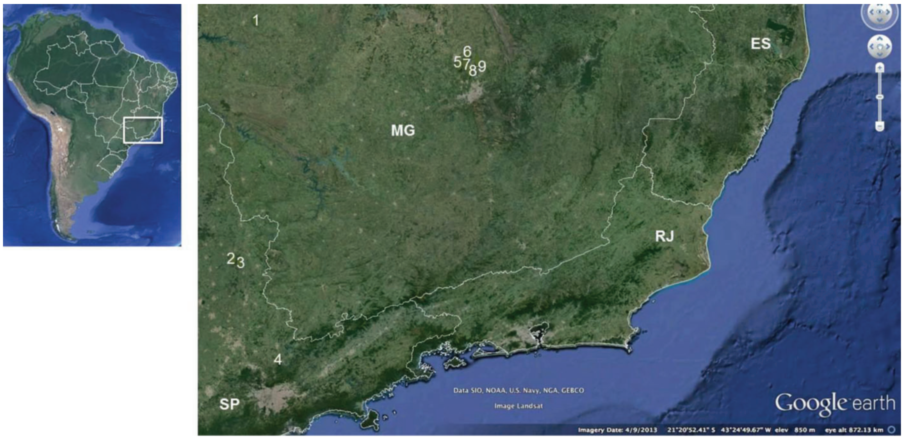

Figure 2. Image of the study area showing the lakes from which mud-water interface samples were collected. 1 = Lake Serra Negra; 2 = Lake Rocha; 3 = Lake Branca; 4 = Lake Maria; 5 = Lake Guilto; 6 = Lake Fora; 7 = Lake Araçá; 8 = Lake Pedrinha; 9 = Lake Sumidouro; SP = São Paulo; MG = Minas Gerais; RJ = Rio de Janeiro; ES = Espirito Santo.

Figura 2. Imagem da área de estudo com os lagos nos quais amostras superficiais foram coletadas. 1 = Lago Serra Negra; 2 = Lago do Rocha; 3 = Lagoa Branca; 4 = Lago Maria; 5 = Lago do Guilto; 6 = Lagoa de Fora; 7 = Lago Araça; 8 = Lago Pedrinha; 9 = Lagoa do Sumidouro; SP = São Paulo; MG = Minas Gerais; RJ = Rio de Janeiro; ES = Espírito Santo.

access to private properties, it was not possible to get an even number of lakes across all categories of lakes three high-use lakes, two medium-use lakes, and four low-use lakes.

Each lake was divided into concentric rings representing intervals of distance from the lake shoreline (Figure 3). The outermost ring represented 2.5 m from shoreline, the second interval was 15 m from the shoreline, then 35 m, and the last one was 50 m. The number of samples collected within each ring was proportional to the surface area of the ring. Thus, more samples were collected in the outermost ring than in the inner rings. Sample locations within each ring were randomly selected. It is important to observe that at Lake Maria, samples from 35 and 50 meters distances were unavailable due to a fence that prevented boat access to the center of the lake. All samples were obtained from the mud-water interface using an Ekman dredge sampler that was released from an inflatable boat. A total of 120 samples were obtained summing data for all lakes.

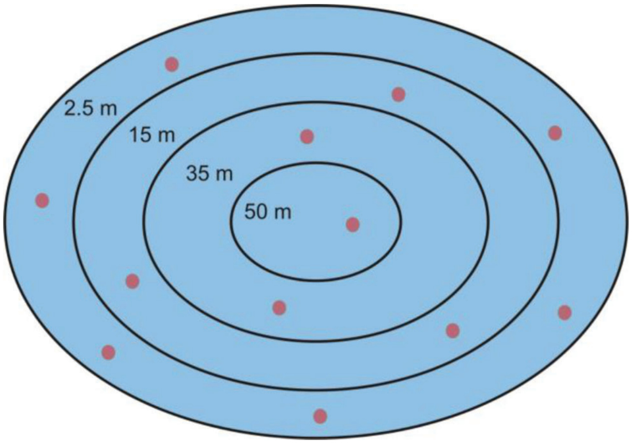

Figure 3. Sketch diagram of the sampling method used showing the concentric rings guiding sampling. Each ring represents a given distance from the lake shoreline. The number of samples from each ring was proportional to its surface area.

Figura 3. Diagrama esquemático do método de amostragem com os intervalos amostrais. Cada intervalo amostral representa a distância da margem do lago. O número de amostras em cada intervalo amostral foi proporcional à sua área de superfície.

2. *Subsampling*

From each sample collected, 1.0 cm^3 of wet sediment was subsampled and processed following standard protocols for palynological analyses (Faegri & Iversen 1989) and separated by density using sodium metatungstate to concentrate the palynomorphs. In each sample, a *Lycopodium* spike containing a known number of spores was added. This technique was used to determine spore and pollen concentrations (Stockmarr 1971). In each sample, 300 pollen grains were counted using a Zeiss Axioskop at magnifications of 630x and 1000x as this typified the sampling effort applied to paleoecological samples (Absy 1991, Colinvaux et al. 1997, Colinvaux et al. 1999, Colinvaux et al. 1996, Ledru et al. 1998, Ledru 1993). *Sporormiella* spores were identified by consulting photographs and through physical descriptions (Aptroot & van Geel 2006, Davis & Shafer 2006, van Geel et al. 2011).

3. *Statistical Analysis*

The spore abundances were compared across distance intervals (concentric rings), and between livestock densities. The data were analyzed using a generalized linear model (Gelman & Hill 2007) from the package *stats* using the statistical program R (R Development Core Team 2015). Distance from the shoreline was the predictor to determine if the mean of the samples at each segment from each lake was significantly different from another. Also, we performed a Two Way ANOVA to analyze if a significant difference existed among lakes supporting high, medium or low livestock use.

Results

1. *Lakes*

Sporormiella spores were present in 97 out of the 120 samples analyzed. In lakes with high cattle use, spores abundance ranged 6.3 and 48.6 % of the total pollen sum. At locations with medium

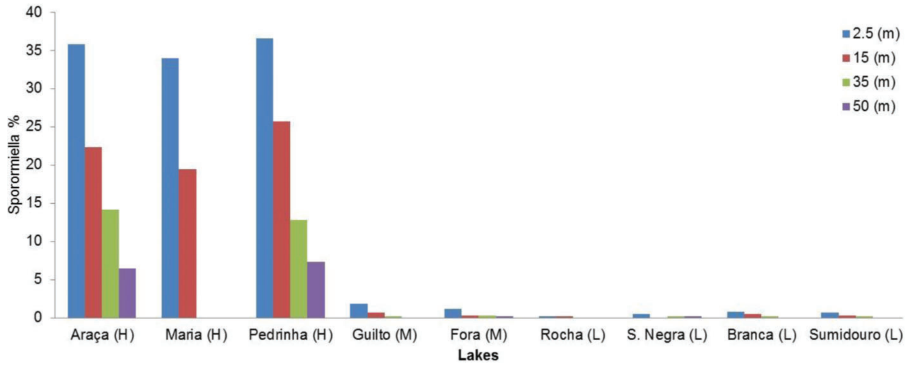

Figure 4. Percentage data for *Sporormiella* representation relative to the pollen sum. Each value represents an average for the given distances from the nearest shoreline. The letters after the names of the lakes denote the category of each lake: H = High cattle use; M = Medium cattle use, and L = Low cattle use.

Figura 4. Dados de porcentagem de *Sporormiella* relativos à soma total de pólen. Cada valor representa a média da distância da margem do lago. As letras após o nome do lago indica a categoria de cada lago: H = Alto; M = Médio; L = Baixo.

Table 2. Two Way ANOVA for percentages data. Dependent Variable: *Sporormiella*. a. R Squared = .994 (Adjusted R Squared = .991).

Tabela 2. Two Way ANOVA dos dados de porcentagem. Variável dependente: *Sporormiella*. a. R Squared = .994 (Adjusted R Squared = .991).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4297.941a	11	390.722	348.304	**<0.001**
Intercept	1430.452	1	1430.452	1275.159	**<0.001**
Category	2542.458	2	1271.229	1133.222	**<0.001**
Distance	452.214	3	150.738	134.373	**<0.001**
Category * Distance	761.889	6	126.981	113.196	**<0.001**
Error	24.679	22	1.122		
Total	5788.643	34			
Corrected Total	4322.621	33			

and low cattle use, the highest spore per sample found was 6.3% of total pollen sum.

Percentages of *Sporormiella* spores were significantly higher at locations with high cattle use in comparison with locations with medium and low cattle use ($p < 0.001$; Figure 4; Table 2).

Concentrations of *Sporormiella* in lakes with high cattle use varied from 1203.9 to 6741.5 spores per cm^3. Locations with medium and low cattle use had much lower concentrations of spores, with values ranging from 0 to 338.7 spores per cm^3. In all cases, samples located at shoreline had concentrations of *Sporormiella* significantly higher than samples close to the center of the lake. The Two Way ANOVA for concentrations of *Sporormiella* per cm^3 also showed that high cattle densities locations were significantly different from locations with medium and low cattle densities ($p < 0.001$; Figure 5; Table 3).

2. Distances

The generalized linear model applied to the percentage and concentration data allowed us to identify the variance among distances within each lake category. Abundance of *Sporormiella* spores followed the same pattern for all lake categories. As the distance from the shoreline increased the abundance of spores decreased. At lakes with high cattle use (Figure 6 A and D), the percentage and concentration of *Sporormiella* were significantly different ($p < 0.001$; Tables 4 and 5) across all distances. Shoreline samples had values notably higher than all the other samples. There was an evident pattern showing the decrease of *Sporormiella* abundance toward the center of the lake. In medium and low cattle use locations, the same pattern of decreasing abundance of *Sporormiella* toward the center of the lake was observed, however, in these two categories of lakes the maximum abundance of *Sporormiella* decreased to values less

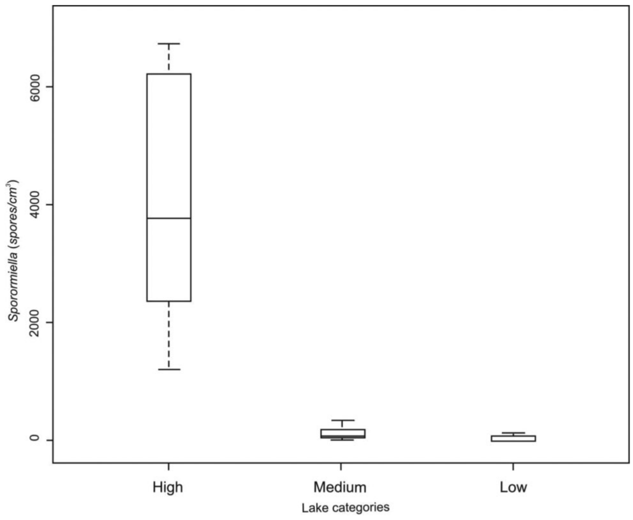

Figure 5. Average concentrations of *Sporormiella* across all distances for the three different use categories of lakes.

Figura 5. Média da concentração de *Sporormiella* de todas as distâncias para as três categorias de lagos.

Table 3. Two Way ANOVA for concentration data. Dependent Variable: *Sporormiella* concentration. a. R Squared = .994 (Adjusted R Squared = .991).
Tabela 3. Two Way ANOVA dos dados de concentração. Variável dependente: *Sporormiella*. a. R Squared = .994 (Adjusted R Squared = .991).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	144.229a	11	13.112	315.145	**<0.001**
Intercept	48.140	1	48.140	1157.061	**<0.001**
Category	85.560	2	42.780	1028.234	**<0.001**
Distance	15.109	3	5.036	121.054	**<0.001**
Category * Distance	25.449	6	4.241	101.946	**<0.001**
Error	.915	22	.042		
Total	194.422	34			
Corrected Total	145.144	33			

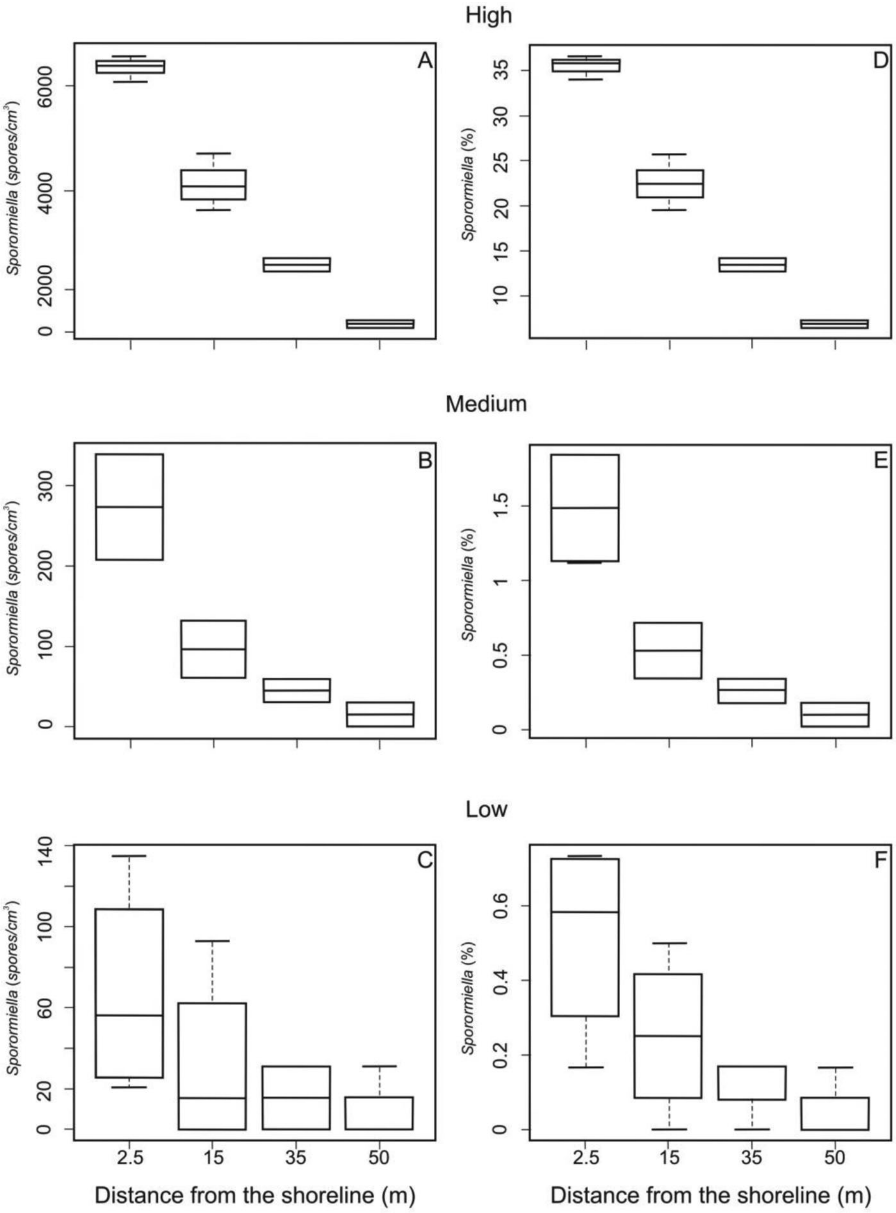

Figure 6. Generalized linear model for concentration (A-C) and percentage data (D-F) for all distances in each lake category.
Figura 6. Generalized linear model análise dos dados de concentração (A-C) e porcentagem (D-F) de todas as distancias para cada categoria de lago.

Table 4. Summary of the results for the generalized linear model on percentage data for all the distances for each lake category.
Tabela 4. Sumário dos resultados da análise linear dos dados de porcentagem para todas as distâncias para cada categoria de lago.

	Distances	Estimate Std.	Error	t value	Pr(>|t|)	Signif. codes
High	**2.5**	-0.59793	0.05793 -	-10.322	4.83e-05	***
	15	-0.63843	0.08809	7.247	-0.000351	***
	35	-1.25848	0.11496 -	-10.947	3.45e-05	***
	50	-2.00163	0.14578 -	13.730	9.28e-06	***
Medium	**2.5**	-4.1872	0.2159 -	19.393	4.17e-05	***
	15	-1.0565	0.4220 -	2.503	0.0665	.
	35	-1.8062	0.5686	-3.176	0.0337	*
	50	-2.9021	0.9334	3.109	0.0359	*
Low	**2.5**	0.0627	0.4395	0.143	0.8889	+
	15	-1.1621	0.6712	-1.731	0.1090	+
	35	-2.0111	0.7969	-2.524	0.0267	*
	50	-3.1982	1.1837	-2.702	0.0192	*
	Signif. codes:	**0 ‘***’**	0.001 ‘**’	0.01 ‘*’	0.05 ‘.’	**0.1 ‘ +’**

than 1.8 % (338.73 spores per cm^3 of sediment) of the total pollen sum. Although all categories exhibited the same tendency for *Sporormiella* abundance to decline toward the center of the lake, the variance between samples was markedly lower at locations with medium and low cattle use, especially for samples at 15, 35, and 50 m from the shoreline (Figures 6 B, E, C and F).

Discussion

Based on modern samples collected in areas with high, medium, and low cattle use our results validate *Sporormiella* as a robust instrument to predict past grazing activities in ancient lake records, as suggested by (Davis 1987), and later observed by other researches (Burney et al. 2003, Davis & Shafer 2006, Gill et al. 2009, Robinson et al. 2005). In essence, large numbers of livestock resulted in more spores of *Sporormiella* being deposited to the center of a lake than low densities of livestock.

The presence of small- and medium-sized herbivores, other than domesticated livestock, appeared to have very little influence on the abundance of *Sporormiella* spores. As these small animals probably support *Sporormiella*, its representation may not decline to zero even following a megafaunal extinction event. Our results are consistent with the 2% detection threshold suggested by Davis (1987), in which *Sporormiella* occurrence at >2% of the pollen sum was a reliable indicator of megafaunal presence. This 2% value has been used to indicate the possible functional extinction of megafauna from the catchment area of the lake (Gill et al. 2013, Gill et al. 2009, Johnson et al. 2015, Parker & Williams 2012). This threshold, however, will probably vary depending on the location of the study as the percentage of *Sporormiella* is dependent on the pollen productivity of the system. Equally important are the concentrations values, which compare positively with the spore percentage data. All samples from locations with high cattle use had *Sporormiella* values greater than 2 %, even from samples located at the center of the lake. On the other hand, at locations with medium and low cattle use, which could be a parallel for a functional extinction in the past, the highest value of the highest average of *Sporormiella* was 1.8 % of the total pollen sum. The values for locations with high cattle use are, without exception, greater than any samples at medium and low cattle use locations (Figure 6). This finding has important implications for paleoecological studies because it suggests that

Table 5. Summary of the results for the generalized linear model on concentration data for all the distances for each lake category.
Tabela 5. Sumário dos resultados da análise linear dos dados de concentração para todas as distâncias para cada categoria de lago.

	Distances	Estimate Std.	Error	t value	Pr(>|t|)	Signif. codes
High	**2.5**	-5.02812	0.04217	- 119.230	2.35e-11	***
	15	-0.45213	0.06753	-6.695	0.000539	***
	35	-0.96383	0.09336	-10.324	4.83e-05	***
	50	-1.62970	0.12348	-13.198	1.17e-05	***
Medium	**2.5**	-0.9780	0.2670	-3.662	0.0215	*
	15	-1.2564	0.4831	-2.600	0.0600	.
	35	-2.0741	0.6324	-3.280	0.0305	*
	50	-3.1944	1.0092	-3.165	0.0340	*
Low	**2.5**	-2.6338	0.4004	-6.577	2.62e-05	***
	15	-0.8123	0.7037	-1.154	0.2708	+
	35	-1.5196	0.9047	-1.680	0.1189	+
	50	-2.2227	1.2120	-1.834	0.0916	.
	Signif. codes:	**0 ‘***’**	0.001 ‘**’	0.01 ‘*’	0.05 ‘.’	**0.1 ‘ +’**

the presence of megafauna can be detected even without knowing the exact locations of paleo-shorelines.

Distance from the shoreline played an important role in the number of spores recovered. It was previously suggested that due to their density, and the clumping of spores as they are released, *Sporormiella* would have had a limited dispersal range (Parker & Williams 2012). Consequently, spores of *Sporormiella* would be expected to be concentrated at the margins of lakes. Our results, along with those of Raper & Bush (2009), support this observation. Similarly, our data are consistent with most other studies in that they show *Sporormiella* spore concentrations and percentages of the pollen sum declining toward the center of the lake.

Raper & Bush (2009) noticed a weak relationship between the percentages of *Sporormiella* and distance from the shoreline at Corner Lake, a location with high cattle activity. This observation could be an artifact of the sampling method applied by those authors, who used a linear transect as a representation of the entire shoreline. To prevent this, the collection of modern samples in our study differed from the method applied by Raper & Bush (2009). We randomly selected samples around the lake to avoid collecting samples closer to a source of *Sporormiella*, or to accidentally select any spot that cattle were avoiding.

Sample location and livestock use are two factors to consider when analyzing the percentages and concentrations of *Sporormiella* in modern settings at any location. Similarly, the morphology of the basin should also be properly evaluated. Etienne et al. (2012) observed that *Sporormiella* abundance at Lake Allos is strongly related to stream flooding, and the authors suggest that a single core obtained at the center of a lake could be a misrepresentation of megafaunal presence in fossil records. Etienne et al. (2012), however, performed their analysis very close to the course of a stream, thereby, emphasizing the role that moving water could play an important part in dispersing *Sporormiella* into a lake, Their study underlines the care needed in selecting a site for any kind of paleoecological reconstruction, as the biases they found in *Sporormiella* distribution would apply equally to other proxies.

One pair of lakes in our study provided some further insights into the importance of stream flow on *Sporormiella* inputs. Lake Pedrinha, a site with high cattle use, had a small inflowing stream that during the wet season would have the capacity to produce flood surges. We chose a coring location, as we would for any paleoecological reconstruction that was not aligned with the stream and its alluvial fan. A comparison of the *Sporormiella* concentrations observed in sediments from this lake was not significantly different to those documented from Lake Araça, which is also a high cattle use location, but lacking a stream input. As *Sporormiella* spores settle out quite quickly, representative samples can be collected by avoiding areas of stream activity.

Conclusion

Our results from 9 lakes and a total of 120 samples indicated that spores of *Sporormiella* are a very sensitive proxy for large herbivore presence. *Sporormiella* is an important paleoecological proxy measure for identifying the presence, and with appropriate metadata, the abundance of megaherbivores. The abundance and concentration of *Sporormiella* spores can be used to assess the timing of the functional extinction of the late-Pleistocene megafauna in the Neotropics.

Distance from the source of dispersion plays an important role in the abundance of spores recovered. As the distance towards the center of the lake increases, the number of spores decreases considerably. Therefore, the location of the core relative to paleoshorelines is important for fossil reconstructions. To overcome this issue multiple cores taken across a basin, cores close to the shoreline of a lake or using independent proxies for lake depth such as fossil diatom abundances coupled with bathymetric models could be used to refine analyses.

As previously stated by some authors (Baker et al. 2013, Johnson et al. 2015), the study of representation of the coprophilous genus *Sporormiella* offers an immense opportunity for a complete approach to understand the past environment: ecosystem and biodiversity of megafauna. Extinctions are extremely complicated processes and are seldom caused by a single, distinct event. In most cases, extinctions are a consequence of a major event that culminates in cascading effects that disturb entire systems (Raup 1991, 1994). We may never identify a single cause for the loss of the Pleistocene megafauna, however, we should make use, as much as we can, of any tool available to understand it; analysis of *Sporormiella* is certainly one of those tools.

Acknowledgments

This research was funded by National Science Foundation (NSF) award DEB 1260983. We thank Instituto Estadual de Florestas (IEF/MG), and Gerência de Projetos e Pesquisas (GPROP) for the authorization (UC 044/13) to collect samples at Lagoa do Sumidouro. We also thank Paulo Eduardo De Oliveira and Rudney Almeida for the field assistance. We also thank Pablo Juarbe Martinez for helping with the pictures.

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Received 20/07/2015
Revised 24/01/2016
Accepted 2/03/2016

Biota Neotropica 16(1): e20140192, 2015
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
inventory

Fish fauna from Sapucaí-Mirim River, tributary of Grande River, upper Paraná River basin, Southeastern Brazil

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OLIVEIRA, A.K., GARAVELLO, J.C., CESARIO, V.V., CARDOSO, R.T. **Fish fauna from Sapucaí-Mirim River, tributary of Grande River, upper Paraná River basin, Southeastern Brazil.** Biota Neotropica. 16(1): e20140192. http://dx.doi.org/10.1590/1676-0611-BN-2014-0192

Abstract: The fish species composition of Sapucaí-Mirim River is herein reported and discussed in the faunistic context of Grande and Paranaíba river basins, both formers of the Paraná River. The Sapucaí-Mirim is an important tributary of this hydrographic system, flowing to the left bank of Grande River in a region occupied by the reservoir of the Porto Colombia hydroelectric power plant, at São Paulo state northeastern region, in southeastern Brazil. The poorly known fish diversity of the Sapucaí-Mirim River is presented on basis of sampling efforts conducted in the main river channel and three creeks located at the mid and lower sections of the basin, allowing comparisons of the fish fauna of these two sections in the light of available information of fish inhabiting Grande and Paranaíba river basins. The study of the fish composition resulted in the recognition of 68 species in the Sapucaí-Mirim River, belonging to 23 families distributed in seven orders, all commonly found in upper Paraná River basin: Characiformes (32 spp.), Siluriformes (25 spp.), Labriformes (4 spp.), Gymnotiformes (3 spp.), Cyprinodontiformes (2 spp.), Perciformes (one species) and Synbranchiformes (one species). Most of the species are representative of the native ichthyofauna, but the total diversity also includes allochthonous species, which were chiefly found in the lower stretch studied. Some species found in the Sapucaí-Mirim River require great areas for their maintenance, as do large-sized species, known to have migratory reproductive habits. Also, the diversity of small and medium-sized species found and their distinct morphological and biological attributes, allied to the occurrence of endangered fish species, indicate that the Sapucaí-Mirim River basin is an important place for fish diversity maintenance in the Grande River hydrographic system.

Keywords: *Neotropical region, freshwater fishes, composition, biodiversity, spatial distribution.*

OLIVEIRA, A.K., GARAVELLO, J.C., CESARIO, V.V., CARDOSO, R.T. **Fauna de Peixes do rio Sapucaí-Mirim, tributário do rio Grande, bacia do alto rio Paraná, sudeste do Brasil.** Biota Neotropica. 16(1): e20140192. http://dx.doi.org/10.1590/1676-0611-BN-2014-0192

Resumo: A composição de espécies de peixes do rio Sapucaí-Mirim é registrada e discutida no âmbito do conjunto faunístico das bacias dos rios Grande e Paranaíba, ambos formadores do rio Paraná, no sudeste do Brasil. O rio Sapucaí-Mirim é um importante, mas pouco conhecido tributário deste sistema hidrográfico, desembocando na margem esquerda do rio Grande, na área atualmente ocupada pelo reservatório da Usina Hidrelétrica de Porto Colômbia, na região nordeste do estado de São Paulo. A diversidade de peixes do rio Sapucaí-Mirim é apresentada com base em dados comparativos obtidos de populações do canal principal do rio e de três córregos localizados nos trechos médio e inferior da bacia, possibilitando uma discussão comparativa entre os dois trechos a luz de informações existentes sobre a fauna de peixes das bacias dos rios Grande e Paranaíba. O estudo da fauna de peixes resultou no reconhecimento de 68 espécies de peixes distribuídas em 23 famílias e pertencentes às sete ordens comumente encontradas na bacia do alto rio Paraná: Characiformes (32 spp.), Siluriformes (25 spp.), Labriformes (4 spp.), Gymnotiformes (3 spp.), Cyprinodontiformes (2 spp.), Perciformes (1 espécie) e Synbranchiformes (1 espécie). A maioria das espécies é representativa da ictiofauna nativa distribuída nos rios Grande e Paranaíba, mas a diversidade total também inclui espécies alóctones, registradas principalmente no trecho inferior. Algumas espécies encontradas no rio Sapucaí-Mirim requerem grandes áreas para sua manutenção, tais como aquelas de grande porte, conhecidas por apresentarem hábitos reprodutivos migratórios. Também, a diversidade de espécies de pequeno e médio porte e seus diferentes atributos biológicos exibidos, aliados ao registro de espécies ameaçadas na bacia do alto rio Paraná, permitem considerar a bacia do rio Sapucaí-Mirim como um importante local para manutenção da diversidade da ictiofauna no sistema hidrográfico do rio Grande.

Palavras-chave: *Região Neotropical, peixes de água doce, composição, biodiversidade, distribuição espacial.*

Introduction

The Sapucaí-Mirim River, situated in northeastern of the São Paulo State, is part of a great drainage area in the upper Paraná River basin that includes the rivers Grande, Pardo and Mogi-Guaçu, three basins that have their fish fauna relatively well known, in comparison with other regions of South America. In fact, this is a region where naturalists have been gathering information and documenting the fish fauna since early XIX century, when Johann Natterer collected specimens of the ichthyofauna that were studied and described by European naturalists (Heckel 1840, Vanzolini, 1993). Initially, until near the 1930s, the studies focused on collecting and describing the species. Later, studies covered up many ichthyological subjects, including lists of species in some areas, descriptions on the species diversity, and studies on biology and ecology of fish populations (see Godoy 1975, Castro & Casatti 1997, Santos & Formagio 2000, Oliveira & Garavello 2003, Birindelli & Garavello 2005, Apone et al. 2008, Oliveira et al. 2009 for overview about those studies).

Although there is significant amount of information on the fish fauna of the upper Paraná River basin, some areas within this drainage lack studies on ichthyological diversity, which represent gaps on the knowledge of species distribution and restrict comparisons with areas already studied. The Sapucaí-Mirim River basin represents one of these little-documented areas and, as other rivers in the upper Paraná basin, is actually been sectioned by hydroelectric power plant dams. Castro et al. (2004) have inventoried small tributaries of the Sapucaí-Mirim River in a broader study about streams fish composition of the Grande River basin, but Casatti et al. (2008) stated that the Sapucaí-Grande is one of the management units of hydric resources in São Paulo State that still need sampling efforts for a better understanding of its fish fauna. A report on the fish fauna composition and structure before the reservoirs had been filled is welcome, since it allows posterior comparative studies and is useful as basis for fish management and conservancy.

In view of the deficiency of information mentioned above and the continuous environmental changes, chiefly the damming process, a study on fish fauna composition and structure in the middle and lower stretches of Sapucaí-Mirim River basin, near the municipalities of São Joaquim da Barra and Guaíra respectively, is herein presented. Fish assemblages from the main channel and three creeks of these two stretches of the Sapucaí-Mirim River basin are reported and their role on the ichthyofaunistic diversity of upper Paraná River system, particularly in Grande and Paranaíba River basins, is discussed.

Material and Methods

1. Study area

The Sapucaí-Mirim River has its headwaters near the crystalline shield of Serra da Laje, at approximately 1,150 m of altitude, in the inland slope of mountains situated near the boundary of the northeastern São Paulo and Minas Gerais states. The drainage is geologically located near the East border of the Paraná Province, on the Serra Geral Basin (Silva et al. 2003). It is a medium-sized Brazilian river with strong riffles and small waterfalls intercalated by runs in its mid course, changing into slow waters and without turbulence in the lower region, where it meets and receives the influence of the lentic waters of the UHE Porto Colombia reservoir, in Grande River. As component of the large aquatic complex of the Grande River, the Sapucaí-Mirim River can be considered among the few rivers from Southeast Brazilian region that remained with its original hydric characteristics relatively preserved until the beginning of the XXI century. In fact, the main Sapucaí-Mirim River channel presented until near 2010 only two small centennial hydroelectric power station: the São Joaquim (previously called Evangelina) Station, constructed in 1911, and Dourados Station, from 1926, both located upstream to the areas herein studied, and thus remaining a river dam free long stretch downstream till the Sapucaí-Mirim River mouth in the Grande River.

Fish sampling were performed at two sites of the Sapucaí-Mirim River, one in its mid stretch (approximate coordinate 20°29′49″S and 47°51′50″W), at the municipality of São Joaquim da Barra, and other in the lower stretch of the drainage, at Guaíra municipality (approximate coordinate 20°11′43″S and 48°15′15″W), at São Paulo State (Figure 1).

The section near São Joaquim da Barra is characterized as a lotic environment, with cobblestones and sand, strongly typifying a rapid with rocky floor large cataracts and small falls, with depth not surpassing three meters deep at the deepest places. This section includes few navigate areas, with lower water velocity and deeper pools, showing short sand areas in the banks with marginal vegetation, thus representing most of the original features of this river.

The section near the municipality of Guaíra has other hydrological characteristics. This area presents running waters without rapids as observed in the middle section. At this area the depth reach up to six meters or more at some great pools, allowing navigation in the Sapucaí-Mirim River downstream to Porto Colombia reservoir. With sandy bottom and preserved banks vegetation, this section of Sapucaí-Mirim is under influence of the reservoir waters. From this place to the large reservoir, where its waters flow, one can observe that there are relatively small variations on the river depth and more homogenous environmental features in comparison with the middle section.

Additionally, three creeks of the Sapucaí-Mirim River basin were sampled in the species inventory. Two of them are left bank tributaries in the mid stretch region (Barra Creek and Imbaúba Creek), near São Joaquim da Barra municipality, and the third (Corta Pescoço Creek) is also a left bank affluent, but located in the lower stretch of the Sapucaí basin, near Guaíra municipality. The sampled stretches of the creeks were located near their mouth within Sapucaí-Mirim and characterized by

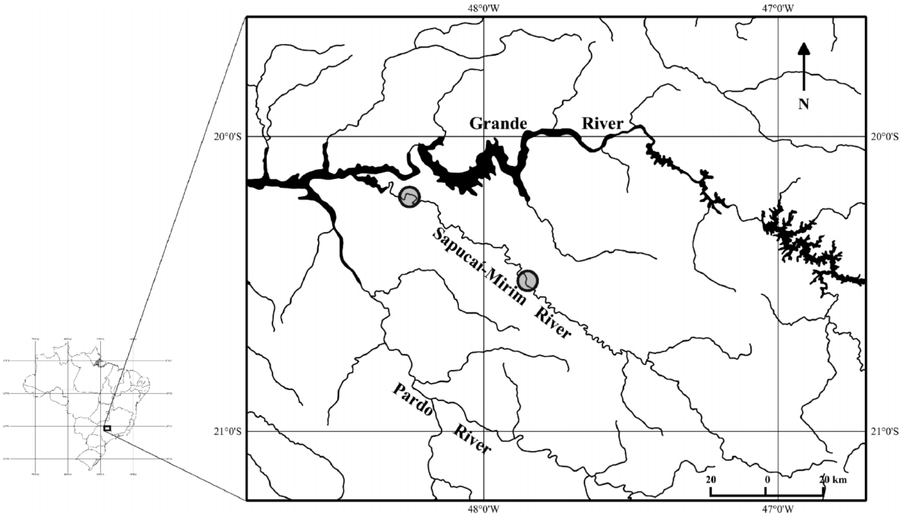

Figure 1. Map showing location of Sapucaí-Mirim River in Grande River basin. Grey circles show the mid and lower studied stretches in the Sapucaí-Mirim River, São Paulo State.

Figura 1. Mapa mostrando a localização do Rio Sapucaí-Mirim na bacia do rio Grande. Círculos em cinza mostram os trechos, médio e baixo, estudados no rio Sapucaí-Mirim, Estado de São Paulo.

sandy bottom pools and runs with moderate water velocity. The creeks are inserted in areas predominantly occupied by sugar cane culture, but their margins presented herbaceous vegetation, shrubs and trees along the sampled stretches.

2. *Fish sampling and analysis*

The ichthyofauna of the Sapucaí-Mirim River was characterized based on fish samplings performed in the main channel and creeks, in different periods. The main river channel at mid stretch was sampled in June 2004, in January, July, August and October 2008, and in February 2009. The lower stretch was sampled in July 2007, January 2008, and in April and June 2009. In these field surveys, fish were caught using gill nets (20 m length, 15 to 80 mm mesh between adjacent knots, installed in the evening and standing in the water for approximately 12 hours until the early morning of next day), casting nets and a small seine net (3 m length and 3 mm mesh). Each fishing gear was applied in appropriate places along the sampled stretch, so gill nets were used in deeper pools, and active fishery gears were applied in shallow places, as small sand beaches, in rapids and under the river bank vegetation. The creeks were sampled in August and October 2008, and in April 2009, using the small 3 mm mesh seine net in stretches located near their mouth within the Sapucaí-Mirim River.

Sampled fishes had their standard length (mm) measured, except Gymnotiformes and Synbranchiformes species, from which total length were registered. All fish specimens collected in the creeks were immediately fixed in 10% formalin, as do some voucher specimens caught in main river channel. In the laboratory the fixed specimens were transferred to a solution of ethanol 70%. Voucher specimens are deposited at the Laboratório de Ictiologia Sistemática da UFSCar (LISDEBE) fish collection under numbers LISDEBE 2140-2163, 2298-2350, 4058-4103, 4309-4377, 4461-4464, 4839 and 6112. Fish species identification was based on comparative ichthyological material from LISDEBE and on consulting specific taxonomic and systematic literature of fish groups. Systematic classification follows Reis et al. (2003) and updated information according to Van der Laan et al. (2014) and Wiley & Johnson (2010), who classified the Cichlidae family as part of Labriformes order. Some species were identified as non-native following Langeani et al. (2007).

The maximum body size of the species were separated in seven classes, following Sturges (1926), to construction of a frequency of occurrence graph and characterization of the body size structure of fish assemblage in the Sapucaí-Mirim River. Body size and fish ecological traits are discussed from the knowledge of the actual ichthyological scenario of the Grande River basin.

Results

The inventory of fish fauna from Sapucaí-Mirim River basin resulted in the identification of 68 species from the collection of 2132 specimens. The species belong to the seven fish orders originally found in upper Paraná River: Characiformes, Siluriformes, Gymnotiformes, Cyprinodontiformes, Synbranchiformes, Labriformes and Perciformes. Characiformes summed 32 species distributed in 10 families: Characidae (11 species), Anostomidae (seven species), Parodontidae and Serrasalmidae (three species each), Curimatidae and Bryconidae (two species), and Crenuchidae, Acestrorhynchidae, Erythrinidae and Prochilodontidae (with one species each). Siluriformes presented 25 species distributed in seven families: Loricariidae (11 species), Heptapteridae (four species), Pimelodidae (four species), Callichthyidae (3 species), and Doradidae, Pseudopimelodidae and Auchenipteridae (a single species each). Labriformes presented four species (all of the family Cichlidae). Gymnotiformes were represented by three species of the families Apteronotidae, Sternopygidae and Gymnotidae (each with a single species). Cyprinodontiformes presented two species of the family Poeciliidae. Perciformes and Synbranchiformes presented one species each, of the families Sciaenidae and Synbranchidae, respectively. Of the 68 inventoried species, 61 were registered in the main river channel (Table 1) and 17 were registered in the creeks (Table 2).

In the main river channel, the middle section at São Joaquim da Barra revealed 51 species, and the lower section of the river, at the area of Guaíra, showed 38 species (Table 1). From the 61 collected species in the river main channel habitats, 28 (46%) were common to both basin stretches. The

Table 1. Species list, number of specimens, and body size (minimum and maximum in mm) of the fish species registered in the main river channel at the two studied sections (mid and lower stretches) of Sapucaí-Mirim River basin, in São Paulo State. Voucher represents the register number of lots deposited in LISDEBE fish collection (X - species from which fish specimens were not deposited in collection but identified and measured during field work).

Tabela 1. Lista de espécies, número de espécimes, e tamanho de corpo (mínimo e máximo em mm) das espécies de peixes registradas na calha principal nas duas seções estudadas (trechos médio e inferior) na bacia do rio Sapucaí-Mirim, no estado de São Paulo. Voucher representa os números de tombo dos lotes depositados na coleção de peixes do LISDEBE (X – espécies cujos espécimes não foram depositados em coleção, mas identificados e medidos durante os trabalhos de campo).

	Mid stretch			Lower stretch			
		body size (mm)			body size (mm)		
	N	min.	max.	N	min.	max.	Voucher
Characiformes							
Parodontidae							
Apareiodon affinis (Steindachner, 1879)	20	102.0	146.0	0			4324
Apareiodon piracicabae (Eigenmann, 1907)	16	33.7	125.8	0			4340
Parodon nasus Kner, 1859	22	64.3	135.0	0			4364
Curimatidae							
Cyphocharax modestus (Fernándes-Yépez, 1948)	3	85.0	117.0	0			X
Steindachnerina insculpta (Fernández-Yépez, 1948)	86	80.0	123.0	40	80.0	125.0	4090
Prochiolodontidae							
Prochilodus lineatus (Valenciennes, 1837)	13	134.0	393.0	2	101.0	144.0	4463
Anostomidae							
Leporinus amblyrhynchus Garavello & Britski, 1987	13	108.0	221.8	0			4362
Leporinus obtusidens Valenciennes, 1837	1	198.0		1	320.0		4319
Leporinus aff. *friderici* (Bloch, 1794)	29	145.0	320.0	34	120.6	353.0	4367
Leporinus lacustris Amaral Campos, 1945	0			2	143.0	164.0	2301
Leporinus octofasciatus Steindachner, 1915	15	97.0	245.0	2	188.0	228.0	4366
Leporinus striatus Kner, 1858	8	97.0	109.0	1	102.2		4361
Schizodon nasutus Kner, 1858	5	226.0	335.0	13	145.0	359.0	4464
Erythrinidae							
Hoplias cf. *malabaricus* (Bloch, 1794)	1	291.0		11	144.5	357.0	2148
Acestrorhynchidae							
Acestrorhynchus lacustris (Lütken, 1875)	0			1	140.0		X
Serrasalmidae							
Metynnis maculatus (Kner, 1858)	5	75.0	123.1	3	90.0	105.9	4096
Myleus tiete (Eigenmann & Norris, 1900)	0			1	275.0		4318
Serrasalmus maculatus Kner, 1858	0			2	67.7	88.1	2150
Characidae							
Astyanax altiparanae Garutti & Britski, 2000	212	64.0	169.0	36	63.0	125.0	4091
Astyanax fasciatus (Cuvier, 1819)	340	72.0	147.0	19	68.0	122.4	4088
Astyanax schubarti Britski, 1964	3	82.4	130.2	6	63.5	69.2	2154
Astyanax bockmanni Vari & Castro, 2007	45	16.0	83.0	0			4328
Bryconamericus stramineus Eigenmann, 1908	12	18.1	74.8	0			4085
Bryconamericus sp.	7	24.7	44.4	0			4086
Galeocharax knerii (Steindachner, 1879)	12	133.0	245.0	25	132.7	165.0	4327
Piabina argentea Reinhardt, 1867	5	54.1	94.0	0			4083
Bryconidae							
Salminus brasiliensis (Cuvier, 1816)	1	480.0		1	364.0		2146
Salminus hilarii Valenciennes, 1850	19	124.0	317.0	9	104.3	242.0	4462
Siluriformes							
Doradidae							
Rhinodoras dorbignyi (Kner, 1855)	1	220.0		4	90.0	143.0	2304
Auchenipteridae							
Glanidium cesarpintoi Ihering, 1928	1	87.6		0			2349
Pimelodidae							
Iheringichthys labrosus (Lütken, 1874)	4	133.0	164.0	0			4330
Pimelodus microstoma Steindachner, 1877	32	114.0	326.0	0			4375
Pimelodus maculatus Lacépède, 1803	0			10	245.0	342.0	2305
Pimelodus sp.	0			1	193.0		2327

Continued on next page

Table 1. Continued.

	Mid stretch			Lower stretch			
		body size (mm)			body size (mm)		
	N	min.	max.	N	min.	max.	Voucher
Pseudopimelodidae							
Pseudopimelodus mangurus (Valenciennes, 1835)	1		453.0	1	115.3		4377
Heptapteridae							
Imparfinis schubarti (Gomes, 1956)	5	98.2	107.0	0			4341
Pimelodella cf. *gracilis* (Valenciennes, 1835)	20	92.7	134.6	0			2316
Rhamdia quelen (Quoy & Gaimard, 1824)	17	113.0	287.0	4	192.0	263.0	2325
Callichthyidae							
Callichthys callichthys (Linnaeus, 1758)	0			3	175.0	194.0	X
Hoplosternum littorale (Hancock, 1828)	5	148.0	201.0	8	124.0	186.0	4310
Megalechis thoracata (Valenciennes, 1840)	1	122.0		29	118.0	147.0	2299
Loricariidae							
Hypostomus ancistroides (Ihering, 1911)	76	15.0	130.0	39	74.7	124.0	4087
Hypostomus heraldoi Zawadzki, Weber & Pavanelli, 2008	62	100.0	270.0	0			4101
Hypostomus cf. *margaritifer* (Regan, 1908)	102	103.0	270.0	4	151.0	204.0	2335
Hypostomus nigromaculatus (Schubart, 1964)	3	54.9	64.5	0			2333
Hypostomus paulinus (Ihering, 1905)	114	62.0	154.0	6	104.0	142.0	4355
Hypostomus regani (Ihering, 1905)	97	73.0	246.0	14	99.8	198.0	4358
Hypostomus cf. *strigaticeps* (Regan, 1908)	81	65.0	204.0	4	125.0	224.0	4357
Hypostomus sp. A	13	55.0	130.0	11	74.6	123.0	4322
Hypostomus sp. B	7	120.0	142.0	0			4373
Loricaria lentiginosa Isbrücker, 1979	21	152.0	390.0	11	172.0	371.0	4376
Rineloricaria latirostris (Boulenger, 1900)	21	100.8	135.3	3	116.7	133.3	4344
Gymnotiformes							
Sternopygidae							
Eigenmannia virescens (Valenciennes, 1836)	7	183.0	262.0	0			2323
Apteronotidae							
Apteronotus brasiliensis (Reinhardt, 1852)	1	298.0		0			4097
Gymnotidae							
Gymnotus sp.	3	373.0		0			4321
Cyprinodontiformes							
Poeciliidae							
Phalloceros harpagos Lucinda, 2008	5	15.2	24.0	0			4080
Synbranchiformes							
Synbranchidae							
Synbranchus marmoratus Bloch, 1795	1	200.0		0			X
Perciformes							
Sciaenidae							
Plagioscion squamosissimus (Heckel, 1840)	0			46	159.0	373.0	2142
Labriformes							
Cichlidae							
Crenicichla jaguarensis Haseman, 1911	0			3	143.9	161.0	2140
Geophagus brasiliensis (Quoy & Gaimard, 1824)	15	19.1	161.0	0			4081
Satanoperca pappaterra (Heckel, 1840)	0			1	154.0		2141
Richness	51			38			
Total abundance	1609			411			

collection sites near the cataracts and waterfalls, in the mid stretch, showed higher specific richness, presenting also more fish families (20 families *vs.* 15 families in the lower stretch). More species per family were registered in the mid stretch, except for the families Serrasalmidae, Callichthyidae, Cichlidae and Sciaenidae. All Gymnotiform families were only registered in this richest middle stretch. Loricariidae (with 11 species in the mid *vs.* 8 species in lower stretch) and Characidae (with 8 species in the mid *vs.* 4 species in lower stretch) were the most species-rich families in the main river channel. Four registered species in the main river channel are considered non-native for the upper Paraná River basin: *Metynnis maculatus* (Kner, 1858), *Satanoperca pappaterra* (Heckel, 1840) and *Plagioscion squamosissimus* (Heckel, 1840) were found only in the lower stretch near the municipality of Guaíra, whereas *Megalechis thoracata* (Valenciennes, 1840) was present in both stretches.

Of the 17 species registered in the three creeks, seven species were found exclusively in this kind of environment: *Astyanax* aff.

paranae Eigenmann, 1914, *Cheirodon stenodon* Eigenmann, 1915, *Hyphessobrycon eques* (Steindachner, 1882), *Characidium* aff. *zebra* Eigenmann, 1909, *Cetopsorhamdia iheringi* Schubart & Gomes, 1959, *Poecilia reticulata* Peters, 1859 and *Laetacara* aff. *araguaiae* Ottoni & Costa, 2009 (Table 2). Of these, *Poecilia reticulata* is non-native for the basin. The species richness in the creeks ranged from three species in the Imbaúba Creek to nine species in the Barra Creek, summing 11 species in these creeks from mid section of the basin. The Corta Pescoço Creek located in the lower portion of the Sapucaí-Mirim drainage, presented 7 species (Table 2).

The range of the species maximum body size (23 mm in *Poecilia reticulata* to 480 mm in *Salminus brasiliensis* (Cuvier, 1816)) encloses part of the different biological characteristics exhibited by the fish diversity found in the Grande River basin. The frequency distribution of the maximum body size classes of the fish species inventoried (Figure 2) showed that the majority of the species are small sized (with less than 200 mm SL), but species that reach medium (up to 400 mm SL) to great size (> 400 mm) were also registered. Small characids, crenuchids, cyprinodontiforms, heptapterids are examples of those smallsized species (Tables 1 and 2). Medium sized are represented by serrasalmids, characins, loricariids and some anostomids (Table 1). Large sized species includes those normally considered migratory native species, such as *Salminus brasiliensis*, *Leporinus obtusidens* Valenciennes, 1837 and *Prochilodus lineatus* (Valenciennes, 1837), and other non-migratory species, such as *Loricaria lentiginosa* Isbrücker, 1979 and *Hoplias* cf. *malabaricus* (Bloch, 1794).

Discussion

The fish fauna of the Sapucaí-Mirim River was chiefly composed by native species of the upper Paraná River drainage, comprising the six fish orders historically assigned for this basin. We classified the fish species in seven orders, following Wiley & Johnson (2010) and considering the Cichlidae family in the Labriformes order, although this is traditionally reported as a family member of the Perciformes order. The dominance of Characiformes and Siluriformes in species richness reflects the ichthyofaunistic diversity of the Neotropical region, where these and the other ostariophysan order Gymnotiformes are the most

Table 2. Species list and number of specimens registered in the tree creeks sampled in two sections (mid and lower stretches) of the Sapucaí-Mirim River basin, in São Paulo State. Barra Creek and Imbaúba Creek are of the mid stretch; Corta Pescoço Creek flow to lower stretch. Body size (minimum and maximum in mm) and voucher lots of LISDEBE fish collection are also presented.

Tabela 2. Lista de espécies e número de espécimes registrados nos três córregos amostrados em duas seções (trechos médio e inferior) da bacia do rio Sapucaí-Mirim, no Estado de São Paulo. Córregos da Barra e Córrego Imbaúba são afluentes do trecho médio da bacia; Córrego Corta Pescoço é afluente do trecho inferior. Tamanhos de corpo (mínimo e máximo em mm) e lotes testemunhos da coleção de peixes do LISDEBE (Voucher) também são apresentados.

	Barra	**Imbaúba**	**Corta Pescoço**	**Body Size (mm)**		**Voucher**
	Creek	**Creek**	**Creek**	**min.**	**max.**	
Characiformes						
Characidae						
Astyanax fasciatus (Cuvier, 1819)	1		2	32.8	33.4	4068
Astyanax aff. *paranae* Eigenmann, 1914		5		31.5	39.2	4078
Astyanax schubarti Britski, 1964			1	42.7		4059
Bryconamericus stramineus Eigenmann, 1908			3	33.7	41.5	4060
Bryconamericus sp.			9	22.9	32.8	4062
Cheirodon stenodon Eigenmann, 1915			27	16.7	24.2	6112
Hyphessobrycon eques (Steindachner, 1882)			15	13.5	28.1	4058
Piabina argentea Reinhardt, 1867	16			28.4	56.5	4071
Crenuchidae						
Characidium aff. *zebra* Eigenmann, 1909	2			53.0	54.4	4074
Heptapteridae						
Cetopsorhamdia iheringi Schubart & Gomes, 1959	1			41.0		4072
Imparfinis schubarti (Gomes, 1956)	1			53.1		4075
Pimelodella cf. *gracilis* (Valenciennes, 1835)	1			103.7		4066
Loricariidae						
Hypostomus ancistroides (Ihering, 1911)	7	3		16.5	96.4	4076
Gymnotiformes						
Sternopygidae						
Eigenmannia virescens (Valenciennes, 1836)		1		246.0		4079
Cyprinodontiformes						
Poeciliidae						
Poecilia reticulata Peters, 1859	14			13.0	23.8	4069
Labriformes						
Cichlidae						
Geophagus brasiliensis (Quoy & Gaimard, 1824)	1			136.4		4065
Laetacara aff. *araguaiae* Ottoni & Costa, 2009			2	22.7	32.5	4063
Richness	**9**	**3**	**7**			
Total abundance	**44**	**9**	**59**			

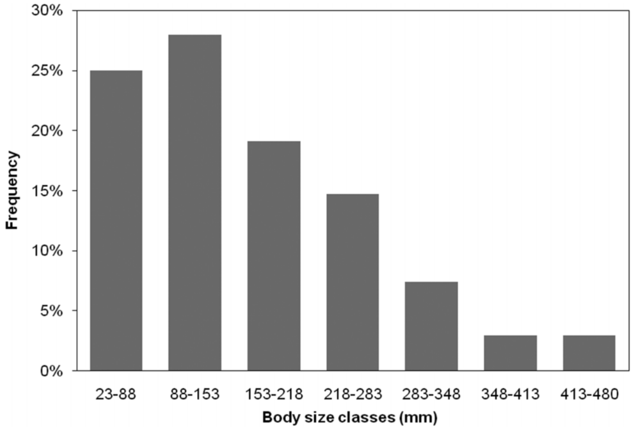

Figure 2. Frequency of occurrence of the fish species maximum body size classes in the Sapucaí-Mirim River, São Paulo State.
Figura 2. Frequência de ocorrência das classes de tamanhos máximos das espécies registradas no rio Sapucaí-Mirim, Estado de São Paulo.

species rich high taxonomical level groups (Albert et al. 2011). According to those authors, despite the exceptional species diversity, the ichthyofauna of the Neotropical region is relatively poor in higher taxonomical levels in comparison with other regions of the world. Additionally to the aforementioned fish orders, Cyprinodontiformes and Synbranchiformes complete the high taxonomical level groups found in the Sapucaí-Mirim River.

Naturally, the well-preserved Sapucaí-Mirim River fish species level composition contains part of the upper Paraná River basin diversity, representing near 20% of the species richness reported by Langeani et al. (2007) for the whole basin. As expected, the fish species inhabiting the Sapucaí-Mirim are shared with the main channel or tributaries of Grande and Paranaíba rivers, as registered by Paiva et al. (2002), Santos (2010), Pavanelli et al. (2007), Langeani & Rêgo (2014) and Sanchez et al. (2014). But these two river basins, formers of the upper Paraná River, also share species with other great rivers that drains the Brazilian Shield plateau, as the Tocantins and São Francisco rivers. Although upper Paraná, São Francisco and Tocantins basins have some degree of endemism, justifying them as ichthyofaunistic provinces (Gery 1969), or as freshwater ecoregions (Abell et al. 2008), the existence of some sheared fish groups and species is evidence of recent reorganization of the fish fauna in these drainages, chiefly in their upper portions. According to Albert & Carvalho (2011), the rearrangements of headwater streams, including barrier formation or drainage capture, result in vicariance or geodispersal processes that influence the Neotropical fish distribution. The geomorphological dynamic that have been occurred since Neogene and extended through Quaternary period in areas of the Brazilian Shield plateau and the biological properties of the species must be considered relevant to understand the fish composition and distribution within and among drainages. In this historical perspective, the native fish fauna here reported to the Sapucaí-Mirim River must be considered result of these complex geological and biological events that still need to be better investigated.

Additionally, to interpret the fish assemblage structure of the Sapucaí-Mirim River is important to understand the ichthyological scenario in the Grande River basin and its environmental state. Southeastern Brazil has their natural areas intensely changed in comparison with other regions of the country. Aquatic environments in this region are mostly changed as consequence of deforestation of rivers banks and damming. The main river channel of the Grande River basin was sectioned by several dams and is actually modified in a hydroelectric complex constituted by a succession of great reservoirs (Agostinho et al. 2008). Dams may intercept the reproductive migration route of several species, interfering over the biogenic capability of the ichthyofauna in the hydrographic system, reducing the food supply and the refuge for the juvenile ichthyofauna as a whole (Agostinho et al. 1994). In this scenario of successive dams located in the main channel of great rivers, tributaries provide environmental requisites (*i.e.*, less modified hydrodynamics and habitats features) for fish maintenance and may be important for fish diversity conservation.

In the middle Grande River drainage, the Sapucaí-Mirim River and the Uberaba River are the main tributaries of the Porto Colombia Hydroelectric Power Plant reservoir. According to Santos (2010), these two tributaries probably represent important spawning sites for the migratory fish species from this reservoir system. A large number of Neotropical fish species from reservoirs access lateral tributaries of these water bodies or other upstream lotic environments to spawn or feed, as indicated by Agostinho et al. (2008). Vazzoler et al. (1997) noted that large sized species, including *Prochilodus lineatus*, *Salminus brasiliensis*, *Pimelodus maculatus* Lacépède, 1803 and *Leporinus obtusidens*, perform great migratory dislocation to spawn at upper stretches of the tributaries of Paraná River, upstream of the Itaipú Power Plant reservoir. This pattern was also evidenced by Santos & Formagio (2000) in the Grande River system, where a large number of medium and large sized species leave the hydroelectric reservoir during the reproductive period. In the Sapucaí-Mirim River some migratory species that attain more than 400 mm standard length were registered, as *Salminus brasiliensis*, *Salminus hilarii* Valenciennes, 1850, *Prochilodus lineatus*, *Pseudopimelodus mangurus* (Valenciennes, 1835) and *Leporinus obtusidens*. The presence of the large-sized migratory species, such as *Salminus brasiliensis* and *Prochilodus lineatus*, in both sections of Sapucaí-Mirim River demonstrates the importance of this river as an alternative route for species that require long migrations to realize its reproductive processes.

On the other hand, the species composition registered in the Sapucaí-Mirim River includes groups of species with other functional attributes relative to those exhibited by large sized species. This reflects the fish morphological diversity find in the Grande and Paranaíba river basins (as shown in the studies of Paiva et al. 2002, Santos 2010, Pavanelli et al. 2007, Langeani & Rêgo 2014 and Sanchez et al. 2014). Promptly distinction of this diversity concerns to species body size. Most of the fish species found in the Sapucaí-Mirim River is composed by small to medium-sized species, of which individuals do not perform long dislocation during their life history. Probably, populations of these species inhabit more restricted areas relative to great sized species. The small-sized species are composed chiefly by characids, parodontids, curimatids, crenuchids, heptapterids and cyprinodontiforms. These groups occur in main channels of great rivers and their distributions commonly include also small rivers and streams in the upper Paraná River basin.

In the same way, medium-sized species (*e.g.*, characiforms of the genera *Galeocharax*, *Hoplias*, *Acestrorhynchus* and some anostomids; siluriforms of the genera *Pimelodus*, *Hypostomus* and the callichthyids; gymnotiforms; and cichlids) that are commonly found in main river channels may be distributed in small rivers of the Grande River basin, as observed by Oliveira et al. (2009) in tributaries of Mogi Guaçu River. Some of the medium sized species also need free impoundment river flow for their biological activities, as do the Loricariidae fishes. It is noteworthy that approximately 13% of the species belong to the genus *Hypostomus*, known to inhabit preferentially rocky bottom (Garavello & Garavello 2004) and turbulent water environments, as found in the middle stretch studied in Sapucaí-Mirim River basin. Medium-sized species of other fish groups also indicate that Sapucaí-Mirim furnishes shelter for fish that require riverine environmental conditions, as do the anostomids of genus *Leporinus* and *Schizodon*, the serrasalmid *Myleus tiete* (Eigenmann & Norris, 1900) and catfishes of the genus *Pimelodus*.

Comparing the mid and lower stretches of the river, the higher ichthyofauna richness found at the middle section (São Joaquim) may be explained by local aquatic conditions with hydrological characteristics similar to the original environment of this river before damming events. This middle stretch area is more heterogeneous and presents a large amount of aquatic niches viable to be explored by species presenting distinct morphological traits as, for example, bottom, nektonic and bank dwellers. The lower section (Guaíra) has the fish composition similar to that of the Porto Colombia reservoir, at Grande River (Gilmar B. Santos and Jefferson L. G. Pimenta, personal communication), which presents less species richness (approximately 30 spp.) and some non-native species, as the sciaenid *Plagioscion squamosissimus*, and cichlids *Cichla* sp. and *Satanoperca pappaterra.* The similarity of the fish composition among the Porto Colômbia Reservoir and the Guaíra stretch may be attributed to the geographical proximity, and probably an influence of the hydrological changes and other modifications of the original environmental characteristics allied to the lacustrine reservoir condition, which interfere in the native populations and turn feasible the colonization by non-native species. So, the differences found in species richness and composition of ichthyofauna registered in the two studied stretches of the Sapucaí-Mirim main river channel may be interpreted as result of natural distribution plus environmental changes. It is noteworthy that the habitat changes in function of human occupation are still in course in Sapucaí basin, including river damming process.

Concerning the fish composition of the three sampled creeks in Sapucaí-Mirim basin, the registered species obviously represent a fraction of the fauna distributed in streams of the upper Paraná River basin. Castro et al. (2004), studying the fish composition in streams of the Grande River basin, reported 41 species for six streams of the Sapucaí-Mirim River basin, with richness ranging from 5 to 26 species. Here we registered 17 species with richness ranging from 3 to 9. The fauna found in the creeks was composed by small sized species and almost all of them were cited by Castro et al. (2004). Three species herein reported (*Cheirodon stenodon* Eigenmann, 1915, *Astyanax schubarti* Britski, 1964 and *Laetacara* aff. *araguaiae* Ottoni & Costa, 2009) should be added to those authors list for the Sapucaí-Mirim River basin streams. This fact reinforces the need to increase sampling efforts in streams environments within the basin, chiefly in headwaters areas near the watersheds with adjacent river drainages.

The poorly explored Sapucaí-Mirim River showed a fish composition that includes high diversity of fish groups and encompasses much ecological diversity. It also presents rare species (as *Glanidium cesarpintoi* Ihering, 1928), some of them probably new to science (as *Hypostomus* sp.) and others that have been cited in threatened species lists. *Myleus tiete* figures as endangered in the national published list by Brasil (2014), and *Pseudopimelodus mangurus* was classified by Oyakawa et al. (2009) as vulnerable in the list of São Paulo State. The occurrence of these species and the significant fish richness registered may be attributed to the good environmental condition exhibited by the Sapucaí-Mirim River in the studied area during the sampling period.

Unfavorably, as the Sapucaí-Mirim is inserted in one of the most densely occupied region of Brazil, the anthropogenic pressure may change the properties of the fish assemblage structure in the future, chiefly because the basin is actually being dammed for hydroelectric purposes. The environmental threat includes not only damming, but also other processes that occur in the drainage area of Sapucaí-Mirim, as deforestation and urban and agricultural waste discharge. Allied to the physical chemical changes that may negatively affect the fish fauna from the basin, species introduction would represent an additional threat to native fauna. The species introduction in the Paraná system, specifically in the reservoirs, as showed by Alves et al. (2007) in the Minas Gerais State portion of the upper Paraná River basin, may bring hard deleterious effects in the native fauna. The occurrence of non native species in Sapuací-Mirim River represents that fish species introduction has been already initiated in the basin and may be intensified after the river impoundment.

The documentation of the little known ichthyofauna partially fulfills the gap of information pointed by Casatti et al. (2008) to the Sapucaí-Mirim Basin and allows to a better understand of the fish distribution in the Grande River. But only further studies on the composition, biological traits and ecology of the fish populations may attend the demand of knowledge in this area of the Grande River basin. These studies must provide basic information on the biology of the species, and serve as foundation to the application of practical actions toward fish conservation and stock maintenance of native species at this river.

Acknowledgements

Our gratitude to Luis Aparecido Joaquim by his help with the field activities. IBAMA provided license for collecting fish (number 10248-1). Fernando Apone, José Luis O. Birindelli and two anonymous referees revised the manuscript and provided useful suggestions. We thank to the Fundação de Apoio Institucional da UFSCar (FAI-UFSCAR) through the PIDICT program that provide a grant to VVC and to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPQ) by the grants to JCG and AKO. Part of this research received financial support from FAPESP (Process 2011/50213-5) in the BIOTA/FAPESP Program (www.biota.org.br)

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Received 15/12/2014
Revised 22/01/2016
Accepted 29/01/2016

Biota Neotropica 16(1): e0059, 2015
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)

short communication

Predator-prey interaction between two threatened species in a Brazilian hotspot

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CANALE, G.R., BERNARDO, C.S.S., **Predator-prey interaction between two threatened species in a Brazilian hotspot.** Biota Neotropica. 16(1): e0059. http://dx.doi.org/10.1590/1676-0611-BN-2015-0059

Abstract: Conflicts in conservation may arise if two or more threatened species are involved in prey-predator interaction. Predators may have a profound effect on small prey populations, thus conservation actions must consider inter-specific interactions involving threatened species. Here we report nest predation events on a wild population of the Endangered red-billed curassow *Crax blumenbachii* Spix, 1825 by a group of the Critically Endangered yellow-breasted capuchin monkeys *Sapajus xanthosternos* Wied-Neuwied, 1820 in the Brazilian Atlantic Forest. This is the first study to report egg predation of an threatened gamebird by an threatened primate. We recommend that systematic conservation planning for these threatened species consider interactions, especially considering upcoming reintroduction programs indicated in the National Action Plans for these species conservation.

Keywords: *Atlantic Forest, coexistence, conservation, Crax blumenbachii, diet, Sapajus xanthosternos.*

CANALE, G.R., BERNARDO, C.S.S., **Interação predador-presa entre duas espécies ameaçadas em um hotspot brasileiro.** Biota Neotropica. 16(1): e0059. http://dx.doi.org/10.1590/1676-0611-BN-2015-0059

Resumo: Conflitos em conservação podem ocorrer quando duas espécies ameaçadas são envolvidas em interações presa-predador. Predadores podem ter um profundo efeito sobre pequenas populações de presas, portanto ações de conservação devem considerar estas interações interespecíficas envolvendo espécies ameaçadas. Reportamos aqui a predação de ovos em uma população selvagem de mutum-do-sudeste *Crax blumenbachii* Spix, 1825 por um grupo monitorado de primatas criticamente ameaçados, macaco-prego-do-peito-amarelo *Sapajus xanthosternos* Wied-Neuwied 1820 na Mata Atlântica. Este é o primeiro estudo a reportar a predação de ovos de uma espécie ameaçada de ave cinegética por um primata também ameaçado de extinção. Recomendamos o planejamento conciliado de ações de conservação para ambas espécies ameaçadas, especialmente por os futuros programas de reintrodução indicados para as respectivas espécies em seus Planos de Ação Nacionais para a Conservação de Espécies Ameaçadas de Extinção.

Palavras-chave: *Mata Atlântica, coexistência, conservação, Crax blumenbachii, dieta, Sapajus xanthosternos.*

Introduction

Species conservation action plans generally focus on ranking conservation priorities, and although the loss of one species may be dire, the loss of species interactions may be even more problematical (Soulé et al. 2003). Thus, conservation actions must also consider the interactions between species (e.g. predator-prey), especially when populations of both of them may be threatened. Researchers have reported conflicts in conservation, when predation influences population survival of threatened prey species (Chadès et al. 2012, Roemer & Wayne 2003, Verissimo et al. 2012), however, most interactions involving threatened species remain understudied.

The Atlantic Forest is currently one of the most fragmented and human-altered biodiversity hotspots (Ribeiro et al. 2009). Fragmentation and isolation of forest remnants might lead to mesopredator release due to the reduced density of populations of apex predators (Crooks & Soulé 1999). In the northern Atlantic Forest, local extinction of top predators are widespread (Canale et al. 2012) and capuchin monkeys are one of the extant mesopredators known to prey on small vertebrates and bird eggs (Canale et al. 2013a).

Several researches report capuchin monkeys as one of the most important nest predators in the tropics (Fedigan 1990, Sieving 1992, Feeley and Terborgh 2008). Egg predation was observed for various species of capuchin monkeys, such as *Sapajus apella*, *Cebus capucinus*, *C. albifrons* and *C. olivaceus* (Janson and Boinski 1992, Riehl and Jara 2009). Moreover, studies with artificial nests have revealed high rates of egg predation in habitat islands harbouring capuchins (Terborgh et al 1997). In Costa Rica, *Cebus capucinus* are known to regularly search for nests during the nesting seasons, and to feed on eggs of many species of birds (Fedigan 1990). Here we report on the predation of eggs of a wild population of the Endangered red-billed curassow (*Crax blumenbachii*) by the Critically Endangered yellow-breasted capuchin monkey

(*Sapajus xanthosternos*). This rare predation event raises the need for strategic coupled conservation actions, such as nest monitoring, for both threatened species.

Methods

1. Study site

The study was developed in Una Biological Reserve (UBR; 18,500 ha) one of the largest forest fragments legaly protected in the range of *S. xanthosternos* and *C. blumenbachii* in the Atlantic Forest of southern Bahia (Figure 1). This region is considered a hotpoint for biodiversity conservation within the Atlantic Forest hotspot (Martini et al. 2007, Laurance 2009). Annual temperature average 24 to 25°C, and rainfall is aseasonal, with about 2000 mm/year (Martini et al. 2007). UBR contains primary forest, secondary forest, swamps, and abandoned plantations.

2. Species

The original distribution of the yellow-breasted capuchin comprises Bahia, Sergipe and northern Minas Gerais, while the red-billed curassow is found in Bahia, Espírito Santo, eastern Minas Gerais and Rio de Janeiro (IBAMA 2004, Lernould et al. 2012). They are both endemic to a small portion of the Brazilian Atlantic Forest and threatened by hunting pressure, habitat loss and forest fragmentation (IBAMA 2004, Lernould et al. 2012). The overlapping area of their original distributions is restricted to a small region in Bahia (Figure 1).

3. Data collection

A group of 14 individuals of *S. xanthosternos* was monitored from September 2007 to December 2008 in UBR. Behavioural scan samples (n = 2,598 scans) were collected every 15 minutes during 3-5 days a month (Altmann 1974). Capuchins were followed from dawn to dusk (n = 55 full days), whenever we were not able to follow them a full-day, we completed sampling period in the following day (n = 42 half days). We collected data on two behaviours associated with food resources: *Feeding* (chewing, swallowing and bringing food to mouth with hands); and *Foraging* (search for food using hands or using teeth to break trunks and branches).

Results

Fruits represented 38.3 ± 8.6% of feeding events, whilst animal prey in the capuchin's diet averaged 36 ± 6.6%, reaching up to 47% of total feeding events in January 2008. Capuchins fed on four animal items: invertebrate eggs, invertebrates, lizards and bird eggs (Figure 2); the latter summed 6% of total of 86 events of consumed animal items identified and recorded during scan samples.

During behavioural scan observation four sub-adult monkeys (two males and two females) were observed feeding on eggs of at least two bird species (*Crax blumenbachii* and non-identified Passeriformes), in five egg predation events. The nests of the non-identified birds were between 8 and 19 m height and all of them were located in the secondary forest. No additional information about nest description was collected (e.g. open cup, cavity) because nests were not completely visible to observers. An eggshell of another Cracidae, the rusty-margined guan (*Penelope superciliaris* Temminck, 1815) was also dropped by one capuchin monkey during the behavioural scan interval.

On 24/10/2007 at 15:03 h, GRC observed a sub-adult female capuchin approaching a red-billed curassow nest, which was located in a 10 m tall liana-covered tree in young secondary forest, estimated to be 10 to 30 years old (Faria et al. 2009). Both the cock and hen were adults (> 3 years-old) and perched less than a metre from the nest. When the capuchins approached the nest, the male curassow glided to the ground, followed by the female. The capuchin fed on both eggs present in the nest and licked the eggshells until 15:22 h. No food-sharing was observed. Because the aim of the research was focused on monkey behaviour, specific nests were not being monitored.

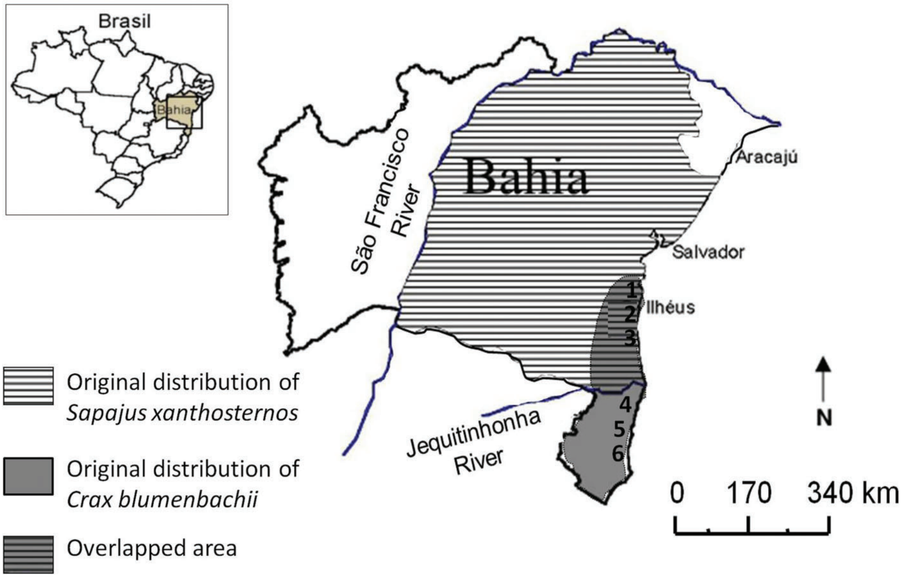

Figure 1. Extent of overlap between the original distributions of the yellow-breasted capuchin (*Sapajus xanthosternos*) and the red billed curassow (*Crax blumenbachii*) within Bahia (Brazil). Areas from 1 to 3 represent the only areas where both species coexist nowadays (1 = Michelin Reserve, 2 = Serra do Conduru State Park, 3 = Una Biological Reserve, the study area). Areas from 4 to 6 represent the areas where the red-billed curassows still coexist with *S. robustus* in Bahia (4 = Pau Brasil National Park, 5 = Monte Pascoal National Park, 6 = Descobrimento State Park).

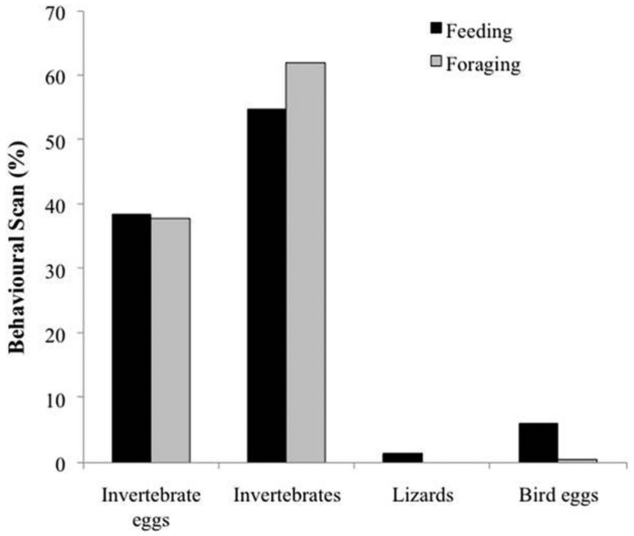

Figure 2. Animal prey in the diet of a *Sapajus xanthosternos* group during field observation in Una Biological Reserve at the northeastern Atlantic Forest, Brazil.

Discussion

Few studies reporting egg predation by primates specifically identify the bird species predated (Janson & Boinski 1992, Estrada et al. 2002). Here we report for the first time the predation of eggs of the Endangered red-billed curassow by the Critically Endangered yellow-breasted capuchin in one of the most threatened biomes of the world, the Brazilian Atlantic Forest. Both species occur in very low densities in the wild (Bernardo et al. in prep), which makes this type of record even rarer. Curassows nests are very difficult to find in the wild and there are only few descriptive studies published (Sick 1970, Lima et al. 2008, Herrera et al. 2009, Toledo-Lima et al. 2013).

Although the predation of red-billed curassow eggs was recorded only once in UBR, we found a high frequency of bird egg predation by yellow-breasted capuchins (6%) in relation to other capuchins (0.6 – 2.3% of bird eggs and nestlings in animal prey) (Janson & Boinski 1992). Predation events are rarely recorded, and observing these events may be difficult even during intensive behavioural monitoring (Fedigan 1990). Thus, any information regarding this issue is useful to contribute to future investigations. The proportion of bird egg consumption alone may be too low to have an immediate impact on population size, but we must consider predation in a broad context (e.g. in synergy with habitat reduction, high hunting pressure) and not as an isolated event.

Generalist predators (mesopredators) may be more abundant in fragmented landscapes due to the extinction of apex predators (Crooks and Soulé 1999, Ritchie et al 2012). Capuchin monkeys are one of the most important mesopredators among the other Neotropical primates and may be superabundant in small forest fragments, especially when subsidized by exotic fruit species in the surrounding crop matrix (Michalski and Peres 2007). The over-abundance of capuchins may depress populations of passerine birds as reported by birdwatchers in the Rio de Janeiro Botanical Garden and researchers in Tijuca National Park (Cunha et al 2006). Indeed, capuchins change foraging areas to those where birds nests are more likely to be found (Jason & Boinski 1992). Despite that populations of capuchins are reported to increase in small forest fragments, this is not the case for *S. xanthosternos* that is more commonly seen in large blocks of forests, from where most of the apex predators have already been wiped out, and are often absent from small fragments (Chagas and Ferrari 2010, Canale et al 2012). Due to overhunting in the northeastern Atlantic Forest, the yellow-breasted capuchin and the red-billed curassow are currently restricted to large forest patches (IBAMA 2004, Canale et al 2012).

Predator-prey interactions are rarely included in species conservation planning because of unreported natural history data. Nest predation effects are sometimes difficult to assess at a local scale, but landscape-scale studies indicate the need to protect large blocks of continuous forests to reduce predation of bird eggs and support avian conservation plans (Stephens et al 2004). Due to the lack of a high number of large protected forests available to reintroduce threatened bird species, such as the red-billed curassow, there might be a careful selection of areas with preferably lower densities of nest predators, such as capuchin monkeys.

Our findings help to augment knowledge on two of the most threatened species in the Brazilian Atlantic Forest which remain poorly studied. Here, predator and prey are focus of conservation efforts by IUCN species specialist groups (SSG) and Brazilian environmental agencies. Among others, captive breeding programmes followed by the future reintroduction of animals into the wild are actions being considered (IBAMA 2004, Lernould et al. 2012). Predator-prey interactions such as nest predation by capuchin monkeys, however, are not explicitly considered in the action plans of both species. Thus, reintroductions of yellow-breasted capuchin monkeys should be planned synchronically with the presence of red-billed curassows and vice-versa. For instance, all three areas indicated for future reintroductions of red-billed curassows in Bahia (IBAMA 2004) harbour populations of yellow-breasted capuchins. Hence, we recommend that prey-predator interaction should be taken into account when assessing population viability of the red-billed curassow (e.g. using Vortex), and, during the monitoring and management of both threatened species (e.g. observation of nests of red-billed curassows).

Acknowledgements

We thank Disney Wildlife Conservation Fund, Fundação Biodiversitas, Zoologische Gesellschaft für Arten-und Populationsschutz, CEPA, Amersfoort Zoo, Apenheul Zoo, Berlin Tierpark, Colchester Zoo, Cologne Zoo, Edinburgh Zoo, GaiaPark, La Palmyre Zoo, La Vallée des Singes, Chester Zoo, Parc Zoologique et Botanique de Mulhouse, Shaldon Wildlife Trust, Zurich Zoo, Twycross, Margot Marsh Conservation Fund. Our gratitude to Paulo Cruz and Saturnino de Sousa (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis) for permission and logistics. We also thank CAPES for PhD scholarship to GRC (process 3342054).

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Received 18/05/2015
Revised 22/11/2015
Accepted 7/12/2015

Biota Neotropica 16(1): e20150035, 2016
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
inventory

Insect galls from Serra Geral, Caetité, BA, Brazil

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NOGUEIRA, R. M., COSTA, E. C., CARVALHO-FERNANDES, S. P., SANTOS-SILVA, J. **Insect galls from Serra Geral, Caetité, BA, Brazil.** Biota Neotropica. 16(1): e20150035. http://dx.doi.org/10.1590/1676-0611-BN-2015-0035

Abstract: We inventoried and characterized the kinds of gall, gall-inducing insects and host plants from Serra Geral between August 2013 and July 2014. Two phytophysiognomies, cerrado *sensu stricto* and caatinga-cerrado, were examined monthly along transects during ca. 4 hours per visit, totaling 48 hours of sampling effort. A total of 49 gall morphotypes were found on 14 species of host plants in 18 genera and 13 families. Fabaceae and Malpighiaceae were the families with the most galls, with 22 and 10 gall morphotypes, respectively. The genera of host plant with the greatest richness of galls were *Copaifera* L. (n = 10), *Bauhinia* Benth. (n = 6), and *Mimosa* L. (n = 5). Galls were found on leaves, buds and stems. The majority of the galls were globoid, glabrous, isolated, and one-chambered. The inducers belong to Coleoptera, Diptera, and Lepidoptera, Cecidomyiidae (Diptera) being the most frequent and diverse gall-inducers. The associated fauna included parasitoids (Hymenoptera), successors (Formicidae), and predators (Pseudoscorpiones), obtained from 13, 2, and 1 gall morphotypes, respectively. Five plant taxa are recorded as hosts of gall-inducing insects for the first time.

Keywords: *Caatinga, Cerrado, Fabaceae, host plant, insect-plant interaction.*

NOGUEIRA, R. M., COSTA, E. C., CARVALHO-FERNANDES, S. P., SANTOS-SILVA, J. **Galhas de insetos da Serra Geral, Caetité, Bahia, Brasil.** Biota Neotropica. 16(1): e20150035. http://dx.doi.org/10.1590/1676-0611-BN-2015-0035

Resumo: Inventariamos e caracterizamos os tipos de galhas, insetos galhadores e plantas hospedeiras da Serra Geral entre agosto de 2013 a julho de 2014. Duas fitofisionomias, cerrado *sensu stricto* e de transição caatinga-cerrado, foram examinadas ao longo de trilhas à procura de galhas entomógenas, durante quatro horas por visita, totalizando 48 horas de esforço amostral. Um total de 49 morfotipos de galhas foi encontrado em 14 espécies vegetais pertencentes a 18 gêneros e 13 famílias. Fabaceae e Malpighiaceae foram as famílias botânicas com maior riqueza de galhas, com 22 e 10 morfotipos, respectivamente. Os gêneros de planta hospedeira mais ricos em galhas foram *Copaifera* L. (n = 10), *Bauhinia* Benth. (n = 6) e *Mimosa* L. (n = 4). As galhas foram encontradas em folhas, gemas e caules. A maioria das galhas foram globoides, glabras, isoladas e uniloculares. Os galhadores pertencem às ordens Coleoptera, Diptera e Lepidoptera, sendo os insetos da família Cecidomyiidae (Diptera) os indutores mais frequentes e diversificados. A fauna associada incluiu parasitoides (Hymenoptera), sucessores (Formicidae, Hymenoptera) e predadores (Pseudoscorpiones), obtidos de 13, dois e um morfotipos de galhas, respectivamente. Cinco táxons de plantas são registrados como hospedeiras de galhas pela primeira vez.

Palavras-chave: *Caatinga, Cerrado, Fabaceae, plantas hospedeiras, interação inseto-planta.*

Introduction

Galls are the abnormal growth of plant tissues formed due to an increase in cell volume (hypertrophy) and/or cell number (hyperplasy) in response to feeding activity, chemical secretions and/or the mere presence of foreign organisms, usually insects or mites (Raman 2007). The gall-inducing species apparently derives all the benefit and the plant suffers loss of substance, deviations in the direction of growth, disturbances in sap flow, premature decay and other injuries (Stone & Schönrogge 2003).

Insect galls can be regarded as extended phenotypes of the inducers, unique in that the parasitic arthropod induces a characteristic adaptation within the host plant (Stone & Schönrogge 2003, Carneiro et al. 2009b). The gall morphology and location depend on the plant species and the kind of organism that is causing it. As a result of this high specificity, gall morphotypes can be used as a surrogate of the insect species (Price et al. 1998, Hanson & Gomez-Laurito 2005) and as tools for plant systematics (Abrahamson et al. 1998).

The history of gall studies in Brazil begins with the work of Tavares (1906). Since the late 1980s, numerous inventories of galls have been developed in Brazil, in the Southeast (e.g., Carneiro et al. 2009a, Fernandes et al. 1988, Gonçalves-Alvim & Fernandes 2001, Maia 2013a, Rodrigues et al. 2014, Saito & Urso-Guimarães 2012), South (Toma & Mendonça Jr. 2013), Midwest (Araújo et al. 2014, Julião et al. 2002, Santos et al. 2010, Santos et al. 2012b), Northeast (Carvalho-Fernandes et al. 2012, Costa et al. 2014a, 2014b, Fernandes et al. 2009, Santos et al. 2011a, 2011b, Santos et al. 2012a, Silva et al. 2011b, Silva & Almeida-Cortez 2006) and North (Almada & Fernandes 2011, Araújo et al. 2012, Julião et al. 2005, Maia 2011, Silva et al. 2011a), Atlantic Forest and Cerrado being the environments most studied.

The knowledge about galls on plants and gall-inducing organisms in Bahia is scarce. Tavares (1915-1922) was the first to collect galls in this state. He recorded 20 gall-inducing species of Diptera associated with plants. More recent inventories of insect galls and host plants from Bahia are restricted to three studies that focused mainly on caatinga (Carvalho-Fernandes et al. 2012) and caatinga-cerrado physiognomies (Costa et al. 2014a, 2014b). In addition, four gall midge species of Cecidomyiidae were recorded for the first time in the State of Bahia (Maia 2014). Clearly, a concerted effort is needed to know the gall-inducing fauna and host plant. Thus, this study aims at making an inventory of kinds of galls, gall-inducing insects and host plants from Serra Geral, a cerrado and caatinga-cerrado transition area in Caetité (BA).

Material and Methods

The study was conducted at Serra Geral (14° 04' S and 42° 29' W), located in the municipality of Caetité, Bahia, Brazil. The Serra area covers 4 km^2 and includes regions of cerrado *sensu stricto* and caatinga-cerrado transition. The highest altitude is 1,064 m. The climate is semi-arid with a well-defined dry season (April to October) and rainy season (November to March) (CEI 1994).

Monthly expeditions were conducted in the study area between August 2013 to July 2014. The different vegetation physiognomies of Serra Geral were examined in search of gall-inducing insects during four hours per visit, totaling 48 hours of sampling effort. All plant organs were investigated, except for the roots. Only plants infested by galls were marked with numbered tags, collected and later pressed in the Laboratory of Botany of the Universidade do Estado da Bahia (UNEB). The vouchers of the host plants were deposited in the HUNEB Hebarium, Caetité Collection. All host plants and gall morphotypes were photographed in field. Samples of attacked organs were collected and transported in numbered plastic bags. In the laboratory, each gall morphotype was dissected under a stereoscopic microscope in order to obtain the gall-inducing insects and characterize the external morphology of the galls (shape, color, and presence/absence of trichomes) and number of internal chambers following Isaias et al. (2013). Pupal exuviae, adults and associated fauna were obtained by keeping samples of each gall morphotype individually in plastic pots covered by absorbent paper. All pots were examined daily for emergence of adults. The emerged insects were collected and preserved in 70% alcohol for identification.

The identification of host plants was made by comparison with specimens deposited in the HUNEB, Caetité Collection and HUEFS, use of taxonomic literature, and consultation with specialists. The list of taxa is organized in alphabetical order by family, genus and species, following the classification system of APG III (2009). The insect were identified based on gall shape, host plant and original description. All material is deposited in the collection of Museu Nacional - Universidade Federal do Rio de Janeiro.

Results

This study in Serra Geral found 49 gall morphotypes on 14 species of host plant distributed in 18 genera and 13 families (Table 1; Figures 1-3). Fabaceae was the plant family with the most galls, followed by Malpighiaceae, with 22 and 10 gall morphotypes, respectively. The genera of host plant with the greatest richness of galls were *Copaifera* L. (n = 10), *Bauhinia* Benth. (n = 6), and *Mimosa* L. (n = 4).

As there were no previous data of host plant of gall-inducing insects from Serra Geral, all records presented here are new to the region. The galls observed on *Byrsonima stannardii* W.R. Anderson (Figure 2I), *Calliandra sessilis* Benth. (Figure 2C), *Eremanthus capitatus* (Spreng.) MacLeish (Figure 1B), *Thryallis* sp. (Figure 2J), and *Ruellia bahiensis* (Nees) Morong are the first records of galls in these taxa.

Galls were recorded on stems, buds and leaves, the last one being the plant organ with the most galls, with ca. 57% of the total of the gall morphotypes. Flower and fruit galls were not found. Regarding the shape of the galls sampled, about 53% were globoid, 20.4% lenticular, 12.3% fusiform, 6.2% conical, 4.1% marginal leaf roll, 2% bivalve-shaped and 2% cylindrical. The majority of the galls were glabrous (83.7%), isolated (77%), and one-chambered (73.5%) (Table 1; Figures 1-3)

Most galls exhibited the same coloration as the plant organ. Green galls predominated on leaves, but was also observed on stems (*Bauhinia acuruana* Moric.; Figure 1F). Brown galls were frequent on stems, but were also verified on leaves of *Duguetia furfuracea* (A.St.-Hil.) Saff. (Figure 1A), *Combretum leprosum* Mart. (Figure 1C) and *Copaifera langsdorffii* Desf. (Figures 1L-2A).

Of six orders of gall-inducing insects (Diptera, Coleoptera, Lepidoptera, Hymenoptera, Thysanoptera, and Hemiptera) three were present in this study: Coleoptera, Diptera, and Lepidoptera. The Cecidomyiidae (Diptera) comprised the most frequent gall-inducing taxon, being responsible for 18.4% of the morphotypes, followed by Lepidoptera (4.1%) (Table 1). The gall-inducers of 73.4% of the morphotypes could not be determined, because the gall samples were collected without dwellers or were occupied by parasitoids and predators. The associated fauna included parasitoids (Hymenoptera), successors (Formicidae), and predators (Pseudoscorpiones), obtained from 13, 2, and 1 gall morphotypes, respectively (Table 1).

Discussion

In several surveys of insect galls from different Brazilian ecosystems, Fabaceae was indicated as the richest plant family in number of gall morphotypes, as in areas of cerrado (Minas Gerais - Gonçalves-Alvim & Fernandes 2001; Goiás - Araújo et al. 2014, Santos et al. 2012b) and caatinga-cerrado transition (Minas Gerais - Luz et al. 2012; Bahia - Costa et al. 2014b). Fabaceae is one of the predominant families of the cerrado and caatinga flora (Queiroz 2009) and is one of the best-represented plant families in Serra Geral. According to the plant diversity hypothesis proposed by Fernandes (1992), the greatest richness of galls is shown by the most speciose plant families of each area. The present study adds more evidences to the previous knowledge about super-host families and the plant richness hypothesis.

Table 1. Morphological description of insect galls in semi-arid environments from Serra Geral, Caetité, Bahia, Brazil. Abbreviations: Pa: parasitoid, Su: successor, Pr: predator.

Host plant Family	Host plant species	Organ	Side	Shape	Color	Pubescense	Group	Chambers	Gall maker	Associated fauna	Figures	Area
Annonaceae	*Duguetia furfuracea* (A.St. Hil.) Saff.	Leaf	Adaxial	Globoid	Green/ Brown	Yes	Grouped	Various	Not identified	Hymenoptera (Pa)	1 A	Cerrado
Acanthaceae	*Ruellia bahiensis* (Nees) Morong	Leaf	Adaxial	Lenticular	White	Yes	Isolated	1	Not identified		-	Cerrado
		Leaf	Adaxial	Globoid	Brown	No	Isolated	1	Not identified		-	Cerrado
Asteraceae	*Eremanthus capitatus* (Spreng.) MacLeish	Stem	-	Globoid	Brown	No	Isolated	1	Coleoptera	Formicidae, Hymenoptera (Su)	1 B	Caatinga-Cerrado
Combretaceae	*Combretum leprosum* Mart.	Leaf	Adaxial	Globoid	Brown	No	Isolated	1	Cecidomyiidae	Hymenoptera (Pa)	1 C	Cerrado
Icacinaceae	*Emmotum* sp.	Stem	-	Globoid	Brown	No	Isolated	1	Not identified	Hymenoptera (Pa) Formicidae (Su)	1 D	Cerrado
		Leaf (petiole)		Globoid	Brown	No	Isolated	1	Lepidoptera		1 E	Cerrado
Fabaceae - Caesalpinioideae	*Bauhinia acuruana* Moric.	Stem	-	Fusiform	Brown	No	Isolated	Various	Not identified		1 F	Cerrado
		Stem	-	Globoid	Green	No	Isolated	1	Cecidomyiidae		1 G	Cerrado
		Stem	-	Globoid	Brown	No	Grouped	Various	Not identified		1 H	Cerrado
		Leaf	Adaxial	Lenticular	Green	No	Isolated	1	Cecidomyiidae		1 I	Cerrado
		Stem	-	Fusiform	Brown	No	Isolated	Various	Not identified		1 J	Cerrado
	Bauhinia pulchella Benth.	Leaf	Adaxial	Globoid	Green	No	Isolated	1	Not identified		1 K	Cerrado
	Copaifera langsdorffii Desf.	Stem	-	Globoid	Orange/ Brown	No	Isolated	Various	Cecidomiiydae	Hymenoptera (Pa)	1 L	Caatinga-Cerrado
		Leaf	Adaxial/ Abaxial	Globoid	Grey/ Black	No	Isolated	1	Not identified		1 M	Caatinga-Cerrado
		Leaf	Adaxial	Globoid	Black	No	Isolated	Various	Not identified		1 N	Caatinga-Cerrado

Continued on next page

Table 1. Continued.

Host plant Family	Host plant species	Organ	Side	Shape	Color	Pubescense	Group	Chambers	Gall maker	Associated fauna	Figures	Area
		Stem	-	Lenticular	Brown	No	Grouped	1	Cecidomyiidae	Hymenoptera (Pa)	1O	Caatinga-Cerrado
		Leaf	Abaxial	Globoid	Brown	Yes	Isolated	1	Not identified		1P	Caatinga-Cerrado
		Leaf	Adaxial	Globoid	Brown	No	Isolated	Various	Not identified		1Q	Caatinga-Cerrado
		Leaf	Adaxial	Globoid	Brown	No	Isolated	Various	Not identified	Hymenoptera (Pa)	1R	Caatinga-Cerrado
		Leaf	Adaxial/ Abaxial	Lenticular	Green	No	Isolated	1	Not identified		1S	Caatinga-Cerrado
		Leaf	Adaxial	Cylindrical	Green	No	Isolated	1	Not identified	Hymenoptera (Pa)	1T	Caatinga-Cerrado
		Leaf	-	Marginal roll	Green	No	Isolated	1	Not identified		2A	Cerrado
Fabaceae – Mimosoideae	*Calliandra dysantha* Benth.	Bud	-	Globoid	Brown	Yes	Grouped	Various	Not identified		2 B	Cerrado
	Calliandra sessilis Benth.	Stem	-	Globoid	Brown	No	Isolated	Various	Not identified		2 C	Cerrado
	Mimosa gemmulata Barneby	Leaf	Adaxial	Globoid	Brown	Yes	Isolated	1	Cecidomyiidae		2 D	Cerrado
		Bud	Adaxial	Globoid	Green	No	Grouped	1	Not identified		2 E	Cerrado
		Leaf	-	Marginal roll	Green	No	Isolated	1	Not identified		2 F	Cerrado
		Stem	-	Fusiform	Brown	No	Isolated	1	Not identified	Hymenoptera (Pa)	2 G	Cerrado
Malpighiaceae	*Banisteriopsis* sp.	Stem	-	Globoid	Brown	No	Isolated	1	Lepidoptera		2 H	Cerrado
	Byrsonima starnnardii W. R.Anderson	Leaf	Abaxial	Conical	Green	Yes	Isolated	1	Cecidomyiidae	Hymenoptera (Pa)	2I	Caatinga-Cerrado
	Thryallis sp.	Leaf	Abaxial	Lenticular	White	Yes	Grouped	1	Not identified	Hymenoptera (Pa)	2 J	Caatinga-Cerrado
	Malpighiaceae sp. 1	Stem	-	Fusiform	Brown	No	Grouped	1	Cecidomyiidae		2K	Caatinga-Cerrado
	Malpighiaceae sp. 1	Leaf	Abaxial	Globoid	Green	No	Isolated	Various	Not identified		2 L	Caatinga-Cerrado

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Table 1. Continued.

Host plant Family	Host plant Species	Organ	Side	Shape	Color	Pubescense	Group	Chambers	Gall maker	Associated fauna	Figures	Area
	Malpighiaceae sp. 2	Bud	-	Bivalve shaped	Orange	No	Isolated	1	Coleoptera		2 M	Cerrado
	Malpighiaceae sp. 3	Stem	-	Conical	Brown	No	Isolated	Various	Not identified		-	Cerrado
	Malpighiaceae sp. 3	Leaf (petiole)	-	Globoid	Green	No	Isolated	1	Not identified		2 N	Cerrado
	Malpighiaceae sp. 4	Stem	-	Conical	Brown	No	Isolated	Various	Not identified	Pseudoscorpiones (Pr)	-	Cerrado
	Malpighiaceae sp. 5	Leaf (vein)	Abaxial	Globoid	Red	No	Grouped	1	Not identified	Hymenoptera(Pa)	2 O	Caatinga-Cerrado
Myrtaceae	*Eugenia punicifolia* (Kunth) DC.	Leaf	Adaxial	Lenticular	Black	No	Grouped	1	Not identified		2P	Caatinga-Cerrado
		Stem	-	Fusiform	Brown	No	Isolated	1	Not identified		2 Q	Caatinga-Cerrado
Nyctaginaceae	Nyctaginaceae sp.	Stem	-	Fusiform	Brown	No	Isolated	1	Not identified		2R	Caatinga-Cerrado
Ochnaceae	*Ouratea* sp.	Leaf	Adaxial	Lenticular	Green	No	Isolated	1	Not identified		2S	Caatinga-Cerrado
Rubiaceae	*Cordiera* sp.	Leaf	Adaxial	Lenticular	Green	No	Grouped	1	Not identified		2T	Cerrado
		Bud	-	Globoid	Green/ Black	No	Isolated	1	Not identified		3 A-B	Caatinga-Cerrado
	Rubiaceae sp.1	Leaf	Adaxial	Lenticular	Green	No	Isolated	1	Not identified		3 C	Cerrado
	Rubiaceae sp.2	Stem	-	Globoid	Brown	No	Grouped	1	Not identified		3 D	Cerrado
Trigoneaceae	*Trigonea nivea* Cambess.	Leaf	Abaxial	Globoid	White	Yes	Isolated	1	Cecidomyiidae	Hymenoptera (Pa)	3 E	Cerrado
Vochysiaceae	*Qualea parviflora* Mart.	Leaf	Adaxial	Lenticular	Green	No	Isolated	1	Not identified		3 F	Caatinga-Cerrado

Figure 1. Insect galls from Serra Geral, Caetité, Bahia, Brazil. A. *Duguetia furfuracea* (A.St. Hil.) Saff. B. *Eremanthus capitatus* (Spreng.) MacLeish. C. *Combretum leprosum* Mart. D-E. *Emmotum* sp. F-J. *Bauhinia acuruana* Moric. K. *Bauhinia pulchella* Benth. L-T. *Copaifera langsdorffii* Desf.

Copaifera and *Bauhinia* were the plant genera with the highest gall diversity in this study. These two genera were already indicated in other gall inventories as super hosts in the caatinga, cerrado and caatinga-cerrado transition (Santos et al. 2011a, Luz et al. 2012, Costa et al. 2014b). The *Copaifera* is reported as super hosts in other vegetation types, such as cerrado (Fernandes et al. 1988, Fagundes 2014) and atlantic forest (Maia 2013b). In some taxa, at lower taxonomic levels, there may be a large concentration of galls, these being known as super hosts (Veldtman & McGeoch 2003). There are a several examples of these in the literature (*Baccharis*: Fernandes et al. 1996, *Copaifera*: Costa et al. 2010; Maia 2013b, *Eugenia*: Mendonça 2007).

The super-host species was *Copaifera langsdorffii* (Fabaceae). This species was considered a super-host in other ecosystems as well, such as the atlantic forest (Maia 2013b), cerrado (Maia & Fernandes 2004) and caatinga-cerrado transition (Costa et al. 2014b). This species has great morphogenetic potential and responds differently to the stimuli of more than 20 gall-inducing insects (Oliveira et al. 2008, Costa et al. 2010).

Leaf and stem were the organs most commonly attacked by gall makers throughout Brazil (e.g., Santos et al. 2011a, Carvalho-Fernandes et al. 2012, Maia 2013b, Costa et al. 2014a, 2014b). It is a widespread pattern pointed by Felt (1940) and confirmed in this study. This preference can be explained because the leaves are abundant and constant resources (Maia 2001).

Globoid, lenticular and fusiform galls were predominant. The predominance of these morphotypes has been also pointed

Figure 2. Insect galls from Serra Geral, Caetité, Bahia, Brazil. A. *Copaifera langsdorffii* Desf. B. *Calliandra dysantha* Benth. C. *Calliandra sessilis* Benth. D-G. *Mimosa gemmulata* Barneby. H. *Banisteriopsis* sp. I. *Byrsonima starnnardii* W.R.Anderson. J. *Thryallis* sp. K-O. Malpighiaceae Indet. sp. 1-4. P-Q. *Eugenia punicifolia* (Kunth) DC. R. Nyctaginaceae Indet. S-T. *Ouratea* sp.

in other inventories (e.g., Costa et al. 2014b, Maia 2013, 2014, Coelho et al. 2013, Urso-Guimarães et al. 2003). This diversity of forms is related to the high specificity of gall-inducing insects and their host plants (Carneiro et al. 2009b), but also with the high phenotypic plasticity to which the tissues of these plants have to be subjected, resulting in injuries during gall formation. The majority of the galls were glabrous, isolated, and one-chambered. Other gall inventories held in Brazil (Pernambuco - Santos et al. 2011a, b, 2012a; Minas Gerais - Luz et al. 2012; Rio de Janeiro - Maia & Souza 2013; Bahia - Costa et al. 2014a, 2014b) corroborate the results of this study.

The inducers were represented by Diptera, Lepidoptera, and Coleoptera. Cecidomyiidae (Diptera) were the most frequent and diverse gall-inducers. This result confirms other data recorded in different Brazilian ecosystems, indicating Cecidomyiidae as the main family of gall-inducing insects (Carneiro et al. 2009a, Santos et al. 2011a, 2011b, Maia 2013a, 2013b, Costa et al. 2014b). Moreover, it is the richest gall-inducing taxon in the world (Gagné & Jaschhof 2014), demonstrating the importance of the family in the community of gall-makers.

The associated fauna included parasitoids (Hymenoptera), inquilines (Lepidoptera and Thysanoptera), successors (Formicidae, Hymenoptera), and predators (Pseudoscorpiones). The presence of parasitoids of the order Hymenoptera has been widely reported in galls as the main factor of the inducers' mortality (Maia 2001, 2013a). In other Brazilian inventories, this

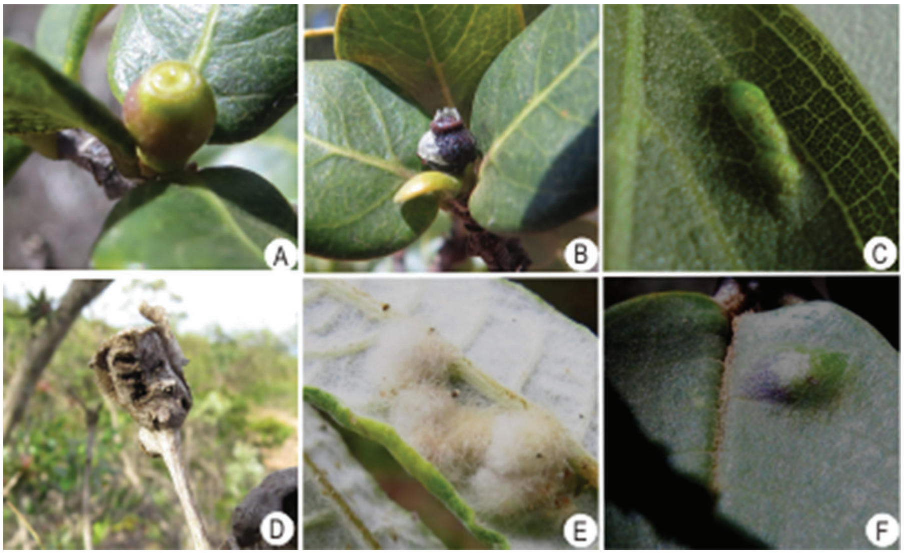

Figure 3. Insect galls from Serra Geral, Caetité, Bahia, Brazil. A-B. *Cordiera* sp. C-D. Rubiaceae sp. 1-2. E. *Trigonea nivea* Cambess. F. *Qualea parviflora* Mart.

order has also been registered with the same habits seen in this study (Maia 2001, Maia & Fernandes 2004, Maia et al. 2008).

In Serra Geral, predators (pseudoscorpions) were recorded in a single gall morphotype. The occurrence of pseudoscorpions in Brazilian surveys is very rare. Only five previous records are known, on bud galls of *Eugenia astringens* Cambess. - Myrtaceae (Maia 2001), stem galls of *Combretum leprosum* Mart & Eicher - Combretaceae (Maia 2002), *Handroanthus* sp. – Bignoniaceae (Maia 2013b), *Calophyllum brasiliense* Cambess – Calophyllaceae (Maia & Souza 2013) and *Myrcia tomentosa* (Aubl.) DC. – Myrtaceae (Costa et al. 2014b).

The five new records of species of host plant presented in this work show the importance of this type of study to increase the knowledge of the richness of gall-inducing insects present in not sampled regions, such as the cerrado and caatinga-cerrado transition areas located in Northeast Brazil.

Acknowledgments

We are grateful to Dr. Luciano Paganucci (UEFS), Dr. Flávio França (UEFS), Dra. Nádia Roque (UFBA), Dr. Benoit Loeuille (USP), Msc. Lander Alves (UESC/ Bioconsultoria) and Denise Loureiro (Bioconsultoria) for plant identification; Fundação de Amparo à Pequisa do Estado da Bahia (FAPESB) for the scholarships conferred to the first author through PIBIC/UNEB (Programa Institucional de Bolsas de Iniciação Científica); and Universidade do Estado da Bahia for supporting this work.

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Received 13/04/2015
Revised 29/01/2016
Accepted 09/02/2016

Biota Neotropica 16(1): e0182, 2016
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
article

Wild vertebrate roadkill in the Chapada dos Veadeiros National Park, Central Brazil

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BRAZ, V.S. FRANÇA, F.G.R. **Wild vertebrate roadkill in the Chapada dos Veadeiros National Park, Central Brazil.** Biota Neotropica. 16(1): e0182. http://dx.doi.org/10.1590/1676-0611-BN-2014-0182

Abstract: Chapada dos Veadeiros National Park is one of the most important protected areas of the Brazilian Cerrado and is inhabited by diverse species, but the area has seldom been studied. From 2006 to 2008, we studied the impact of roads on wild vertebrates by recording roadkill on the two main roads located in the vicinity of the park. Of 824 killed vertebrates belonging to 138 species that were recorded, the species that were found most often in each vertebrate group were the Schneider's toad (*Rhinella schneideri*), the grassland sparrow (*Ammodramus humeralis*), the yellow-toothed cavy (*Galea flavidens*), and the marbled lancehead (*Bothrops marmoratus*). The roadkill rate was 0.096 animals km^{-1}. Vertebrate mortality was significantly higher during the wet season. There is a significant relationship between habitat structure and the vertebrates that were found as roadkill: amphibians are associated with nearby forest and paved roads, birds with nearby pastures, reptiles with nearby grassland, and mammals with unpaved roads. Action should be taken such as highway fencing in combination with safe crossing opportunities for wildlife in order to decrease the number of animals killed on the roads.

Keywords: *road ecology, protected areas, conservation, cerrado.*

BRAZ, V.S. FRANÇA, F.G.R. **Impacto do atropelamento de vertebrados do Parque Nacional da Chapada dos Veadeiros no Brasil Central.** Biota Neotropica. 16(1): e0182. http://dx.doi.org/10.1590/1676-0611-BN-2014-0182

Resumo: O Parque Nacional da Chapada dos Veadeiros é uma das mais importantes Unidades de Conservação do Cerrado brasileiro e, apesar de abrigar uma enorme biodiversidade, ainda são escassos os estudos na área. Entre 2006 e 2008 foi estudado o impacto das duas principais rodovias que margeiam o Parque sobre os vertebrados silvestres utilizando os registros de atropelamento. Foram registrados 824 vertebrados atropelados pertencentes a 138 espécies, sendo as mais encontradas o sapo-cururu (*Rhinella schneideri*), o tico-tico-do-campo (*Ammodramus humeralis*), o preá (*Galea flavidens*) e a jararaca (*Bothrops marmoratus*). A taxa de atropelamento foi de 0.096 animais km^{-1}, com uma mortalidade significativamente maior durante a estação chuvosa. Foi encontrada uma relação significativa entre a estrutura do habitat e as classes de vertebrados atropelados nas rodovias, sendo o grupo dos anfíbios associados a fragmentos florestais e trechos pavimentadas das rodovias, o das aves associado com pastagens circundantes, répteis com campos e mamíferos com trechos não pavimentados das rodovias. Medidas como barreiras que impeçam a movimentação dos animais nas estradas, bem como passagens seguras são indicadas para a redução do número de animais mortos nas rodovias na região do Parque.

Palavras-chave: *ecologia de estradas, áreas protegidas, conservação, cerrado.*

Introduction

Roads have recently been recognized as an important cause of habitat fragmentation and wildlife decline around the world (Coffin 2007). The construction of a new road or highway across a preserved landscape has direct and indirect impacts on local wildlife (Sherewood et al. 2002). Roads may induce direct mortality to wildlife through collisions with vehicles, create barriers to animal movement and consequently isolate populations, produce edge effects, alter animal behavior and reproductive ability, disrupt water supplies to and from wetlands, or intensify the toxic contamination and pollution of habitats alongside roads (Andrews 1990, Spelleberg 1998, Lodé 2000, Trombulak & Frissel 2000). In addition, the creation or enlargement of roads may damage natural environments by creating new road cuttings and embankments that scar the landscape, increase traffic noise, and increase road lighting (Sherewood et al. 2002; Forman et al. 2003).

Because of these threats, a number of recent studies on road ecology have been conducted, especially in Europe, the United States, and Australia (Coffin 2007). These studies have emphasized the need to plan road systems and have indicated that conservation should be a major goal of road planning (Forman et al. 2003). In spite of the great influence of roads on the dynamics of wildlife populations, most studies examined their effects only on specific groups, such as amphibians (Hels & Buchwald 2001), birds (Reijnen et al. 1995), mammals (Meunier et al. 1999), or reptiles (Hartmann et al. 2011), or even individual species, such as the Iberian lynx (*Felis pardina*) (Ferreras et al. 1992), the eastern barred bandicoot (*Perameles gunnii*) (Mallick et al. 1998) or the Mediterranean snake (*Hierophis viridiflavus*) (Capula et al. 2014). A few studies have dealt with the impact of roads on the local vertebrate community, describing the species that are susceptible to road mortality and identifying those whose conservation status may be threatened by roads (Yanes et al. 1995, Lodé 2000, Dodd et al. 2004, Boitet & Mead, 2014).

The effects of roads may be more severe in protected areas (Coelho et al. 2008). A protected area is defined as an area of land that is especially dedicated to the protection and maintenance of biological diversity and that is designated and managed to achieve specific conservation goals. The effectiveness of a protected area depends on conservation of biodiversity not only within the park or reserve but also in its vicinity (Chape et al. 2005, West et al. 2006). In Brazil, most protected areas are crossed by roads or highways, or have transportation infrastructure at or close to their borders, such as Iguaçu National Park (Paraná State, 185.262,20 ha), Emas National Park (Goiás State, 131.800 ha), and Águas Emendadas Ecological Station (Distrito Federal, 10,400 ha), so they experience the previously described effects of roads (Cândido Jr. et al. 2002, Rodrigues et al. 2002, Lima & Obara 2004, Coelho et al. 2008). Brazil's road network extends over 1,713,885 km and is expected to increase due to new government incentives (PAC II – Brasil 2010). New studies should be conducted to determine the impact of these new roads on the Brazilian fauna, particularly in protected areas. In this article we investigate roads as a cause of vertebrate mortality in the Chapada dos Veadeiros National Park, located in Central Brazil, and address the composition, seasonal patterns, and influence of environment on wildlife mortality due to roads.

Materials and Methods

1. *The study area*

The study was conducted in Central Brazil, in the state of Goiás (GO), on two roads that border the Chapada dos Veadeiros National Park (CVNP) (13°51'S to 14°10'S, and 47°25'W to 47° 42'W). The main road, GO 239, runs between Alto Paraíso and Colinas and comprises 72 km (22 km of paved and 50 km of unpaved road). It provides the main access to the official gate of the CVNP, located in São Jorge village (Figure 1). Additional data was obtained from highway BR 010, which runs between Alto Paraíso and Teresina de Goiás and includes 64 km of paved road. The CVPN covers approximately 65,512 ha of relatively undisturbed Cerrado. It is located in a mountainous region, the Planalto Central Goiano (Felfili et al. 2007), which has altitudes ranging between approximately 620 m and 1,700 m and includes Central Brazil's highest peak (Pouso Alto, 1,784 m). The climate is type Aw in the Köppen classification, receiving annually 1500–1750 mm of a highly predictable and strongly seasonal precipitation, restricted almost entirely to October–March (Nimer 1989). Long-term climatic data from the Chapada dos Veadeiros region are summarized in Figure 2. Average temperatures vary between 20°C and 26°C (Silva et al. 2001). The vegetation is characterized by a predominance of gallery forest formations at low elevations and Cerrado with montane savannas at high elevations (Felfili et al. 2007).

2. *Impact of roads*

Roads as a cause of vertebrate mortality were investigated through surveys of animals killed by vehicles and by recording dead vertebrates observed on both roads on non-consecutive days, between November 2006 to April 2008. Road surveys were undertaken once every three days. The surveys were conducted by driving at 25–50 km h^{-1} along GO 239 and at 60–80 km h^{-1} along BR 010. When a dead animal was spotted, we stopped the car for closer inspection, identified the animal

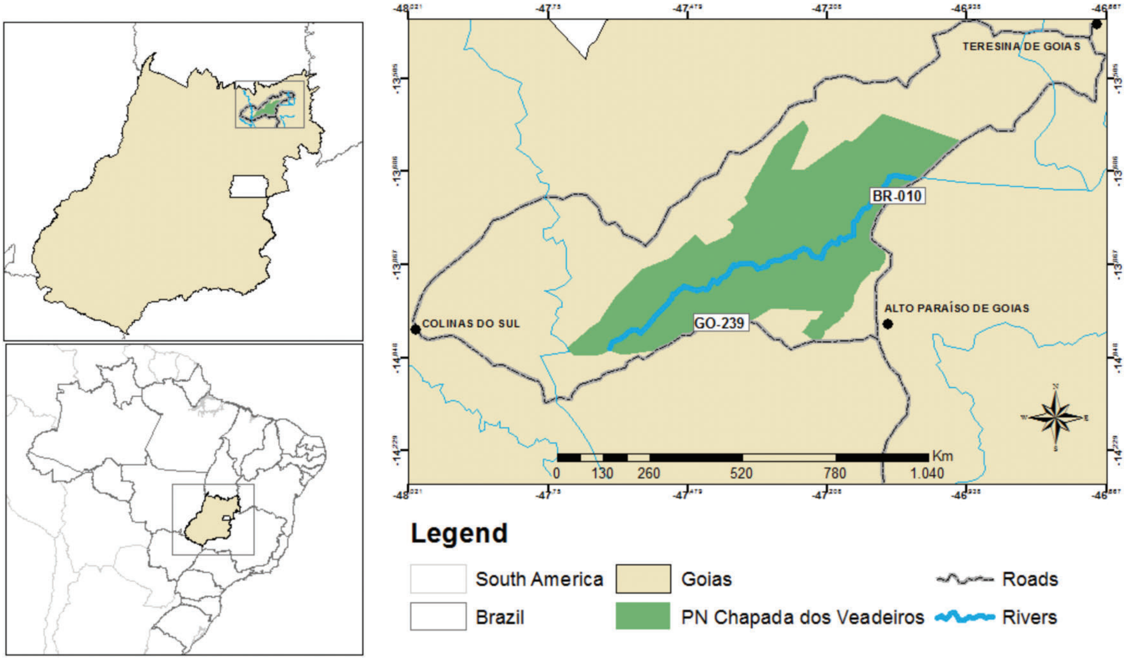

Figure 1. Study area showing the Central Brazil with Chapada dos Veadeiros National Park and the roads GO 239 and BR 010.

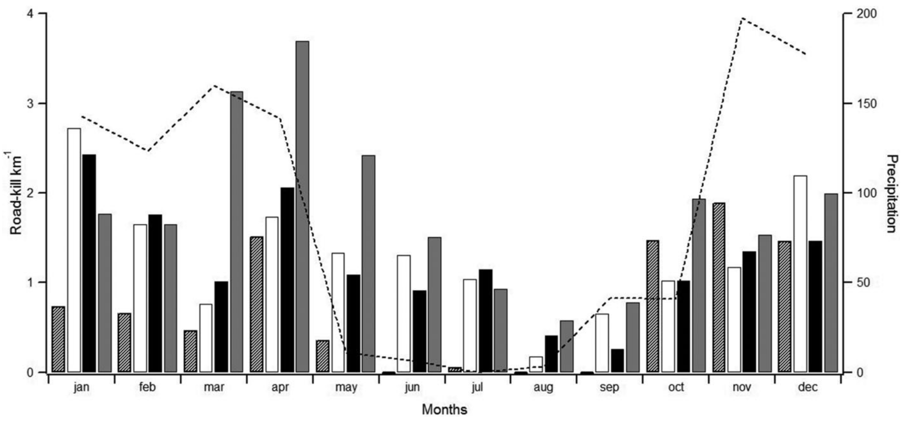

Figure 2. Monthly data of precipitation mean and road mortality rates of vertebrate classes of Chapada dos Veadeiros National Park during 2006 -2008. Bars indicate vertebrate groups: Amphibians: Grey bars with the black board; Birds: White bars; Mammals: Black bars; Reptile: Grey bars.

to the lowest taxonomic level possible, recorded the location with GPS, and removed the carcass from the road. Carcasses in good condition were preserved and added to the vertebrate collections of Universidade de Brasília.

The frequency of roadkill was calculated by dividing the number of individuals killed by the number of kilometers covered. The average frequencies of animals and species killed were compared between the dry season (April to September) and the rainy season (October to March). A paired t-test was used to evaluate the difference between dry and rainy seasons. Multiple regression was used to evaluate whether an association existed among roadkill, precipitation, and the structure of nearby vegetation.

3. *Estimates*

We constructed a species accumulation curve for all road-killed species and for each taxonomic class found on the road, using the individual-based rarefaction method (with the nonparametric Mao Tau estimator and with 95% confidence intervals) (Gotelli & Colwell 2001). The function of richness (Mao Tau) was computed as the accumulation function of individuals of each species. Species richness estimators were computed using nonparametric incidence-based estimators (Bootstrap, Chao 2, ICE, Jacknife 1 and 2) and abundance-based estimators (ACE and Chao 1) (Colwell & Coddington 1994, Colwell 2011). Both species accumulation curve and species richness estimators were performed to evaluate the sampling effort, allowing a better comparison among the groups of vertebrates found and pointing out which groups are underestimated through the method. Species rarefaction and richness estimators were performed with Estimates 8.2.0 software.

4. *Correlation of landscape with roadkill*

The attributes of landscapes near roads were assessed at 1 km intervals along the entire extent of the roads, both in the preserve and in the adjacent environment, using a 1:25000 topographic map. Landscape categories were assigned according to the proportions of environmental variables contained within 50 m on both sides of the the road shoulders on each kilometer. The categories included cerrado, grassland, forest, and pasture. In addition, the presence or absence of watercourses and the presence of paved or unpaved roads surfaces were recorded at the same intervals.

To examine the relationship between road-killed vertebrates and the road landscape, we performed a Canonical Correspondence Analysis (CCA; Ter Braak 1986), associating variation in one matrix (vertebrate abundance as the dependent variable) with variation in another matrix (landscape characteristics as the independent variable). In this analysis, we investigated whether a connection existed between specific habitat characteristics and the abundance of particular vertebrate groups. CCA was performed with CANOCO 4.5 (Ter Braak & Smilauer 1998), using the following options: focus scaling set on symmetric, biplot scaling type, downweighting of rare species, Monte Carlo test with 1,000 permutations of the reduced model, and unrestricted permutations.

Results

A total of 260 surveys of road-killed animals were conducted in 10,658 km: 212 on GO 239 (covering 7,463 km) and 48 on BR 010 (covering 3,195 km). In all, 824 vertebrates of 138 species were recorded along the two roads (Table 1). The most commonly road-killed species for each group of vertebrates were the yellow-toothed cavy (*Galea flavidens*) (10.2% of total vertebrate casualties), the marbled lancehead (*Bothrops marmoratus*) (7.5%), the Schneider's toad (*Rhinella schneideri*) (5.2%), and the grassland sparrow (*Ammodramus humeralis*) (3.0%). Six species that are nationally listed as threatened (MMA 2008) were found: black-masked finch (*Coryphaspiza melanotis*, $n = 1$, 0.12% of total vertebrate casualties), sharp-tailed tyrant (*Culicivora caudacuta*, $n = 1$, 0.12%), maned wolf (*Chrysocyon brachyurus*, $n = 7$, 0.84%), cougar (*Puma concolor*, $n = 1$, 0.12%), ocelot (*Leopardus pardalis*, $n = 3$, 0.36%), and giant anteater (*Myrmecophaga tridactyla*, $n = 1$, 0.12%). The overall number of road-killed vertebrates in relation to road length was 0.096 animals km^{-1}; the overall roadkill incidence-interval was 10.42 km per roadkill. Reptiles were the most frequently killed group on both roads, followed by birds, mammals, and amphibians (Table 2).

Vertebrate mortality was significantly higher during the wet season than during the dry season (paired t-test, $t = 4.935$, $df = 285$, $P < 0.000$) and mortality differed between the two seasons for all taxonomic groups: amphibians (paired t-test, $t = -2.576$, $df = 23$, $P = 0.017$), birds (paired t-test, $t = -3.184$, $df = 125$, $P = 0.002$), mammals (paired t-test, $t = -2.854$, $df = 45$, $P = 0.007$) and reptiles (paired t-test, $t = -2.141$, $df = 89$,

Table 1. Vertebrate species killed during dry and rainy seasons on highways GO-239 and BR-010 in Chapada dos Veadeiros National Park, Central Brazil.

Species	Common name	GO 239		BR 010	
		Dry	Rainy	Dry	Rainy
Amphibians					
Rhinella granulosus	Common Lesser Toad	0	2	0	0
Rhinella rubescens	Toad	1	10	0	0
Rhinella schineideri	Schneider's Toad	2	40	0	1
Bufonidae NI		0	3	0	7
Hypsiboas albopunctatus	Spotted Treefrog	1	10	0	0
Hypsiboas lundii	Usina Treefrog	0	3	0	0
Leptodactylidae NI		0	5	0	0
Leptodactylus fuscus	Whistling Frog	1	6	0	0
Leptodactylus labirinthicus	Pepper Frog	0	2	0	0
Leptodactylus ocellatus	Llanos Toad-frog	0	1	0	0
Physalaemus cuvieri	Cuvier's Frog	0	1	0	0
Siphonops paulensis	Boettger's Caecilian	0	1	0	0
Birds					
Alipiopsitta xanthops	Yellow-faced Amazon	0	0	0	1
Ammodramus humeralis	Grassland Sparrow	15	10	0	0
Anumbius annumbi	Firewood-gatherer	0	1	0	0
Eupsittula aurea	Peach-fronted Parakeet	1	8	0	0
Athene cunicularia	Burrowing Owl	0	0	0	1
Brotogeris chiriri	Yellow-chevroned Parakeet	3	1	0	0
Hydropsalis longirostris	Band-winged Nightjar	0	3	0	0
Antrostomus parvulus	Little Nightjar	1	2	0	0
Antrostomus rufus	Rufous Nightjar	2	0	0	0
Caracara plancus	Crested Caracara	0	1	0	1
Cariama cristata	Red-legged Seriema	7	7	0	1
Chordeiles pusillus	Least Nighthawk	2	4	0	0
Colaptes campestris	Campo Flicker	0	2	0	0
Colaptes melanochloros	Green-barred Woodpecker	1	0	0	0
Colibri serrirostris	White-vented Violet-ear	1	0	0	0
Patagioenas cayennensis	Pale-vented Pigeon	0	1	0	0
Patagioenas plumbea	Plumbeous Pigeon	0	1	0	0
Columbina talpacoti	Ruddy Ground-dove	0	1	0	0
Coryphaspiza melanotis	Black-masked Finch	1	0	0	0
Crotophaga ani	Smooth-billed Ani	0	1	0	0
Crypturellus parvirostris	Small-billed Tinamou	2	2	0	1
Crypturellus undulatus	Undulated Tinamou	0	1	0	0
Culicivora caudacuta	Sharp-tailed Tyrant	1	0	0	0
Cypsnagra hirundinacea	White-rumped Tanager	1	0	0	0
Elaenia cristata	Plain-crested Elaenia	1	3	0	0
Elaenia NI		0	4	0	0
Emberizidae NI		0	2	0	0
Emberizoides herbicola	Wedge-tailed Grass-finch	0	3	0	0
Gallinago undulata	Giant Snipe	0	0	0	1
Geothlypis aequinoctialis	Masked Yellowthroat	1	1	0	0
Guira guira	Guira Cuckoo	0	1	0	0
Gnorimopsar chopi	Chopi Blackbird	0	1	0	0
Gubernetes yetapa	Streamer-tailed Tyrant	1	1	0	0
Hydropsalis torquata	Scissor-tailed Nightjar	0	1	0	0
Melanerpes candidus	White Woodpecker	1	0	0	0
Mimus saturninus	Chalk-browed Mockingbird	1	3	0	2
Myiarchus tyrannulus	Brown-crested Flycatcher	1	0	0	0
Myiophobus fasciatus	Bran-coloured Flycatcher	1	0	0	0
Nothura maculosa	Spotted Nothura	8	13	1	1
Nyctibius griseus	Common Potoo	0	1	0	0

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Table 1. Continued.

Species	Common name	GO 239		BR 010	
		Dry	Rainy	Dry	Rainy
Nyctidromus albicollis	Pauraque	1	2	0	0
Nystalus chacuru	White-eared Puffbird	0	4	0	0
Passeriforme NI		1	14	1	0
Penelope superciliaris	Rusty-margined Guan	0	1	0	0
Piaya cayana	Piaya cayana	1	0	0	0
Rhea americana	Greater Rhea	1	2	0	0
Rhynchotus rufescens	Red-winged Tinamou	2	2	2	0
Saltattricula atricollis	Black-throated Saltator	0	2	0	0
Sicalis citrina	Stripe-tailed Yellow-finch	1	2	0	0
Sicalis flaveola	Saffron Finch	1	0	0	0
Sporophila plumbea	Plumbeous Seedeater	1	2	0	0
Sporophila NI		1	1	0	0
Suiriri suiriri	Suiriri Flycatcher	1	1	0	0
Synallaxis albescens	Pale-breasted Spinetail	1	0	0	0
Synallaxis frontalis	Sooty-fronted Spinetail	1	1	0	0
Tangara palmarum	Palm Tanager	1	0	0	0
Troglodytes musculus	Southern House Wren	0	1	0	0
Turdus leucomelas	Pale-breasted Thrush	0	1	0	0
Tyranidae NI		0	3	0	0
Tyto furcata	Common Barn-owl	0	0	1	0
Vanellus chilensis	Southern Lapwing	0	0	0	1
Volatinia jacarina	Blue-black Grassquit	2	8	0	0
Zonotrichia capensis	Rufous-collared Sparrow	0	2	0	0
Mammals					
Alouatta caraya	Black Howler	0	2	0	0
Callithrix penicillata	Black-pencilled Marmoset	0	1	0	0
Caluromys lanatus	Brown-eared Woolly Opossum	2	1	0	0
Cerdocyon thous	Crab-eating Fox	0	2	0	0
Chrysocyon brachyurus	Maned Wolf	2	3	1	1
Conepatus semistriatus	Striped Hog-nosed Skunk	8	9	2	1
Didelphis albiventris	White-eared Opossum	0	2	0	0
Puma concolor	Cougar	0	1	0	0
Galea flavidens	Yellow-toothed Cavy	29	50	0	5
Gracilinanus agilis	Agile Gracile Opossum	0	1	0	0
Leopardus pardalis	Ocelot	0	2	0	0
Lycalopex vetulus	Hoary Fox	7	16	2	13
Mazama gouazoupira	Gray Brocket	0	0	0	1
Mimon bennettii	Golden Bat	0	2	0	0
Myrmecophaga tridactyla	Giant Anteater	0	1	0	0
Nasua nasua	South American Coati	0	2	0	0
Ozotoceros bezoarticus	Pampas Deer	0	1	0	0
Procyon cancrivorus	Crab-eating Raccoon	0	1	0	2
rodent NI		7	7	0	0
Sylvilagus brasiliensis	Tapeti	1	0	0	0
Tamandua tetradactyla	Southern Tamandua	0	1	0	2
armadillo NI		0	1	1	1
Tapirus terrestris	South American Tapir	0	1	0	0
Reptiles					
Ameiva ameiva	Giant Ameiva	0	1	0	0
Amphisbaena alba	White Worm-lizard	0	2	0	1
Amphisbaena mensae	Worm-lizard	0	1	0	0
Amphisbaena NI		0	1	0	0
Apostolepis ammodytes	Red Burrowing Snake	0	1	0	0
Boa constrictor	Boa Constrictor	0	1	0	3
Bothrops moojeni	Brazilian Lancehead	5	17	0	2

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Table 1. Continued.

Species	Common name	GO 239		BR 010	
		Dry	Rainy	Dry	Rainy
Bothrops marmoratus	Marbled lancehead	9	43	5	5
Chironius flavolineatus	Boettger's Sipo	3	1	0	0
Chironius exoletus	Linnaeus' Sipo	0	0	1	0
Chironius quadricarinatus	Central Sipo	0	1	0	0
Crotalus durissus	South American Rattlesnake	8	16	2	4
Taeniophallus occipitalis	Spotted Savanna Racer	0	1	0	0
Epicrates cenchria	Rainbow Boa	3	6	1	1
Erythrolamprus aesculapii	Aesculapian False Coral Snake	0	1	0	0
Leptodeira annulata	Banded Cat-eyed Snake	0	1	0	0
Erythrolamprus almadensis	Almada Legion Snake	1	2	0	2
Erythrolamprus maryellenae	Maryellen's Ground Snake	0	1	0	0
Erythrolamprus meridionalis	Lined Ground Snake	1	4	0	1
Erythrolamprus poecilogyrus	Trash Snake	1	0	2	0
Erythrolamprus reginae	Royal Ground Snake	0	1	0	0
Liotyphlops ternetzii	Ternetzi's Slender Blindsnake	1	0	0	0
Lystrophis nattereri	Hognose Snake	0	1	0	0
Mastigodryas bifossatus	Rio Tropical Racer	0	1	4	0
Ophiodes aff. striatus	Striped Worm Lizard	1	5	0	0
Oxybelis aeneus	Brown vinesnake	1	2	0	0
Oxyrhopus guibei	False Coral Snake	3	7	0	0
Oxyrhopus rhombifer	Amazon False Coral Snake	7	3	0	1
Oxyrhopus trigeminus	Brazilian False Coral Snake	9	12	4	0
Philodryas aestivus	Brazilian Green Tree Snake	2	2	2	0
Philodryas nattereri	Paraguay Green Racer	2	4	1	1
Philodryas olfersii	Southeastern Green Racer	1	1	0	1
Philodryas patagoniensis	Patagonian Savanna Racer	4	2	0	1
Phimophis guerini	Argentine Pampas Snake	3	1	0	1
Polycrus acutirostris	Brazilian Bush Anole	15	3	2	0
Pseudablabes agassizi	Burrowing Night Snake	0	3	0	1
Pseudoboa nigra	Black False Boa	1	1	0	0
Sibynomorphus mikanii	Brazilian Slug-eating snake	5	7	0	1
Tantilla melanocephala	Black-headed Snake	0	4	0	0
Thamnodynastes hypoconia	Argentine Large-eyed Snake	3	8	1	1
Thamnodynastes sp.	Large-eyed Snake	0	1	0	0
Tupinambis merianae	Black Tegu	0	1	0	0
Xenodon merremi	Merrem's False Pit Viper	1	3	1	1
Xenopholis undulatus	Jensen's Ground Snake	0	1	0	0
Phrynops vanderhaegei	Vanderhaege's toad-headed turtle	0	1	0	0

$P = 0.035$). In addition, a stepwise multiple regression analysis showed that there was no association between vertebrate roadkill and precipitation ($r = 0.489$; $F = 3.138$; $P = 0.107$).

Species rarefaction curves did not reach stability (Figure 3). The species richness estimators produced estimates greater than the actual recorded species richness for all taxonomic groups (Table 3). The major estimates with the major standard deviations were recorded with Chao 1 and 2 and the minor estimates were recorded with Bootstrap estimator (Table 3).

A summary of road and landscape attributes appears in Table 4. On the basis of 9,999 permutations of a Monte Carlo test and the first canonical axis, we found a significant relationship

Table 2. Road-kill frequencies and incidence-intervals of vertebrates on highways GO-239 and BR-010 in Central Brazil.

Vertebrates	GO 239 (7463 km)			BR 010 (3195 km)		
	N	Frequency (ind km^{-1})	Incidence-interval	N	Frequency (ind km^{-1})	Incidence-interval
All	716	0.096	10.41	108	0.033	30.30
Amphibian	89	0.012	83.33	8	0.002	500.0
Bird	198	0.026	38.46	15	0.005	200.0
Mammal	163	0.022	45.45	32	0.010	100.0
Reptiles	266	0.036	27.78	53	0.017	58.82

http://dx.doi.org/10.1590/1676-0611-BN-2014-0182

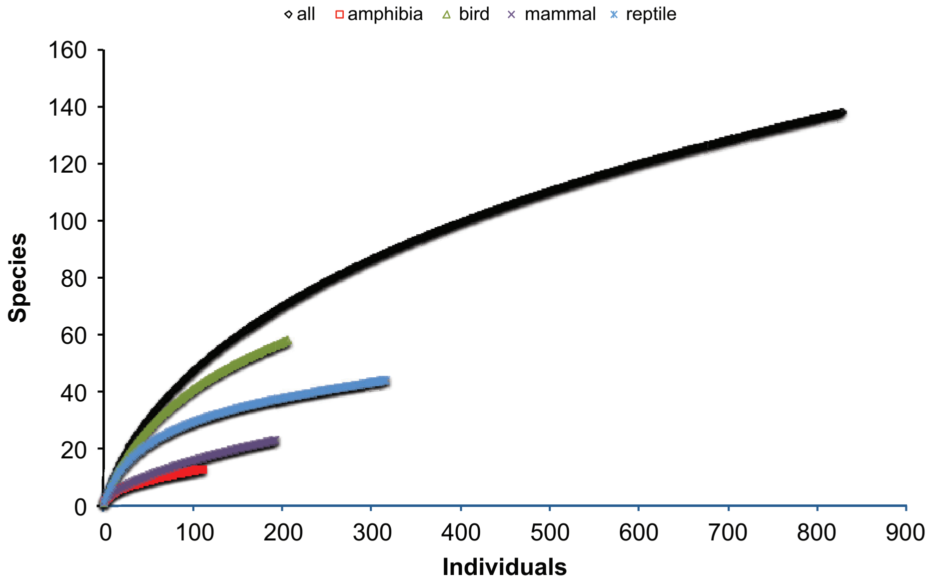

Figure 3. Individual-based rarefaction curves of roadkilled amphibians, birds, reptiles and mammals of Chapada dos Veadeiros National Park.

between habitat structure within arrays and vertebrate groups found there (eigenvalue = 0.146, $F_{4,35} = 14.958$, $P < 0.001$). In addition, all canonical axes were significant (trace = 0.205, $F_{4,35} = 4.444$, $P < 0.001$). Amphibians were associated with nearby forest and paved roads, birds were associated with nearby pasture, reptiles were associated with nearby grassland, and mammals were associated with unpaved road (Figure 4).

Discussion

The high number of road-killed vertebrates in CVNP indicates that the roads surrounding the park may significantly affect the wild vertebrates populations. The species richness found in our study (138 species) was greater than that reported by other long-term studies of Brazilian roads or motorways. Coelho et al. (2008) recorded 92 species on two roads in the northern coastal plain of Rio Grande do Sul; Rodrigues et al. (2002) found 100 species on four roads that delimit Águas Emendadas Ecological Station, in Distrito Federal; and Prada (2004) found 83 species on six roads in northeastern São Paulo. Fisher et al. (2003) recorded 140 species of vertebrates on BR 262, in the Pantanal wetlands of Mato Grosso do Sul, over the course of an 8-year-long study. The road mortality around CVNP is also high in comparison with other areas worldwide, such as Australia (Taylor & Goldingay 2004, n = 53), Europe (Lodé 2000, n = 97), and North America (Ashley and Robinson 1996, n = 100). However, the overall number of 0.096 road-killed vertebrates per kilometer was similar to that of other studies in Brazil, ranging from 0.078 animals km^{-1} on BR-383, in Rondônia (Turci & Bernarde 2009), to 0.138 on BR-307, in Acre (Pinheiro & Turci 2013).

Despite the high number of vertebrates found during our surveys, the results are still an underestimate of total roadkill. The survey method of the present study (searches by car) allows the record of many roadkills, but due to the car speed it may overlook small animals, such as small amphibians and birds (Coelho et al. 2008). Besides, by not searching the roads constantly (more than twice a day, for example), some animals are not recorded because they quickly disappear. For instance, scavenging predators could have removed numerous small dead animals from the roads (Antworth et al. 2005). In addition, some animals may have been thrown away from the road by the collision or may have been only wounded by the collision and died far from the road (Slater 2002). Nevertheless, the method of search by car permits the inspection of a great road extension in a short amount of time and it is comparable to similar surveys. Rarefaction curves for all groups do not reach stability, a common trend in roadkill studies (Santana 2009, Pinheiro & Turci 2013). Estimates also show that a high number of species for all groups are affected by the roads in CVNP. For example, at least 47 species of snake inhabit the park (França & Braz 2013), of which we found only 37 on the

Table 3. Richness estimators of road-killed vertebrates on Chapada dos Veadeiros roads.

Estimators	All (143)	Amphibians (12)	Birds (63)	Mammals (23)	Reptiles (45)
ACE	216.46 ± 1.19	21.51 ± 3.13	86.72 ± 1.36	49.34 ± 2.0	59.42 ± 0.71
ICE	216.27 ± 1.19	20.8 ± 3.06	86.63 ± 1.35	48.89 ± 1.97	59.3 ± 0.71
Chao 1	243.88 ± 38.89	18.0 ± 5.54	90.5 ± 17.22	65.25 ± 38.52	72.13 ± 20.9
Chao 2	243.88 ± 38.89	17.95 ± 5.5	90.34 ± 17.14	65.25 ± 38.52	72.13 ± 20.9
Jack 1	197.93 ± 7.46	18.95 ± 2.37	83.87 ± 4.76	35.93 ± 3.47	58.95 ± 3.77
Jack 2	240.84 ± 1.01	22.89 ± 0.9	100.75 ± 1.37	46.83 ± 0.97	69.9 ± 0.84
Bootstrap	163.35 ± 0.32	15.51 ± 0.3	69.25 ± 0.52	28.23 ± 0.36	50.32 ± 0.31

Table 4. Means for landscape characteristics of 35 quadrats of roads in the Chapada dos Veadeiros National Park.

Landscape	Mean ± SD
Pasture	2.06 ± 0.41
Grassland	6.38 ± 0.48
Savanna	3.32 ± 0.47
Forest	5.35 ± 0.77
Water	2.20 ± 0.41
Paved road	6.38 ± 0.48
Unpaved road	3.61 ± 0.48

roads. Some species that are common in the Cerrado and that have been found in previous studies are the brown-banded water snake (*Helicops angulatus*), the southern crested caracara (*Caracara plancus*), the American black vulture (*Coragyps atratus*), the greater grison (*Galictis vittata*), and the nine-banded armadillo (*Dasypus novemcinctus*). These species will probably appear in future surveys of roads around the CVNP.

Among the four vertebrate classes found as roadkill, the impact on amphibians is most likely to have been underestimated, due to their small size, their thin skin, and the slow locomotion of many amphibian species. The carcasses do not last as long on roads as those of other vertebrates because scavengers eat them rapidly or they are run over many times and are rapidly obliterated by vehicles (Hels & Buchwald 2001). Also, due to their activity patterns, seasonal reproduction, population structure, and selected habitats, amphibians are commonly more vulnerable to being hit by vehicles than other species (Hels & Buchwald 2001). Most data regarding road-killed amphibians are for large toads and frogs of the Bufonidae and Leptodactylidae families, the carcasses of which remain longer on the roads (Fahrig et al. 1995). The most commonly found amphibian in our surveys, the Schneider's toad (*Rhinella schneideri*), is a very common species in the Brazilian Cerrado, and individuals belonging to the genus *Rhinella* are often found as roadkill in different regions, such as Amazonia and the Atlantic Forest (Silva et al. 2007, Turci & Bernarde 2009).

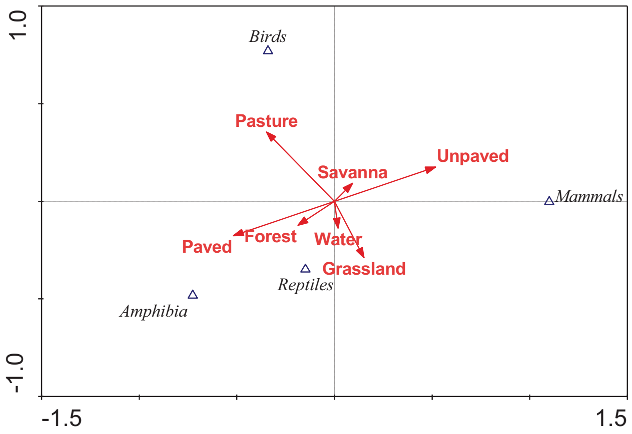

Figure 4. Plot of Canonical Correspondence Analysis comparing matrices of structural habitat characteristics with roadkill vertebrates sampling data. The plot shows the position of each vertebrate class among arrays on first two canonical axes. Lengths of environmental vectors indicate significance strength and points of arrows represent centroids of impact of environmental variables on each vertebrate class' distributions among arrays.

Birds are also likely underestimated, particularly small passerines. Usually birds are hit while they are in flight and are thrown off the roads by the impact (Erritzoe et al. 2003). Many hawks and buzzards are hit while scavenging roadkill (Antworth et al. 2005). In addition, the type of habitat near roads can attract birds to the roads and increase their risk of becoming roadkill. For example, many small birds move and forage in the vegetation along the roads (Orłowski 2005). In natural landscapes crossed by roads, the roadside vegetation serves as a corridor and ecotone used by insects and birds, facilitating movement and feeding along the border of an area, but birds that spend time in this area are at higher risk of being hit by vehicles (Orłowski 2008, Rosa & Badger 2012). Most road-killed birds in the CVNP were species that use road borders frequently, such as the grassland sparrow (*Ammodramus humeralis*) and the blue-black grassquit (*Volatinia jacarina*). Although some authors have described roadkill as having low influence on the population dynamics of birds (Reijnen et al. 1995), these impacts can be proportionally greater in threatened species, such as certain grassland birds in the Cerrado, like the black-masked finch (*Coryphaspiza melanotis*). This species should receive special attention and mitigation programs, because it is nationally threatened species in Brazil (Brazilian National list of endangered species Portaria MMA no 444/2014).

Mammals are usually affected by roads when they have wide home ranges and terrestrial habits, which make them use roads as corridors for movement (Smith-Patten & Patten 2008). Also, many mammals are nocturnal and/or are scavengers. At night, they are targets for vehicles because they can become blind and immobilized on roads when cars' headlights shine on them (Barthelmess & Brooks 2010). Both the hoary fox (*Lycalopex vetulus*) and the crab-eating fox (*Cerdocyon thous*) are commonly hit by cars for this reason. These omnivorous, nocturnal and generalist foxes have ample distributions in South America and abundant populations (Wozencraft 2005) and are frequently found on various roads (Vieira 1996, Silveira 1999, Coelho 2003, Prada 2004). Another small mammal that was frequently found on CVNP roads was the yellow-toothed cavy (*Galea flavidens*). Despite its high abundance in the CVPN, this species is not common, as it is endemic to Brazil and restricted to the montane savanna habitat (Bonvincino et al. 2005, Weksler & Bonvicino 2008). Finally, other mammals that require special conservation attention are the giant anteater (*Myrmecophaga tridactyla*), the cougar (*Puma concolor*), and the maned wolf (*Chrysocyon brachyurus*). These are Brazilian threatened species and their populations are low in Central Brazil (Brazilian National list of endangered species Portaria MMA no 444/2014).

Snakes are the reptiles that are most likely to be hit on roads, due to their characteristic long body morphology and their habit of frequently using roads as thermoregulation sites (Bernardino & Dalrymple 1992, Bonnet et al. 1999). Most reptiles found on CVPN roads were snakes or long-bodied lizards, such as *Ophiodes aff. striatus*. Terrestrial and sit-and-wait genera, such as *Bothrops*, *Crotalus*, and *Oxyrhopus*, and slow-moving reptiles, such as *Polychrus acutirostris* and the worm lizards of the genus *Amphisbaena,* are commonly hit by vehicles. No reptile species are listed as threatened in Central Brazil. However, species with life histories characterized by low reproductive rates and low adult mortality, such as the Vanderhaege's toad-headed turtle (*Phrynops vanderhaegei*), and huge snakes and vipers, are more vulnerable to the demographic consequences of road mortality (Forman et al. 2003, Shepard 2009).

The species richness of roadkill and the roadkill rates are influenced by seasonality as well as by type of nearby habitat (Trombulak & Frissell 2000, Rosa & Bager 2012). There are two well-defined seasons in Central Brazil, the wet or rainy season, characterized by high precipitation, and the dry season, during which almost no rain falls (Nimer 1989). Vertebrate mortality on CVNP roads was significantly higher during the wet season, as reported by previous studies in Central Brazil (Rodrigues et al. 2002). Studies show that more Brazilian mammals (Cáceres et al. 2012) and anurans (Coelho et al. 2012) are killed on roads during the rainy season. The Cerrado of Central Brazil shows high seasonality and the activity of vertebrates becomes more intense after the first rainfalls (Oliveira & Marquis 2002). Even for plants, the rainy season is a more active time; although fructification of anemochorous and autochorous species occurs during the dry season, the fructification of zoochorous species is dispersed throughout the rainy season (Batalha & Mantovani 2000). Also, many animal species of Cerrado show dispersion and migratory movements and reproductive activities during the rainy season, when roads become barriers to their intense locomotion.

Amphibians were associated with patches of paved road with nearby forest habitat. In the Cerrado, gallery forests are always associated with streams and rivers, suitable environments for amphibians (Colli et al. 2002). These animals are at increased risk of being hit on high-speed paved roads and are killed mainly during the reproductive season. In contrast, there were more road-killed birds along roads next to pasture habitats. Despite their preference for forest habitats, birds that live in rural landscapes are usually associated with roads that are bordered by native vegetation. These roads can be attractive habitat and potentially a population sink, and offer a higher abundance of insects than other areas, attracting birds (Orłowski 2008).

In contrast with amphibians and birds, most of the reptiles and small mammals of the Cerrado are associated with open areas, and the majority of snakes found in the CVNP are found in grasslands or open savanna environments (França & Braz 2013). Roadkilled mammals were strongly associated with unpaved road. In spite of the fact that mammals inhabit mainly forest habitats in the Cerrado (Johnson et al. 1999), most species have wide home ranges and may traverse the entire Cerrado. Compared with paved roads, unpaved roads appear to be more suitable and less exposed environments that enable the movements of CVNP mammals.

Due to the importance of the CVNP as a protected area that harbors and maintains the biodiversity of the Cerrado, it is important to remain monitoring the impact of the park's roads on wild vertebrates. Further studies may use recent indices and analyses to measure the impact of roads on the fauna of the CVNP and to establish priorities for mitigation programs (Coelho et al. 2008, Bager & Rosa 2011). Some mitigation actions are urgently needed, such as highway fencing in combination with safe crossing opportunities for wildlife (Clevenger et al. 2001).

Acknowledgments

The authors are grateful to Daniel Rios de Magalhães Borges and ICMbio for collection permits in the Chapada dos Veadeiros National Park (IBAMA license 051/2007 and SISBIO license 15325-1). We thank Santos Balbino, Davi Pantoja, and Iubatã Farias for their generous help during fieldwork, Rafaela França for the map of CVNP, and José Augusto Drummond, Marcel Bursztyn, Marília Machado and Rebeca Roysen for their suggestions to improve the manuscript. We also thank the National Counsel of Technological and Scientific Development (CNPq) for a graduate scholarship and the Fundação O Boticário de Proteção à Natureza for financial support (0754_20072).

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Received 02/12/2014
Revised 20/10/2015
Accepted 18/11/2015

Biota Neotropica 16(1): e20140164, 2016
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
article

The ShearStress importance on the spatial distribution pattern of the invader *Limnoperna fortunei* in the Upper Paraná River Basin. - An assessment based on the Spatial Distribution Models

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CAMPOS, M.C.S., PEIFER, D., CASTRO, P.T. **The ShearStress importance on the spatial distribution pattern of the invader *Limnoperna fortunei* in the Upper Paraná River Basin. - An assessment based on the Spatial Distribution Models.** Biota Neotropica. 16(1): e20140164. http://dx.doi.org/10.1590/1676-0611-BN-2014-0164

Abstract: The introduction of the golden mussel, *Limnoperna fortunei* (Dunker, 1857) in South America was related to the discharge of ballast water, with its first record in 1991 in the La Plata River estuary. Since then, the species is spreading throughout the continent, with several economic and ecological negative consequences. ***Aim***: To model, in the headwaters of Parana River, the spatial distribution of *L. fortunei* and to understand the determinants of the current pattern of species distribution and the risk of invasion of areas not yet colonized. ***Methods:*** The ecological niche of *L. fortunei* was modeled using the algorithm MAXENT (Maximum Entropy Method) combined with records of occurrence of the bivalve, limnological data and the shear force measured by the index Hack (SL). The evaluation of the performance of different models was based on AUC (Area Under the Curve).The analysis of each variable's contribution to the responses of the models was made based on the Jackknife test, available in the Maxent program. The models were validated with real absence data collected between 2006 and 2007. Based on the limnological characterization of the area and on outputs of the models, this analysis sought to understand the contributing aspects to the current and potential spatial distribution and to verify the risk of invasion of environments not yet colonized by the species. ***Results/Conclusion:*** The limnological characterization showed that the ecological requirements for the species as, pH, calcium, oxygen and chlorophyll *a*, were appropriate in both the connected stretches, invaded and non-invaded. Turbidity showed significant spatial differences which proved to be higher in environments with higher levels of Hack (SL), i.e. higher energy fluvial. In addition, the algorithm showed the importance of hydrodynamical aspects expressed by Hack index (SL) to the spatial distribution of species, since the models with the best performances were those that considered the Hack index (SL) as one of the environmental layers of the mussel's niche. All models indicated a high risk of invasion into the reservoir of São Simão.

Keywords: *invasive species, biological invasions, niche modeling, Maxent, ecological requirements.*

CAMPOS, M.C.S., PEIFER, D., CASTRO, P.T. **Importância da força de cisalhamento no padrão de distribuição espacial do invasor Limnoperna fortunei na Bacia do Alto rio Paraná. – Uma avaliação com base em Modelos de Distribuição Espacial.** Biota Neotropica. 16(1): e20140164. http://dx.doi.org/10.1590/1676-0611-BN-2014-0164

Resumo: A introdução do mexilhão dourado, *Limnoperna fortunei* (Dunker, 1857) na América do Sul esteve relacionada às descargas de água de lastro, com seu primeiro registro em 1991, no estuário do rio da Prata. Desde então a espécie vai adentrando o continente – com várias consequências negativas em âmbitos econômicos e ecológicos. ***Objetivo***: modelar em escala local a distribuição espacial de *L. fortunei* buscando melhor entender os fatores determinantes do padrão atual de distribuição da espécie e estimar o risco de invasão de áreas ainda não colonizadas. ***Métodos:*** A modelagem do nicho de *L. fortunei* foi realizada por meio do algoritmo MAXENT (Maximum Entropy Method) aliado a registros de ocorrência do bivalve, à dados limnológicos e à força de cisalhamento medida pelo índice de Hack (SL). A avaliação do desempenho dos diferentes modelos foi feita com base na AUC (Área sob a Curva). A análise da contribuição isolada das diferentes variáveis para as respostas dos modelos foi feita com base no teste Jackknife disponível no programa Maxent. Os modelos gerados foram validados com dados reais de ausência coletados entre 2006 e 2007. Com base na caracterização limnológica da área e nas respostas geradas pelos modelos de distribuição potencial, buscou-se entender quais aspectos estariam contribuindo para a distribuição espacial atual e potencial e verificar o risco de invasão de ambientes ainda não colonizados pela espécie. ***Resultados/Conclusão***: A caracterização limnológica mostrou que os requerimentos ecológicos para a espécie como pH, cálcio, oxigênio e clorofila *a* foram igualmente adequados entre trechos invadidos e não invadidos conectados. Diferenças espaciais significativas foram encontradas em relação à turbidez, que se mostrou mais elevada nos ambientes com maiores índices de Hack (SL), ou seja, com maior energia fluvial. O algoritmo utilizado mostrou a importância de aspectos hidrodinâmicos, expressos pelo índice de Hack (SL) na distribuição espacial da espécie, uma vez que, os modelos com melhor desempenho foram aqueles que consideraram o índice de Hack (SL) como uma das camadas ambientais na composição do nicho da espécie. Todos os modelos indicaram também o alto risco de invasão para o reservatório de São Simão.

Palavras-chave: *espécies invasoras, invasões biológicas, modelagem de nicho ecológico, Maxent, requerimentos ecológicos.*

Introduction

Exotic invasive species can cause the extinction of vulnerable native species, either by predation, competition, or even the alteration of the habitat. These modifications have been taking place globally (Morton 1997, Karatayev et al. 2007, Karatayev et al. 2008, EPA 2013) and will continue into the future (Ricciardi & MacIsaac 2000), with predictable declines in biodiversity (Sala et al. 2000). Therefore, it is essential to understand the invasion process, predict its successes and effects on the new environment. This includes, among other aspects, the identification of the invading species and the evaluation of probable areas of invasion (Mack et al. 2000).

Knowledge of the environmental characteristics of a given region, together with records of the occurrence of a species, can be used to indicate a range of environmental factors which determine locations in which a species could maintain populations or not – known as the ecological niche (Chase & Leibold 2003). In general, potential distribution models can be considered as the adjustment of a function between the points of occurrence of a species and a multivariate group of environmental data (Phillips et al. 2006). However, an invading species must overcome some filters in order to settle in a new region (Power et al. 1992). These filters include: geographical barriers; the physical environment, which characterizes the target habitat and may constitute a more or less favorable environment to a certain invading species; the demographical resistance; and, finally, the biological filter, which can be defined by the competition and predation between previously settled species and invading species (Williamson 1996). The points of occurrence assumed in the modeling process represent areas in which the physical habitat conditions are favorable to the invading species. However, other areas with similar conditions must exist, where the presence of the species is halted by the existence of filters related to inter-specific interactions, the existence of geographical barriers, long distances, and also the non-existence of the species dispersion vector. For this reason, in order to the use potential distribution models it is necessary to take into account the distinctions between the sub-space for the conditions and the sub-space for the resources (Soberón 2007). The available environmental data must represent the sub-space for the conditions only, rather than the species niche as a whole (see Hutchinson's (1957) concept).

Limnoperna fortunei (Dunker, 1857) – popularly known as the golden mussel, is a non-native species which is currently spreading unchecked in South America. It was introduced in 1991 on the Argentinian shore, close to the Rio de la Plata (Pastorino et al. 1993), by means of ballast water discharges (Darrigran & Pastorino 1995). It is a freshwater bivalve originally from Chinese and Southeastern Asian rivers (Morton 1975), which has been causing considerable economic and environmental impact. The occurrence of *L. fortunei* from the southern part of South America to the headwaters of the upper Paraná River (Campos et al 2012) shows how much its spatial distribution has been expanding in Brazil since 1998. For this reason, a better prediction of the environment's potential to accept or avoid the establishment of *L. fortunei* on the basis of niche modeling is essential for developing prevention and control strategies.

Different studies involving the prediction of the spatial distribution of aquatic species have focused on distinct environmental characteristics at the regional or continental levels (Peterson 2001, Peterson & Vieglais 2001, Drake and Bossenbroek 2004, Iguchi et al. 2004, Kluza & McNyset 2005, Campos et al 2014). The first studies related to the generation of ecologic niche models for aquatic species (Strayer 1991, Iguchi et al. 2004, Drake and Bossenbroek 2004, Bossenbroek et al 2007) utilized environmental variables (environmental layers) restricted to global climatic environmental variables (*e.g.*, rainfall and air temperature).

In the case of bivalve molluscs, variables such as temperature, pH, concentration of calcium in the water, alkalinity, hardness, chlorophyll, granulometric characteristics of natural substrates or even the presence of artificial substrates for settlement may be very important for its establishment in a new environment (Hincks & Mackie 1997 Claudi & Mackie, 1994 Mac Mahon, 1996). Ramcharam et al. (1992) and Mellina & Rasmussen (1994) used pH and dissolved calcium in niche modeling for aquatic species; Koutnik & Padilla (1994) focused on geological information (especially rock types).

Among the studies of the *L. fortunei* potential distribution which considered limnological variables, two used data points, from field sampling, to evaluate the distribution of the mussel in the Upper Paraguay River basin in Brazil and in some rivers in North America (Oliveira et al, 2010a, 2010b).

None of these works, however, highlights the importance of the shear stress (Bathurst 1982) or shear strength (Christofoletti 1981) as one of the potential determining variables for the niche and the potential distribution of *L. fortunei*. Considering that this bivalve is an epifaunal species, that the attachment to hard substrates is by means of a byssus (Morton 1973), and that its planktonic larval stages are easily dragged by water currents, the hypothesis presented in this paper is that the competence of a river, here indicated by the shear strength, is an important factor in the composition of *L. fortunei*'s ecological niche, influencing its establishment in a new environment and consequently determining its distribution. For the study area in the lower Paranaíba River basin, Campos et al. (2012) indicated several factors that would impose a certain "hydrodynamic stress" on larval stages and would contribute to slowing the establishment of the mollusc, thus making it difficult for the bivalve to

http://dx.doi.org/10.1590/1676-0611-BN-2014-0164

overcome the geographic barrier represented by the São Simão hydroelectricity plant and to establish in the river segment upstream. To prove this hypothesis, we modeled the *L. fortunei* niche using the algorithm Maximum Entropy Method (Maxent), incorporating the shear strength of the aquatic environments as one of the environmental layers of the ecological niche of *L. fortunei*.

This paper uses a model of potential distribution of the species based on limnological data and validation with real data. From the evaluation of the best-case and worst-case scenarios, we sought to illustrate that the distribution pattern of the invasive bivalve in a river stretch of the Upper Paraná River basin may have been influenced by a hydraulic component that has been neglected in studies of this species' niche modeling.

Material and Methods

1. Area of Study

The region of study comprises the confluence of the Paranaíba and Grande Rivers, in the borders of the states of Minas Gerais, Goiás, Mato Grosso do Sul and São Paulo (Figure 1). This region is part of the headwaters of the Paraná River and its tributaries, which are geographically connected to watercourses of other very important Brazilian watersheds. The segment of the lower Paranaíba River, downstream from the Hidroeletric Powerplant of São Simão, which belongs to Cemig (Companhia de Energia de Minas Gerais – Electric Energy Company of Minas Gerais), corresponds to the initial portion of the Paraná-Tietê waterway, where vessels transporting grains represent the main dispersion mechanism of the invading mussel.

The records of the bivalve occurrence, as well as the physical-chemical data used for the construction of the environmental layers, were obtained in 12 field campaigns which took place between 2006 and 2007, encompassing the rainy and dry seasons, in the lower Paranaíba River. Even eight years late, it must be emphasized that the spatial distribution pattern was not drastically modified and until now, the mussel has not invaded the São Simão reservoir.

In general, the presence points were used to construct the ecological niche models while the absence points were helpful in validating the generated models.

When modelling invasive species it must be considered that invasives are not in equilibrium with their environment and niche quantification and transferability in space and time are limited (Gallien et al. 2012). For the purpose of this study, only records from the Brazilian invaded region were used. In the case of an invasive species like *L. fortunei*, the true potential range of occurrence may differ from the realized range because of dispersal limitation, competition or other factors, so that evaluating model performance is a complex task and the use of observed absences may be misleading (Elith et al 2006). For instance, true absences could be allocated in areas that are either unsuitable for the species, or that are suitable but currently do not host any population. In this way for the case of modelling the potential distribution of an invasive species the techniques that play down the importance of absence information may be better suited to estimation of the ecological and distributional potential of the species, whereas methods incorporating absence information more directly may be more suitable for estimating actual distributions of species (Jimenez–Valverde et al 2011).

1.1 Occurrence points (presence). Six presence points of the species occurrence (Figure 1) were found within a sampling net with 21 points located upstream and downstream from the São Simão reservoir (Figure 1). According to Stockwell & Peters (2002), who assessed the accuracy of predictive models generated by different algorithms by comparing them with the number of occurrence records, under a machine-learning methods, average success rate at predicting occurrence of a species at a location or accuracy was 90% within ten sample

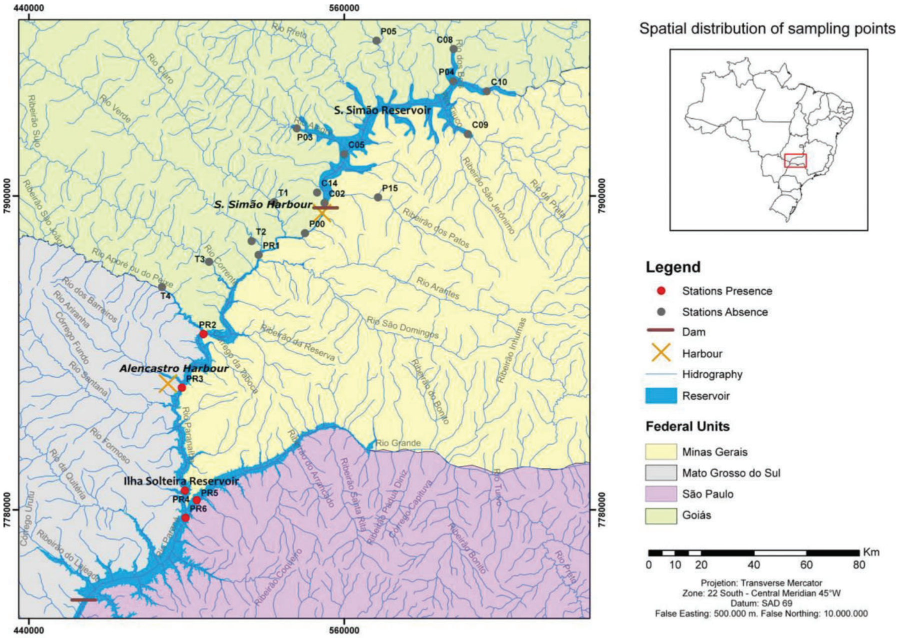

Figure 1. Sampling stations and golden mussel occurrence points along the Paranaíba River, upstream and downstream from the São Simão reservoir (MG/GO), Upper Paraná River Basin.

points. So such a number of recorded presences represents a very satisfactory percentage for the purposes of this study.

1.2 Absence points. The species was not found in the São Simão reservoir and its affluents or in the tributaries of the Paranaíba River right margin – Claro (T1), Verde (T2), Corrente (T3) Rivers. In relation to the Aporé (T4) River, the invasive bivalve was found only in the confluence of the Aporé and Paranaíba Rivers (PR2), as it was showed in the Figure 1.

2. *Environmental Layers*

The choice of the environmental layers was based on the importance of the variables to the species' biology and its representability of the local heterogeneity (Table 1). As well, the correlation degree between the variables was evaluated to identify a possible collinearity among them. In this way, pH / dissolved oxygen / chlorophyll *a* / turbidity / conductivity and calcium were considered as directly important to *L. fortunei* survival (Morton 1975, Ricciardi 1998, Sylvester et al. 2004, Karatayev et al. 2007, Pareschi et al. 2008). The spatial variation of the physical-chemical properties of water, chlorophyll *a* concentrations and the *L. fortunei* density were assessed by applying a one-way ANOVA and the Tukeys method a posteriori or, a Kruskal-Wallis test for non-normal distribution cases with post-hoc comparisons of mean ranks of all pairs of group (Siegel & Castellan 1988). The degree of correlation between the variables was tested using the non-parametric Spearman's correlation coefficient. Analyses were performed and graphed using STATISTIC 7 software (StatSoft South America, São Caetano do Sul – SP, Brazil).

For this study, an additional variable was chosen: the Hack Index or Stream Length-Gradient Index (SL), which expresses the energy of a fluvial environment and consequently its shear strength (Hack 1973, Etchebehere et al. 2004, Etchebehere et al. 2006).

The Hack Index is generally calculated using a topographic map and is mathematically defined as: $SL = \frac{\Delta H}{\Delta L} L$, where: L represents the length of the river segment, taken from its source (longest reach); ΔH represents the altimetric variation, and ΔL represents the horizontal distance – thus signifying the average declivity of the segment. From these empirical evidences (Hack 1957, Hack & Young 1959), Hack observed that the river competence is proportional to the channel declivity (S) and the channel length (L) – an increase in size of the particles being deposited in the river channel corresponds to an increase in SL – in other words, the Hack Index (Hack 1973). Assuming that the competence of a river is directly related to its energy, it is understandable that the Hack Index (SL) should be taken as a measure or an indication of the river energy – and, therefore, as a comparative basis between them (Etchebehere et al. 2004, Etchebehere et al. 2006).

The environmental layers used in the simulation resulted from georeferencing the sampling points indicated in Figure 1, and from which abiotic data was obtained. From the spatial distribution of these points in a drainage network, interpolations of the spatial variation of limnological data were possible for segments with no punctual sampling. A total of 420 registers were used to create and to test the model. The points of confluence were taken into account in the calculation of the concentrations of abiotic constituents in river segments devoid of information. In these sites, there is a sudden increase in the discharge and sediment load transported by the river, making adjustments in the river physical-chemical characteristics necessary, in order to compensate for the perturbation of a previous state (Best 1986, Leopold & Langbein 1964, Benda et al. 2004).The interpolation tools used were the Inverse Distance Weighting (IDW) and Kriging, these methods are available on the ArcGIS Spatial Analyst, version 9.

3. *Algorithm*

The software MAXENT version 3.2.1 (http://www.cs.princeton.edu/~schapire/maxent/) was used to model the *L. fortunei* ecological niche and ArcGis (version 9.3) was used to spatially represent the output data. The Software MAXENT - Maximum Entropy Method uses the maximum entropy principle, which states that the best approximation for an unknown probability distribution is the one that complies with any restriction to the distribution. This is a method used to make predictions or inferences using incomplete information (Phillips et al. 2006). The application of MAXENT to generate spatial distribution models results in the estimation of the probability of the species occurrence by finding the maximum entropy probability distribution submitted to a set of restrictions that represent the incomplete information on the target distribution.

The option "Auto features" was selected, using as output format the "Logistic" option – which offers an estimate between 0 and 1 for the probability of the presence of the species. 75% of the data was considered training points and was used to construct the model, and the remaining 25% was used as testing points, which are the points (data) used to assess the quality of the model.

From all possible combinations in the Maxent simulations, eight models of the golden mussel ecological niche were selected as representative of the extreme model performance situations – the best-case and worst-case scenarios of potential distribution. The eight chosen models, using different combinations of environmental layers, were: (1) all environmental layers; (2) all layers, excepting chlorophyll *a*; (3) all layers, excepting dissolved oxygen; (4) all layers, excepting the Hack Index (SL); (5) all layers, excepting dissolved oxygen / pH; (6) all layers, excepting dissolved oxygen / pH / calcium / conductivity; (7) all layers, excepting conductivity /pH / dissolved oxygen; (8) only the layers chlorophyll *a* / SL.

The statistic method used to ascertain the model quality was the Area Under the Curve (AUC) calculated by Maxent software itself.

The evaluation of a model is based on the forecast performance and includes the determination of a minimum threshold of the quantitative value produced for the potential presence of a species. The sensibility of a model is defined as the proportion of true presences in relation to the total of presences predicted by the model. The specificity is defined as the ratio of true absences in relation to the total of absences predicted by the model. Thus, the Receiver Operating Characteristics (ROC) curve is obtained plotting the sensibility against 1 minus the specificity for different values of the probability threshold, generating an evaluation method of the threshold independent of the model (Manel et al. 2001). In addition, the area below the curve AUC is extensively used in species distribution modelling (SDM), characterizing the performance of the model, in all possible thresholds, based on a single value that can be used as an objective approach in comparing different models (Elith et al. 2006; Phillips et al.

Table 1. Mean, minimum and maximum values of limnological variables from São Simão dam and tributaries upstream the dam, Paranaíba river and right bank tributaries, Grande and Paraná Rivers.

		Main Rivers			*Reservoirs downstream tributaries*				*São Simão Reservoir*	*Reservoirs upstream tributaries*			
Station		**Paranaíba P00 – PR4**	**Grande PR5**	**Paraná PR6**	**Claro T1**	**Verde T2**	**Corrente T3**	**Aporé T4**	**C2, C5, C8, C9, C10, C14 Average**	**Alegre P03**	**Preto P04**	**São Francisco P05**	**Patos P15**
Water Temperature (°C)	Average	25.92	26.19	26.16	24.06	23.89	24.05	23.91	**26.59**	20.5	21.5	20.6	20.6
	Min.	18	22.97	23.63	20.3	19.9	20.3	19.3	**22**	22.43	22.93	20.6	25.12
	Max.	30.4	29.63	29.7	28.8	27.9	28.9	28.1	**32.1**	26	25.9	20.6	31.4
Conductivity (μS.cm^{-1})	Average	37.22	47.29	41.39	21.53	19.23	19.46	32.12	**42.29**	41.33	44.83	19	96.8
	Min.	23.7	44.33	36.33	17.9	14.9	14	23.5	**30**	31	36	19	62
	Max.	58	55	53.47	26	25	33	43.7	**57**	53	51	19	159
pH	Average	6.82	6.81	6.83	6.91	6.75	6.47	6.54	**7.4**	7.11	7.14	6.79	7.29
	Min.	5.83	6.04	6.27	6	6.22	5.64	5.46	**6.01**	6.93	6.85	6.79	6.15
	Max.	7.89	7.87	7.7	7.7	7.55	7.5	7.22	**9.99**	7.56	7.58	6.79	8.7
Dissolved Oxygen (mg.L^{-1})	Average	7.75	7.53	7.48	7.83	8.76	7.55	7.48	**7.82**	7.39	5.93	7.5	7.75
	Min.	5.1	5.7	6.6	6.8	7.5	6.8	5.5	**6**	6.6	4.5	7.5	7.1
	Max.	9.6	8.7	8	9	10.4	8.3	9	**9.1**	8.03	7.2	7.5	8.4
Turbidity (NTU)	Average	6.23	2.71	4.75	33.87	49.48	12.43	17.68	**4.22**	14	26	28	1
	Min.	0.08	0.19	0.63	2.68	2.88	2	2	**0**	4	10	28	1
	Max.	44	11.67	21.33	97	133	28	48	**22**	24	42	28	1
Calcium (mg.L^{-1})	Average	4.16	3.95	4.15	2.54	2.14	2.49	3.43	**4.21**	4.93	4.67	4.49	11.03
	Min.	1.87	2.87	2.74	1.73	1.36	1.65	2.58	**2.41**	3.85	3.98	3.56	6.42
	Max.	23.5	6.8	6.4	3.88	3.46	3.54	3.93	**14.3**	5.79	5.04	5.41	16.08
Chlorophyll *a* (μg.L^{-1})	Average	12.16	6.31	4.74	9.11	6.13	3.39	1.77	**12.36**	0.62	6.03	4.62	9.41
	Min.	0	1.25	1.6	0	0.07	1.42	0	**2.39**	0.27	2.25	2.57	8.13
	Max.	242.22	17	11.48	58.5	21.63	6.41	4.85	**101.21**	0.97	12.55	6.68	10.68

2006). The AUC varies from 0 to 1, where 1 indicates high performance, while values lower than 0.5 indicate low performance (Luoto et al. 2005; Elith et al. 2006). In spite of recent criticisms (e.g., Lobo et al. 2008), AUC can still be useful comparing models of the same species in a similar geographical space. In this work, true records of absence were not considered, so the calculation of the AUC made use of the "background" data (also called pseudo-absences), chosen uniformly and randomly from the study area (Phillips et al 2006). Only the models that yielded an AUC value higher than 0.75 were considered in this study. Some measures were taken to minimize the limitations of the AUC as the use of true absences to validate the output scenarios and a good spatial distribution of the presence registers along of the study area.

Jackknife analysis was used to test the importance of the variables in the predictive ability of each model generated by Maxent.The Jackknife assessment excludes one variable at a time and recreates the model to determine the relative contribution of the predictor variable to the habitat suitability. It also considers each variable separately to determine whether it alone contributes significantly to the model.

Results

5.1 Limnological characterization of the environments in 2006/2007

The average larval densities were low in the Paranaíba (that includes stations P00-PR4), Grande (PR5) and Paraná (PR6) rivers never exceeding 300 ind.m^{-3}. A longitudinal distribution gradient was noticed, which increased significantly between upstream and downstream, from the PR2 station on the Paranaíba River, to its confluence. A large density of golden mussel larvae was found at the PR3 station, on the Paranaíba River (Kruskal-Wallis test: $H = 58.69$ and $p = 0.0001$) and downstream.

The surface waters yielded mean temperatures of 20-26°C with a range of 18.0-30.4°C (Table 1). The lowest average dissolved oxygen concentration corresponded to the tributaries located in the upstream portion of the dam of the hydroelectric plant of São Simão ($F = 3.66$ and $p = 0.013$), although all environments present themselves well oxygenated, measuring always above the average value of 5.0 mg.L^{-1}. In general the conductivity was low, but varied significantly between environments ($H = 94.80$, $p = 0.000$). The average conductivity of the reservoir's downstream tributaries was smaller than that of the reservoir and its upstream tributaries. For the Paranaíba, Grande and Paraná Rivers, the average conductivity was between 37.22 µS.cm^{-1} and 47.29 µS.cm^{-1}, measuring higher in the main rivers than in the downstream tributaries and lower than in the upstream tributaries of the São Simão reservoir. The maximum value recorded was 159 µS.cm^{-1} in the Patos River, where the presence of organic load was noticed.

The waters were more turbid in the upstream tributaries (average = 17.25 NTUs) and downstream tributaries (28.37 NTUs) than in the others environments ($H = 36.17$ and $p = 0{,}000$). The highest turbidity values were found in the Claro and Verde rivers, which correspond to typical lotic environments, with very expressive water speed and turbulence, resulting in high-energy segments (Figure 1). The turbidity in the São Simão reservoir and in the confluence of the Paranaíba, Grande and Paraníba Rivers was low (< 6.23 NTUs).

Chlorophyll *a* concentrations in the study area were usually high, with mean values varying from 1.77 to 12.16 µg.L^{-1}. Chlorophyll *a* values were higher in the Paranaíba River than in its right-margin affluents, reaching a maximum of 242.22 µg.L^{-1}, probably, due to blooms. The mean values in the Paranaíba River varied around 12.22 µg.L^{-1} and were close to the mean values obtained for the reservoir. In tributaries and other rivers, the chlorophyll concentrations were never higher than 10 µg.L^{-1}. However, differences between means were not statistically significant. In general, the environments downstream from the reservoir were more acid than upstream, but these differences were not statistically significant. The lowest pH recorded was 5.83. The average calcium (Ca) values were around 4.1 mg.L^{-1} in the main rivers, the lowest being 1.8 mg.L^{-1} and the highest 23.5 mg.L^{-1}. Mean Ca concentrations were lower in the downstream tributaries than in the Paranaíba, Grande and Paraná rivers ($F = 7{,}66$ and $p = 0{,}000$). Ca concentrations were lower than 2.56 mg.L^{-1} in the Claro, Verde and Corrente tributaries and corresponded to 3.4 mg.L^{-1} in the Aporé River. In the São Simão reservoir, the total mean Ca values were around 4.2 mg.L^{-1}. The highest mean values were obtained from tributaries upstream from the reservoir, especially in the Patos River, where organic and industrial wastes are discharged.

In relation to the spatial distribution of the surface drainage energy (Figure 2), the segments of higher energy are the initial, lotic portion of the São Simão reservoir, its right-margin affluents (P03, P04 e P05) and the tributaries that flow to the Paranaíba River right margin, downstream from the reservoir (Claro River, T1, and Verde River, T2). The Paranaíba River channel is narrower and the water speed is higher up to station PR1, being highly energetic in this portion. From this point on, the Hack Index (SL) progressively decreases, indicating the enlargement of the Paranaíba River flooding area, which includes the backwater of the Ilha Solteira Dam, located downstream the confluence of the Paraná and Paranaíba rivers.

5.2 L. fortunei's potential distribution simulated by the MAXENT algorithm

The parameters used to evaluate the models' performance, generated by MAXENT, are recorded in Table 2, where it is possible to see a greater similarity between the responses for models 1, 3, 4, 5, 6, and 7, with very close AUC values for the training points. In relation to testing points, there was greater variation, and again, the lowest values were obtained from models 2 and 8.

Models 2 and 8 – which exclude SL and chlorophyll *a* data respectively, were less accurate. Model 2 was the least efficient of all models, with AUC of 0.862 and 0.449 for training and testing points respectively, followed by model 8, which yielded AUC of 0.893 and 0.750 for training and testing points respectively.

Among the group of models considered more efficient, the spatial distribution generated by model 1 (Figure 3A) was chosen because it considered, simultaneously, all environmental variables (pH, dissolved oxygen, chlorophyll *a*, turbidity, conductivity, calcium and SL) although model 3 using a smaller number of variables and which has the same accuracy, could be preferable due to its simplicity. The model 1 showed that the areas which are the most sensitive to an *L. fortunei* invasion are the Paranaíba and Grande Rivers confluence, to nearly 80 km upstream, near the confluence with the Aporé River (T4). This prediction was confirmed by the actual data of the presence of mussels collected

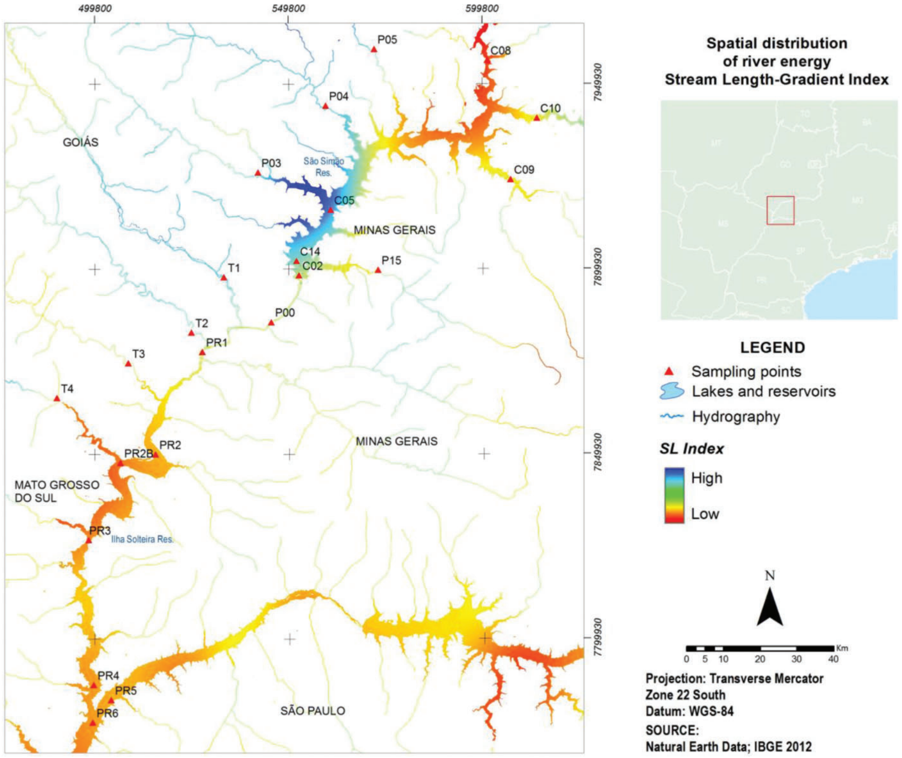

Figure 2. Spatial distribution of the surface drainage energy – from the Hack index – SL, interpolated by kriging.

for the same period. The reservoir area not yet invaded, corresponding to the stretches of points C08 and C10, was also considered highly vulnerable to invasion by the mussel. Other areas not colonized by the species showed a low risk of colonization: the Alegre, Preto and São Francisco Rivers (points P03, P04 and P05), upstream from the São Simão dam, or even rivers downstream of the reservoir, such as the Claro, Verde and Corrente Rivers (points T1, T2 and T3). In the Aporé River (T4) the invasion risk was medium and the probability of the species to occur tended to increase towards the confluence with the Paranaíba River, which is in accord with the records obtained in 2006 and 2007 and presented in Figure 1.

The *L. fortunei* potential distribution simulated by the MAXENT adopting model 1 showed a good adjustment with the observed data (Figure 3A): the areas where the probability of the mollusc occurrence is low in great part coincide spatially with the points of true absences confirmed by field checks.

In contrast, the spatial distribution simulated by model 2 showed that, when the variable SL is excluded from the niche modeling (Figure3B), most of the points where there are no records of the species corresponded spatially to areas of high probability of the mussel occurrence. These areas included not only the confluence of the Paranaíba and Grande rivers and the adjacent 80 km mentioned earlier, but also the whole segment from the "absence point" PR1 to the "absence point" C05 (including "absence points" P00, PB031, C02, C14, and C05) and the segments downstream from "absence points" P15 and P03; C08 and C10. Therefore, excluding SL from the list of variables that compose the *L. fortunei* niche, there was a clear decrease in the efficiency of the model to predict its real distribution area (AUC for training points is 0.862 and AUC for testing points is 0.449) and an inconsistency of simulated with actual absence data.

Figure 3C shows the potential distribution generated by model 8, which uses all environmental layers except chlorophyll *a*. The areas most vulnerable to an *L. fortunei* invasion were those which correspond to the segment from the mouth of the Paranaíba River to approximately 120 km upstream and

Table 2. Parameters to assess the accuracy of the models of potential distribution generated by Maxent

(Model) / Environmental layers used in each model	AUC (training points)	AUC (testing points)
(1) All layers	0.917	0.896
(2) Except SL	0.862	0.449
(3) Only Chlorophyll *a* / SL	0.916	0.899
(4) Without layers OD / pH / Calcium / Conductivity	0.918	0.917
(5) Without layers OD / pH	0.918	0.917
(6) Except OD	0.917	0.896
(7) Without layers OD / pH / Conductivity	0.918	0.917
(8) Except Chlorophyll *a*	0.893	0.750

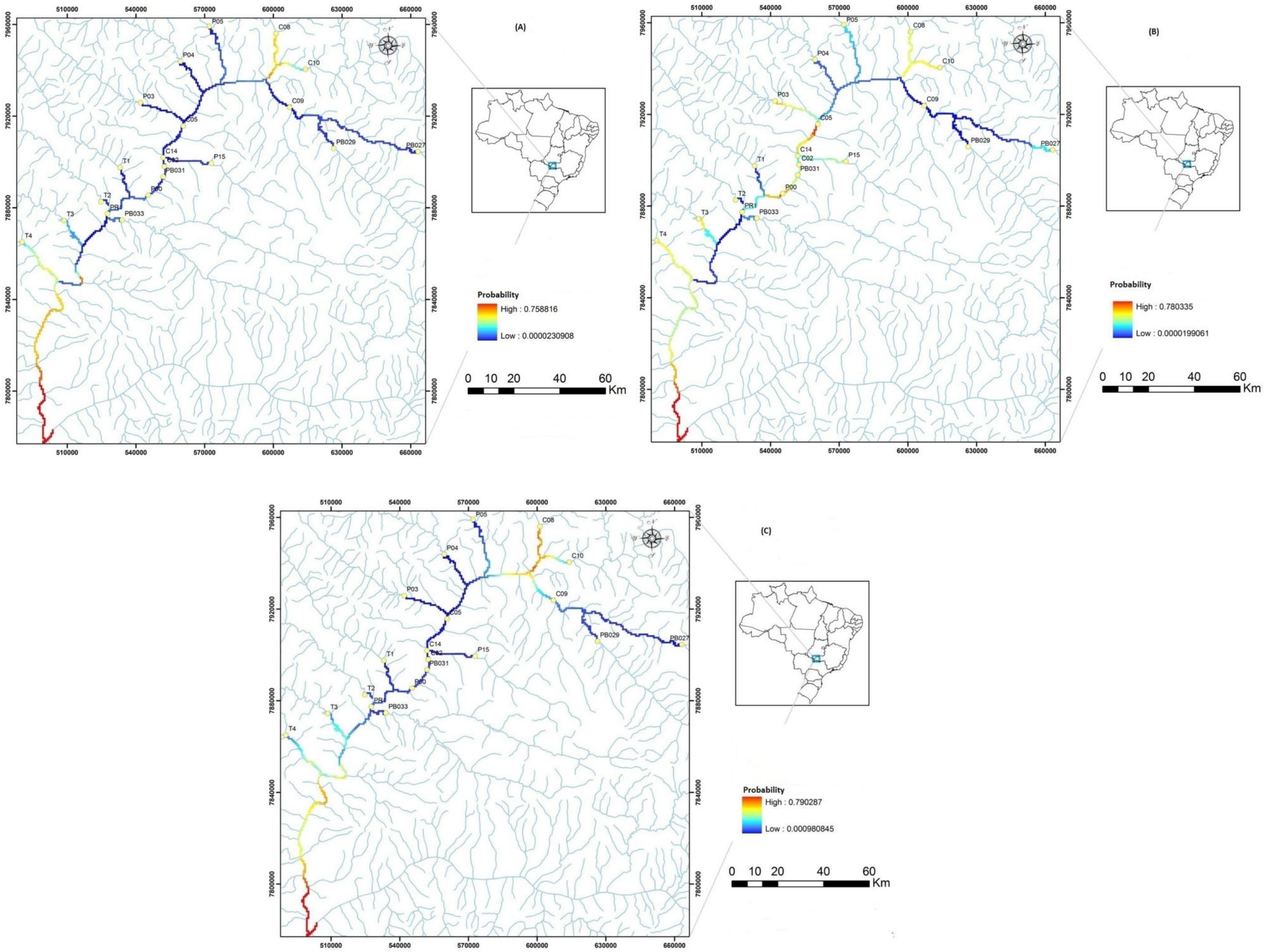

Figure 3A-C. *L. fortunei* potential distribution in the Upper Paraná River simulated by MAXENT, A) using pH, dissolved oxygen, chlorophyll *a*, turbidity, conductivity, calcium and SL data. B) using pH, dissolved oxygen, chlorophyll *a*, turbidity, conductivity and calcium and excluding SL. C) using pH, dissolved oxygen, SL, turbidity, conductivity and calcium and excluding chlorophyll *a*. For comparison, the yellow dots represent the absence of the golden mussel from 2006 to 2007.

segments downstream, including "absence points" T3 (Corrente River) and T4 (Verde River). The segment downstream from "absence points" C08, C10 and C09 was also prone to invasion. AUC for training points is 0.893 and for testing points is 0.750. The exclusion of the chlorophyll *a* variable led to a niche model with a better performance than model 2, which excluded SL, and a worse performance than model 1, which included all physical-chemical variables, in particular the hydrological variable SL.

The analysis of the results of the Jackknife test, which evaluates the isolated contribution of the environmental layers in the training and testing rounds of model 1 (Figure 4), shows that SL was the environmental layer that individually contributed the most for the construction of the niche model and for good evaluation (largest "gain"). From the training data, when the SL and chlorophyll *a* variables were omitted, a decrease in the efficiency of the model was observed. A variable that decreases the efficiency of the model quality tests was pH (excluding pH, the "gain" of the testing data was negative), whereas dissolved oxygen and conductivity did not seem to contribute or even to disturb the construction of the model. Calcium was less important when compared to the other variables (turbidity, chlorophyll *a* and SL).

Discussion

In 2004, *L. fortunei* was detected in Porto Alencastro (PR3), located less than 120 km downstream from the São Simão reservoir (Campos et al. 2012). Considering that the speed of invasion upstream along the Rio de la Plata averaged 240 km/year (Darrigran & Drago 2000), we can consider that the advance of the species is decelerated in this portion of the Paranaíba River, even with the continuous traffic of vessels that dock in the port downstream from the São Simão reservoir and bring the mussels attached to their hulls. Which factors could then explain the dissimilar *L. fortunei* occupation pattern in this segment of the river and in the reservoir – in other words, which factors are limiting the establishment of the mussel in these parts where it does not occur? According to Soberón & Peterson (2005) and Soberón (2007), the establishment of an invading species is represented by the intersection of three components: adequate environmental conditions, favorable biotic interactions, and accessibility to the new region. Along the whole segment of the Paranaíba River downstream from the São Simão Reservoir, the lack of dispersion vectors from the colonized to the non-colonized areas could not be considered as a negative factor to the establishment of the golden mussel, considering the constant

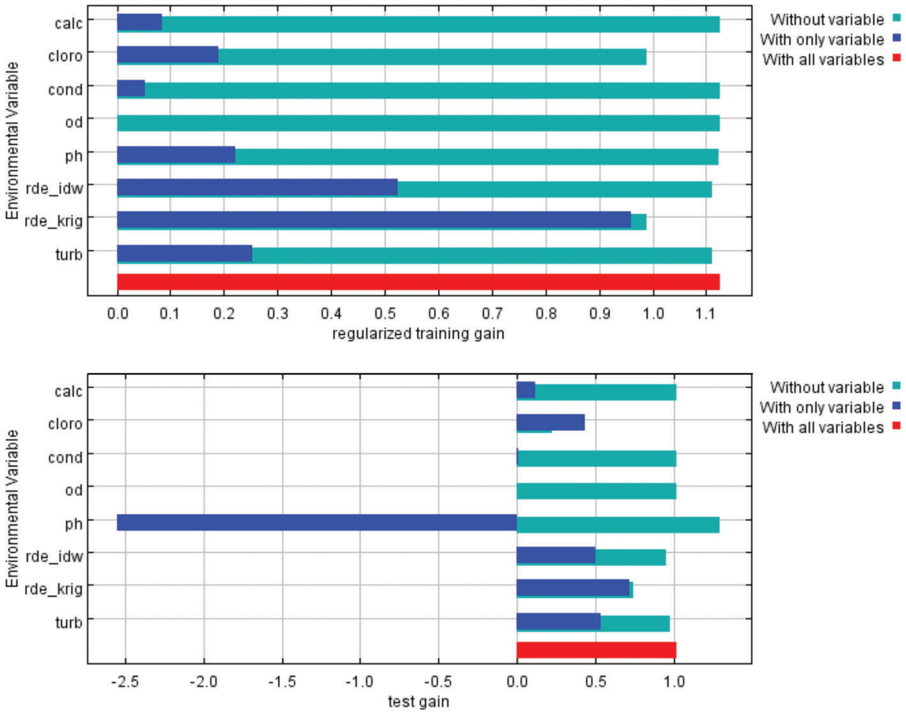

Figure 4. Results of Jackknife evaluations of relative importance of predictor variables (training data above and test below): pH, dissolved oxygen (DO), chlorophyll *a* (cloro) , turbidity (turb), conductivity (cond), calcium (calc) and Rde_idw and Rde_krig (note: different methods to interpolate the SL layer).

traffic of vessels coming from infested areas. A second filter relates to biological interactions, which were also considered less important, because in the areas further downstream from the same fluvial segment, the population densities of the invading bivalve are high, exceeding possible limitations regarding the availability of food or other negative interactions, such as parasites, competitors or even predators. Thus, unfavorable environmental conditions would be one of the most important filters in the conformation of the actual or potential spatial distributions.

Different physical-chemical aspects of the water were considered when generating niche models during this study (*i.e.,* pH, dissolved oxygen, calcium, conductivity, chlorophyll *a* and turbidity), which have already been indicated by other researchers as determining factors for a causal relationship of the invading bivalve occurrence records (Oliveira et al 2010a, b). For instance,

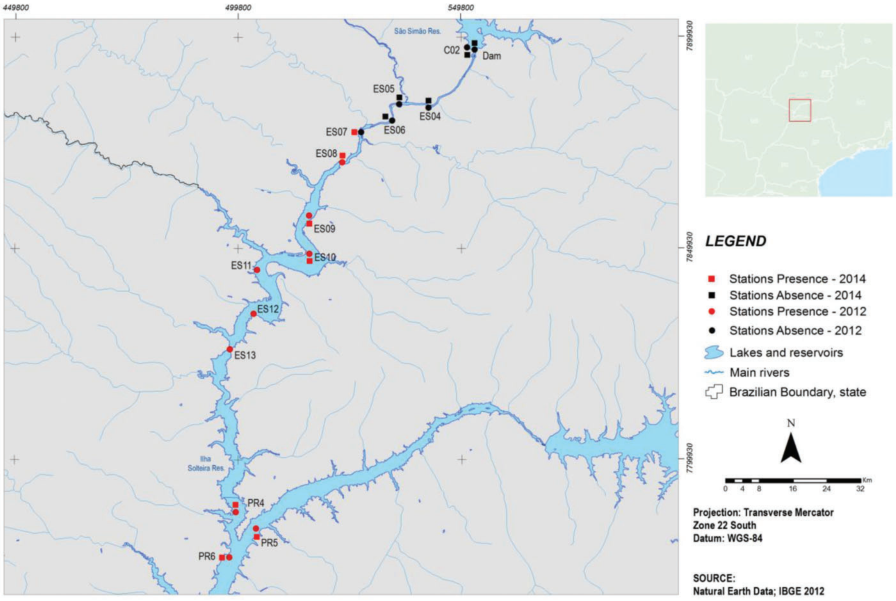

Figure 5. Golden mussel occurrence points along the Paranaíba River, upstream and downstream from the São Simão reservoir (MG/GO), Upper Paraná River Basin obtained during the period from 2012 to 2014. (data unpublished from ECOGERAES Consultoria Ambiental).

some studies indicate a pH value > 5.0 as favorable for the species survival (Ricciardi 1998, Montalto & Marchese 2003, Karatayev et al. 2007). For calcium, minimum values for the survival of adult mussels in natural waters range between 1 and 3 mg/L (Ricciardi 1998).

Considering the limnological environmental characterization, the great part of variables presented similar and suitable average values to allow the survival of the mussel in the study area: oxygen values were generally high, and either the pH as the chlorophyll *a* levels, for the great majority of the situations, would not constitute a limiting aspect to the species' survival. Just the turbidity and the calcium concentrations showed a significative spatial variation between invaded and uninvaded environments (Table 1). However, the lowest Ca concentration, found in one of the downstream tributaries, was close to 1.36 $mg.L^{-1}$ meeting the minimum limits required for the species survival.

In turn, the highest values of turbidity occurred in the tributaries, upstream from the dam (P03, P04 e P05) or downstream (Claro River, T1, and Verde River, T2) and all of them corresponded to uninvaded river stretches as well as the segments of highest energy (high SL Index, high shear stress). Therefore, the aspects related to the energy and sediment transport of the fluvial environments appeared as the primary factors to explain the spatial heterogeneity and possible different levels of habitat suitability. In addition, differences in hydrodynamic aspects between invaded and uninvaded environments would be more relevant to determine the susceptibility to the establishment of the species than pH, calcium, chlorophyll, and others (Neary & Leach 1992, Ramcharam et al. 1992, Mellina & Rasmussen 1994).

This trend also appeared in the simulations generated by MAXENT. Three clear patterns for the *L. fortunei* potential distribution models were obtained: (1) models generated with the inclusion of environmental layers SL and chlorophyll *a* (independent from the other variables); (2) models generated excluding the environmental layer SL; (3) models generated excluding environmental layers SL and chlorophyll *a*.

The highest statistical accuracy values were obtained from models included in pattern (1) whose predictions coincided with the distribution of validation points. The models included in pattern (2) - models generated excluding environmental layer SL, yielded low statistical accuracy values in a broad sense (training and testing data), especially in the intermediate lotic portion, not coinciding with the points of real absence of the invading species. The models of pattern (3) - excluding SL and chlorophyll *a*, yielded the lowest statistical accuracy values and conflicted with the points of absence of the species.

These observations, plus the Jackknife analysis generated by MAXENT, led us to qualitatively rank the environmental layers according to their importance in predicting the potential distribution of *L. fortunei* in the lower Paranaíba River: SL > Chlorophyll *a* > Turbidity > Calcium > Dissolved Oxygen = Conductivity > pH. Strictly speaking, SL was the variable that contributed the most to the efficiency of the constructed models.

Such ranking, allied to the environmental characterization, indicates that the shear strength (SL) or energy of the river waters could be the key factor related to the *L. fortunei* spatial distribution in the study area, while the other variables would be less influential in the golden mussel distribution, at least in the spatial scale considered.

A validation of these simulations results could also be done by observing the real spatial distribution of *L. fortunei* obtained later, from 2012 to 2014. As the Figure 5 shows, the most recent distribution area of the invasive mussel is quite similar to that simulated with data from 2006-2007. This indicates that the environmental conditions did not change expressively, and that the hydrodynamic is the key factor to force the spatial pattern until the present.

The importance of the hydrodynamic aspects for the environmental suitability of bivalve species has been pointed out in the literature. Clarke & McMahon (1996) investigated the effect of the water speed on the production of byssus filaments in adult zebra mussels (*D. polymorpha*), which are invading species with ecological characteristics similar to those of the golden mussel, and observed that the water flow eliminated the byssus production, which could be associated with the mechanical perturbation of the adhered mussels and influence on the ability to press the foot against the substrate to consolidate the filament. Another direct relationship can occur between the river energy and the strength to drag the planktonic larval stages, or the interference of the flow strength in larvae mortality. According to Horvath & Lamberti (1999), zebra mussel veliger larvae seem to be highly susceptible to damage caused by physical strength such as shearing and consequently larvae mortality in turbulent flows could be an important mechanism to limit the dispersion of the zebra mussel downstream. The veliger larvae can be particularly sensitive to the breakage of the valves while feeding, because the valves must be open to allow food particles to enter the gills (Sprung 1993). An open shell can expose a larger surface and tissue area, being more susceptible to shearing.

The physical-chemical characteristics of the water in the region of the upper Paraná River – also the lower Paranaíba River – are generally adequate to the establishment of the invading species and therefore responded in a less important manner to the composition of the ecological niche models that best adjusted to the present spatial distribution of the species in the study area.

Furthermore, in its native area, the Pearl River (Zhujiang), *L. fortunei* is present in pH ranges of 6.9 - 8.4 and calcium concentrations of 5.0-65.2$mg.L^{-1}$, (values taken in 75 hydrological stations in the Zhujiang for the period of 1958–2002, according Zhang et al. 2007). The limnological aspects from São Simão dam and tributaries upstream the dam, Paranaíba river and right bank tributaries, Grande and Paraná Rivers, when compared to the values of limnological variables from Pearl River, suggest that *L. fortunei* can withstand lower limits of pH and calcium than those for Asian environments. This information shows that the invaded niche is not contemplated in the native niche and indicates a greater invasiveness of this species and its potential area of dispersion.

On the other hand, the competence of the fluvial channels translated by the Hack Index proved to be an important component to describe the environmental suitability to the invading *L. fortunei*.

Although significance tests have not been done, all the best case scenarios correspond to models that include the hydrodynamic component. The result obtained in this study shows that, in similar future studies, the use of SL and other related hydrologic variables that have been neglected when modeling the *L. fortunei* niche should be taken into consideration. Should the use of SL be very complicated, it can be replaced by other variables that indicate the shear strength of the fluvial currents (flow, Reynolds number, etc.).

Despite the fact that the mussel has not established in the São Simão reservoir until now (2015), all the best models indicated the high risk level of invasion of this environment, with high degree of habitat suitability especially in some of its branches. Most likely, the invasion has not yet happened due to low pressure propagules (Campos et al 2012) that reach the reservoir. All these tools indicate that the invasion of this new environment will be a question of time and therefore, the intensification of preventive measures should be undertaken immediately.

Acknowledgments

This work was supported by the Electric Power Company of Minas Gerais - Cemig, the Agência Nacional de Energia Elétrica - ANEEL and the Program for Crustal Evolution and Natural Resources, Federal University of Ouro Preto, which granted a doctoral thesis, related to this work. The authors acknowledge Pedro Fialho for his assistance with the ARC GIS and two anonymous reviewers for their helpful suggestions.

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Received 10/11/2014
Revised 15/02/2016
Accepted 15/02/2016

Biota Neotropica 16(1): e0085, 2016
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
article

Diversity Assessment of Lotic Macroalgal Flora by the Application of Taxonomic Distinctness Index

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TONETTO, A.F., BISPO, P.C., BRANCO, C.C.Z. **Diversity Assessment of Lotic Macroalgal Flora by the Application of Taxonomic Distinctness Index.** Biota Neotropica. 16(1): e0085. http://dx.doi.org/10.1590/1676-0611-BN-2015-0085

Abstract: The main aim of this study was to assess the diversity of four stream algal divisions (Cyanobacteria, Chlorophyta, Ochrophyta and Rhodophyta) by comparing results obtained with taxonomic distinctness index and diversity patterns of previous studies. The data were obtained from a study made in 1000 stream segments in North American biomes. The taxonomic arrangement of the taxa was created from species to division level in order to obtain the taxonomic tree, which is used in taxonomic distinctness index. The results of taxonomic distinctness index showed that stream macroalgal diversity was different from that commonly found. Herein, Ochrophyta was the division with the highest diversity, whereas in previous studies Chlorophyta has been in the first position. Cyanobacteria also presented different results, showing the lowest diversity with taxonomic distinctness index, but it is often one of the most diverse divisions in previous studies. The application of statistical methods should match the research aims and be appropriate to the data set collected. However, different methods can complement ecological analyzes, taking into account what aspect of the community the statistical measure better explains.
Keywords: *Biodiversity, taxonomic distinctness, macroalgae.*

TONETTO, A.F., BISPO, P.C., BRANCO, C.C.Z. **Avaliação da Biodiversidade de Macroalgas Lóticas pela Aplicação do Índice de Distintividade Taxonômica.** Biota Neotropica. 16(1): e0085. http://dx.doi.org/10.1590/1676-0611-BN-2015-0085

Resumo: O objetivo deste estudo foi avaliar a diversidade de quatro divisões de algas de riachos (Cyanobacteria, Chlorophyta, Ochrophyta e Rhodophyta), comparando os resultados obtidos com o índice de distintividade taxonômica com os padrões de diversidade encontrados em trabalhos anteriores. Os dados foram coletados a partir de um estudo feito em 1000 segmentos de riachos em biomas da América do Norte. O arranjo taxonômico dos táxons foi criado a partir do nível de espécies até o nível de divisão, a fim de se obter a árvore taxonômica, que é utilizada no índice de distintividade taxonômica. Os resultados do índice de distintividade taxonômica mostraram que a diversidade de macroalgas de riachos foi diferente do que é comumente encontrado. Aqui, Ochrophyta foi a divisão com a maior diversidade, enquanto que no estudo original foi a divisão Chlorophyta. Cianobactérias também revelaram resultados diferentes, mostrando a menor diversidade com o índice de distintividade taxonômica, enquanto é frequentemente uma das mais diversas em trabalhos anteriores. A aplicação de métodos estatísticos deve coincidir com os objetivos da pesquisa e ser apropriada para o conjunto de dados coletados. No entanto, diferentes métodos podem complementar análises ecológicas, levando em consideração o aspecto da comunidade que a medida estatística melhor explica.
Palavras-chave: *Biodiversidade, distintividade taxonômica, macroalgas.*

Introduction

In many parts of the world, the scientific community has been producing studies about community ecology of lotic environments (Allan 1995). Stream macroalgae have raised interest because of their important role in the primary production of such environments (Sheath & Burkholder 1985, Entwisle 1990, Sheath & Cole 1992, Hu & Xie 2006). In previous studies, diversity measures have been used as an important tool for a better understanding of the ecology of such organisms. An example of such approach is the biogeographical distribution of lotic macroalgae. In such studies, researchers relate the diversity of several algal groups to the environmental conditions where they are. Hence, these organisms are mapped in relation to the environmental conditions (Sheath & Cole 1992, Necchi 1989).

However, the diversity measures used in most of these studies may bring different results depending on the method or sampling used (Warwick & Clarke 1991). More recently, the taxonomic distinctness index (TDI) has been used as a measurement of diversity for several communities (Clarke & Warwick 1995, 2001).

A positive characteristic of such index is its independence of the sampling effort, which facilitates the use and comparison of different data types (Clarke & Warwick 1998). Moreover, another aspect emphasized by TDI (and not raised by preceding models) is assigning weight to the taxonomic organization in the statistical analysis, which provides more detailed information about the diversity of communities.

So far, the application of this index has been limited to the assessment of fish biodiversity (Hall & Greenstreet 1998), coral reefs and macrozoobenthos (Piepenburg et al. 1997, Mistri et al. 2000). Therefore, this statistical tool has been little used for algal flora. For instance, Ceschia et al. (2007) is the only study of this nature regarding seaweeds from marine environments. This study has assessed and compared the biodiversity of macroalgae in the Gulf of Trieste at two different times. The main aim of the authors was to assess the possible alterations in community structure owing to changes in environment, particularly those caused by human activities. The results of this study suggest that the level of TDI may have more general validity and, therefore, deserves to be further investigated.

Thus, we aimed to assess the diversity of lotic macroalgal communities in a wide region, applying the TDI, what was never used to assess the diversity of these organisms. Hence, we used data obtained from the taxonomic survey from 1,000 U.S. streams (Sheath & Cole 1992) for the major biomes of North America. We expected that the application of TDI would reveal a different relationship between macroalgal diversity and the North America biomes.

Materials and methods

Investigations on diversity of lotic macroalgae using the TDI, and the reliability of the results of this study, were carried out based on data published in the study by Sheath & Cole (1992). In this study, macroalgae were collected in 1,000 streams of North America, from latitude 73° N to 10° N. The taxonomic survey of this study showed the presence of 259 species of macroalgae, grouped into four divisions (Cyanobacteria, Chlorophyta, Rhodophyta and Ochrophyta) and according to their occurrence in each biome. The list of species recorded by Sheath & Cole (1992) was implemented in Microsoft® Office Excel program, in the form of two tables, namely: i) a table of presence/absence of species in each biome (Tundra, Boreal Forest, Conifers Forest, Hardwood-Hemlock Forest, Desert Chaparral, Deciduous Forest, Tropical Rainforest and Coastal Plain), and ii) a table with the systematic arrangement of the species up to division level. The systematic arrangement used to make this table was based on Wehr & Sheath (2003). For the green algae (Chlorophyta), the taxonomic level family was taken away from analysis, since, according to Wehr & Sheath (2003), this taxonomic level is not clearly defined.

The evaluation of diversity of each algal division (Cyanobacteria, Chlorophyta, Rhodophyta and Ochrophyta) by biome was carried out through the indices of taxonomic distinctness (Δ^+) and variation in taxonomic distinctness (Λ^+) based on qualitative data, as proposed by Warwick & Clarke (1995) and Clarke & Warwick (2001). The assessment of distinctness was performed using equal weights among hierarchical taxonomic levels (W: 111111). The values of Δ^+ and Λ^+ were graphed in accordance with the biomes. This procedure allowed the comparison of the diversity of each algal division in the habitats studied and also the verification of a possible correlation between Δ^+ and Λ^+.

Expected distinctness tests were applied in order to compare the results obtained from the TDI for each algal division and biome with expected values (Warwick & Clarke 1998, Clarke & Warwick 1998, 2001). This index is divided in two analyzes: Average Taxonomic Distinctness (AvTD or Δ^+) and Variation in Taxonomic Distinctness (VarTD or Λ^+). The value of Δ^+ is simply calculated by adding the paths that connect each pair of species in a taxonomic tree divided by the number of paths (Warwick & Clarke 1995). Such paths are assumed to be the steps between each hierarchical level: species to genus, the genus to family, up to the same level of the species pair (Figure 1).

However, Clarke & Warwick (2001) realized that it would be feasible to observe equal values of Δ^+ to communities that possess a distinct taxonomic structure, although with the same number of species. The example in Figure 2 suggests that a community with species belonging to several genera and one family may have Δ^+ equal to another community with the same number of species, but belonging to a few genera and more families. Such differences in taxonomic structures can be observed by the variability of the distances between pairs in relation to the mean value, which is calculated by Δ^+. The change in the taxonomic distinctness (Λ^+) is simply the variance of the path traveled between the pairs of a taxonomic tree species.

The taxonomic distinctness observed (Δ^+ and Λ^+) was compared with a reliance interval of 95%, based on random testing (5,000 randomizations) of the list of species of each algal division. The representation of results from this test can be represented by a funnel-shaped or ellipse chart. Such graphs describe a reliance interval (95%) calculated from the mean values of the index for each subgroup size within the total pool of species of each algal division. In this sense, the actual values of Δ^+ and Λ^+ in the funnel/ellipse will be in the expected diversity limits for that species pool and, as a consequence, the values being positioned below or above the limits of the funnel/ellipse

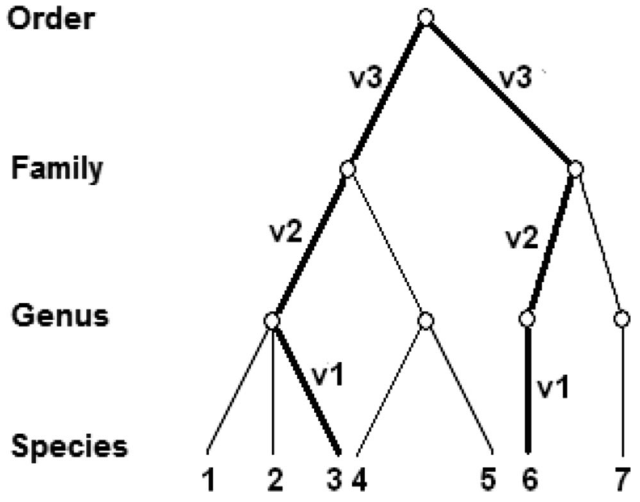

Figure 1. Example of Taxonomic tree with a sample of 7 species showing the definition for steps (p1 - p6) traveled through hierarchical levels between a pair of species (in this case 3 and 6). A simple average for these paths defines the index of taxonomic distinctness (Δ^+ or AvTD). Figure extracted from Clarck & Warwick (1998).

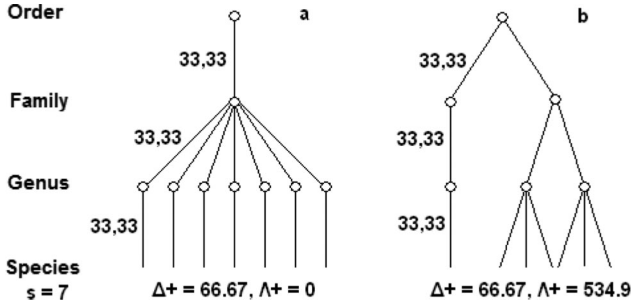

Figure 2. Two examples of taxonomic trees (a and b) in which the index of taxonomic distinctness (Δ^+) is identical, but the variation in taxonomic distinctness (Λ^+) differs substantially, reflecting a large gap between the structure of trees. Figure extracted from Clarck & Warwick (1998).

will be understood to have respectively higher and lower than expected range.

All analyses were carried out using PRIMER 5.0 for Windows.

Results

The results showing the numbers of species and the values of Δ^+ and Λ^+ for algal division by biome/region are shown in Tables 1-2 and Figures 3-4.

Cyanobacteria exhibited the highest value of Δ^+ (AvTD) in the Tundra biome and the lowest value for Coastal Plain (Table 1, Figure 3). The comparison between observed Δ^+ and the expected limits based on randomization of subsets from the overall species pool (Figure 4) showed that only Coastal Plain biome recorded values outside the reliance interval of 95%. Furthermore, it was clear that although only the Coastal Plain biome was below the lower limit of the funnel, the index values for the Deciduous Forest, Coniferous Forest and Hemlock-Hardwood Forest were positioned below the global mean of division, while the biomes of Tropical Rainforest and Boreal Forest recorded values near the global average.

Considering the division Rhodophyta, the TDI values showed that Desert Chaparral has the highest diversity for this algal group, whereas Tundra showed the lowest (Table 1, Figure 3). The analysis of the funnel for this algal division showed that, while no biome was outside the limits of the reliance interval, the index values were below the overall average, except for Tropical Rainforest and Desert Chaparral (Figure 4).

Table 1. Values of Δ^+ and the number of species sampled for each algal division by biome. **TU** – Tundra, **BF** – Boreal Forest, **CF** – Conifers Forest, **HH** – Hemlock-Hardwood Forest, **DF** – Deciduous Forest, **CP** – Coastal Plain, **TR** – Tropical Rainforest and **DC** – Desert-Chaparral.

	Cyanobacteria	Chlorophyta	Rhodophyta	Ochrophyta
TU	59,16 (16)	69,66 (26)	50,66 (6)	82,22 (6)
BF	56,66 (20)	64,89 (40)	56,36 (11)	80,07 (28)
CF	54,94 (14)	67,37 (34)	52,16 (16)	80,17 (20)
HH	55,07 (21)	69,93 (30)	56,04 (14)	79,92 (19)
DF	52,38 (7)	67,47 (39)	53,52 (15)	79,33 (19)
CP	45,45 (12)	71,20 (38)	54,61 (19)	81,83 (13)
TR	56,71 (26)	72,86 (26)	67,09 (22)	85,11 (8)
DC	57,77 (6)	71,89 (18)	68,33 (9)	82,53 (7)

Table 2. Values of Λ^+ for each algal division by biome. **TU** – Tundra, **BF** – Boreal Forest, **CF** – Conifers Forest, **HH** – Hemlock-Hardwood Forest, **DF** – Deciduous Forest, **CP** – Coastal Plain, **TR** – Tropical Rainforest and **DC** – Desert-Chaparral.

	Cyanobacteria	Chlorophyta	Rhodophyta	Ochrophyta
TU	179,86	282,03	686,22	795,06
BF	221,63	321,14	524,95	631,62
CF	259,42	297,05	628,63	650,84
HH	254,62	285,74	590,94	626,76
DF	325,01	312,79	613,29	771,88
CP	215,02	265,82	771,05	820,41
TR	203,58	200,11	576,43	344,03
DC	291,35	221,89	583,88	594,60

Values of Δ^+ for Chlorophyta division showed that maximum diversity of green algae was found in the Tropical Rainforest biome and the lowest one was observed in the Boreal Forest biome (Table 1, Figure 3). Index values were relatively heterogeneous among biomes, which led to an obvious scattering of biomes within and outside the limits of the reliance interval (Figure 4). The biomes of Conifers Forest, Deciduous Forest and Boreal Forest were positioned below the expected limit for the division. Other biomes lie within the funnel, some positioned above the global average and others close to it.

Finally, for Ochrophyta division, the TDI values for all biomes were high. The Tropical Rainforest biome was the one which recorded the highest Δ^+, whereas the Deciduous Forest biome the lowest (Table 1, Figure 3). The high values of Δ^+ showed for this division were reflected in the positioning of all biomes above the global average of species, although included within the limits of reliance interval (Figure 4).

The TDI values for lotic macroalgae communities from the studied biomes in North America showed that the Tropical Rainforest recorded the greatest diversities for two algal divisions (Chlorophyta and Ochrophyta) and also high values for the two other divisions (Table 1). On the other hand, Coastal Plain reported the lowest value of TDI (Cyanobacteria).

Table 3 shows the comparison between algal division diversity found here (using TDI) and the diversity found in previous studies. It is clear that Ochrophyta and Cyanobacteria changed their position among algal group diversity. While TDI revealed that Ochrophyta exhibited the highest diversity, in previous studies it was typically found as one of the lowest diverse group. Similarly, Cyanobacteria exhibited the lowest diversity regarding TDI analyses, but previously it was the opposite.

Discussion

The results of diversity from TDI found in this study will be discussed considering the main general patterns of stream macroalgal diversity reported in previous studies, including Sheath & Cole (1992) (e.g., Sheath & Burkholder 1985, Branco et al. 2009, Peres et al. 2010).

In general, Chlorophyta is reported as the most diverse division of algae in lotic macroalgae communities around the world (Sheath & Burkholder 1985, Sheath & Cole 1992,

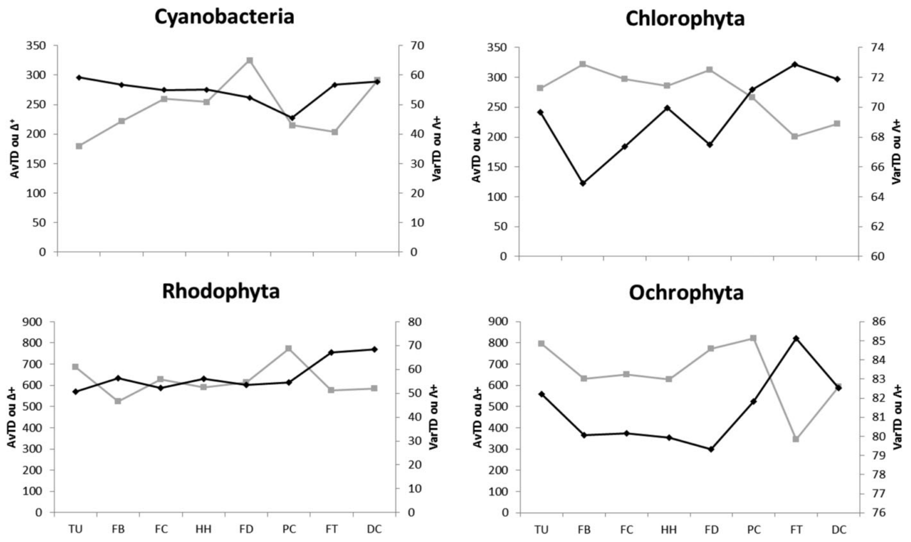

Figure 3. Values of Δ^+ (♦) and Λ^+ (■) for algal divisions according to the biomes. TU – tundra, BF – Boreal Forest, CF – Conifers Forest, HH – Hemlock-Hardwood Forest, DF – Deciduous Forest, CP – Coastal Plain, TR – Tropical Rainforest, and DC – Desert-Chaparral.

Branco et al. 2009, Peres et al. 2010). The same tendency was observed in Sheath & Cole (1992). However, using the TDI, the most diverse algal division was the brown algae. According to several studies involving classic measures of macroalgal diversity, Ochrophyta consistently appears as a group with low values of diversity (e.g. Krupek & Branco 2012, Necchi et al. 2003). In this context, our findings suggest that there is a high dispersion of their species along the taxonomic gradient, despite the brown macroalgae of lotic systems, which showed a limited occurrence and distribution.

Similar to Chlorophyta, Cyanobacteria has been considered as one of the most diverse algal group showing recurrently high specific richness (Krupek et al. 2007, Necchi et al. 2003). However, the diversity of Cyanobacteria of North American streams, when applied the TDI, was the lowest among the four algal divisions analyzed. Although commonly exhibiting high occurrence, the species of this taxonomic group show low taxonomic dispersion, which means that the species found in the study area belong to few taxonomic groups.

Using TDI to investigate the latitudinal distribution of stream macroalgal groups, we observed that the green algae showed a clear latitudinal tendency, with values of diversity increasing from the Arctic to the tropics. This biogeographycal trend shown by Δ^+ could not be recognized from the species richness data alone, and it is in complete accordance with increment in irradiance toward the tropics (Hut et al. 2013) and with the preference for a larger quantity of light typically observed for Chlorophyta (Richardson et al. 1983, Necchi Jr. 2004). Furthermore, pigment

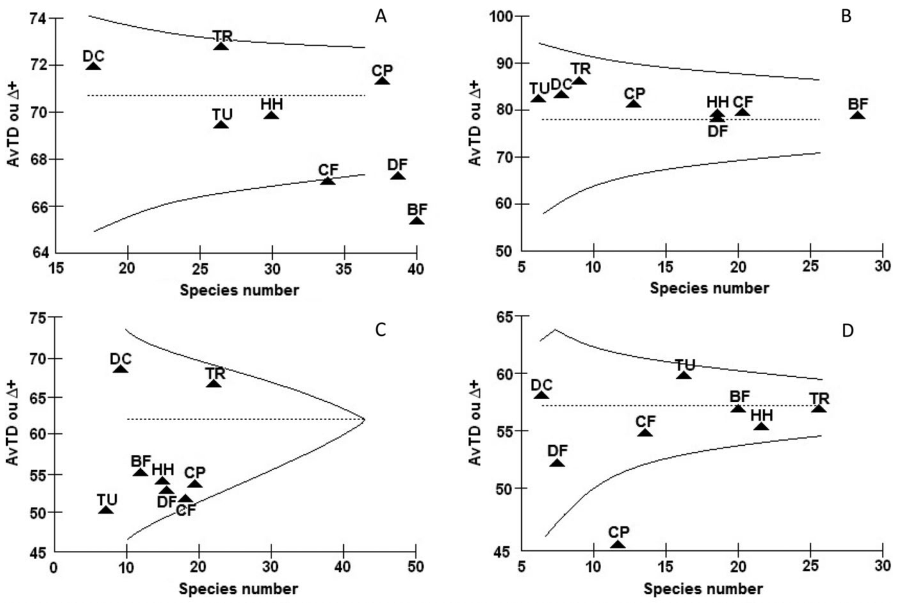

Figure 4. Graphical representation of the values of average taxonomic distinctness (Δ^+) observed in each algal division by biome investigated. These values are compared with expected diversity values represented by the funnel. A – Chlorophyta; B – Ochrophyta; C – Rhodophyta; D – Cyanobacteria.

Table 3. Hierarchical diversity of algal divisions (Cyanobacteria, Chlorophyta, Rhodophyta and Ochrophyta) in the present study (using Taxonomic Distinctness Index) and previous studies (richness).

Literature	**Algal Divisions**			
	Higher divesity	→		**Lower diversity**
Present study				
Taxonomic Distinctness Index (TDI)	Ochrophyta	Chlorophyta	Rhodophyta	Cyanobacteria
Previous sudies				
Sheath & Cole 1992, North America	Chlorophyta	Cyanobacteria	Ochrophyta	Rhodophyta
Necchi et al. 1995, Southeastern Brazil	Chlorophyta	Cyanobacteria	Rhodophyta	Ochrophyta
Branco et al. 2008, South Brazil	Chlorophyta	Cyanobacteria	Ochrophyta	Rhodophyta
Sherwood 2006, Hawaiian Islands	Chlorophyta	Cyanobacteria	Ochrophyta	Rhodophyta
Hu & Xie 2006, North China	Chlorophyta	Cyanobacteria	Ochrophyta	Rhodophyta
Bojorge-Garcia et al. 2010, Central Mexico	Chlorophyta	Rhodophyta	Cyanobacteria	Ochrophyta

contents of the green algae exhibit more efficient physiological activity under high irradiance (DeNicola & Hoagland 1992).

Considering the values of the TDI, we found that the most diverse biome was the Tropical Rainforest, with the highest values for Chlorophyta and Ochrophyta, and very high values for Rhodophyta and Cyanobacteria. This is a relevant result, mainly when confronted with data from species richness, a very common type of information used to describe and discuss stream macroalgal community structure and biogeography (see, for instance, the discussion presented by Sheath & Cole 1992). If only the species richness is considered, Boreal Forest was the North American biome with highest diversity in stream macroalgal communities. It is known that the characteristics of biomes are relevant in determining patterns of diversity and distribution of macroalgae communities (McGregor et al. 2006, Oliveira et al. 2013), but depending on the information used in these analyzes we can end up in different conclusions, even contradictory, as shown in the comparison presented above.

Regarding all results and discussion made herein, we showed that using TDI, algal groups contribute differently on stream macroalgal diversity than showed by previous studies. However, TDI cannot substitute other diversity measurements such as number of species or Shannon diversity (Ceschia et al. 2007). Instead of this, it is important to combine the statistical analyses to the project goals. Warwick & Clarke (2001) made a comparison among statistical analyses, and they found that some methods are more sensitive than others. Thus, in general, the data must be analyzed properly and in consonance to researcher's questions, what may help to improve the interpretation of the information.

More specifically, traditional diversity measures based on species richness and evenness exhibit disadvantages regarding the assessment of biodiversity change on wide spatial and temporal scales (Warwick & Clarke 2001). Hence, measures based on species relatedness (e.g. taxonomic distinctness) rose to overcome these problems and they have been used widely for conservation purposes. Herein, we showed the differences between TDI results and typical lotic macroalgal diversity found previously. So, we suggest that TDI should be used as a complementary measure to species richness, which would favors a more accurate definition of biodiversity conservation priorities (Loidi et al. 2015). For instance, a species without close relations to any others would have higher priority for conservation than a species with many close relatives (Warwick & Clarke 2001).

In this context, it is possible to observe that the application of different diversity measures may reveal different results and conclusions, even based on the same data set. Although species richness have been used to assess the diversity in conservation programs, the taxonomic indices as TDI would help to understand better the general diversity patterns and to improve strategies of biodiversity conservation (Loidi et al. 2015), not only for stream macroalgae. Furthermore, TDI could be used in broad scale geographical comparisons of biodiversity, regarding more ecological questions, mainly those related to contrasting habitats. Finally, we expect that TDI must be further investigated to find application in a broad sense.

Acknowledgements

The authors would like to thanks to FAPESP for financial support granted to AFT (Proc. 2010/17563-0) and to CCZB (Proc. 2014/22952-6); and to CNPq for financial support granted to CCZB (Proc. 302354/2008-5).

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Received 06/07/2015
Revised 15/11/2015
Accepted 22/12/2015

Biota Neotropica 16(1): e0034, 2016
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
short communication

First report on dung beetles in intra-Amazonian savannahs in Roraima, Brazil

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FRANÇA, F.M., KORASAKI, V., LOUZADA, J., VAZ-DE-MELLO, F.Z. **First report on dung beetles in intra-Amazonian savannahs in Roraima, Brazil.** Biota Neotropica. 16(1): e0034. http://dx.doi.org/10.1590/1676-0611-BN-2015-0034

Abstract: This is the first study to address the dung beetle (Coleoptera: Scarabaeidae: Scarabaeinae) diversity in intra-Amazonian savannahs in the state of Roraima, Brazil. Our aim was to survey the dung beetle fauna associated with these savannahs (regionally called '*lavrado*'), since little is known about the dung beetles from this environment. We conducted three field samples using pitfall traps baited with human dung in savannah areas near the city of Boa Vista during the rainy seasons of 1996, 1997, and 2008. We collected 383 individuals from ten species, wherein six have no previous record in intra-Amazonian savannahs. The most abundant species were *Ontherus appendiculatus* (Mannerheim, 1829), *Canthidium* aff. *humerale* (Germar, 1813), *Dichotomius nisus* (Olivier, 1789), and *Pseudocanthon* aff. *xanthurus* (Blanchard, 1846). We believe that knowing the dung beetles diversity associated with the intra-Amazonian savannahs is ideal for understanding the occurrence and distribution of these organisms in a highly threatened environment, it thus being the first step towards conservation strategy development.

Keywords: *Tropical environments, new species occurrence, 'lavrado', Scarabaeinae.*

FRANÇA, F.M., KORASAKI, V., LOUZADA, J., VAZ-DE-MELLO, F.Z. **Primeiro registro de besouros rola-bosta em savanas intra-amazônicas de Roraima, Brasil.** Biota Neotropica. 16(1): e0034. http://dx.doi.org/10.1590/1676-0611-BN-2015-0034

Resumo: Este é o primeiro estudo da diversidade de besouros rola-bosta (Coleoptera: Scarabaeidae: Scarabaeinae) nas savanas intra-amazônicas de Roraima, Brasil. Nosso objetivo foi inventariar a fauna de besouros associada com savanas (conhecidas regionalmente como '*lavrado*'), uma vez que pouco se sabe sobre esses besouros nesse ambiente. Nós amostramos em savanas próximas a cidade de Boa Vista durante a estação chuvosa nos anos 1996, 1997 e 2008, utilizando armadilhas pitfall iscadas com fezes humanas. Coletamos 383 indivíduos de dez espécies, das quais seis não haviam ocorrência prévia para savanas intra-amazônicas. As espécies mais abundantes foram *Ontherus appendiculatus* (Mannerheim, 1829), *Canthidium* aff. *humerale* (Germar, 1813), *Dichotomius nisus* (Olivier, 1789) e *Pseudocanthon* aff. *xanthurus* (Blanchard, 1846). Nós acreditamos que conhecendo a diversidade de besouros associada às savanas intra-Amazônicas se torna ideal para o entendimento da ocorrência e distribuição desses organismos em um ambiente altamente ameaçado, sendo o primeiro passo para a tomada de estratégias de conservação.

Palavras-chave: *Ambientes tropicais, nova ocorrência de espécies, lavrado, Scarabaeinae.*

Introduction

The Amazon environment comprises a mosaic of ecosystems, including deciduous forests, '*campinaramas*' (meadows), semi-deciduous seasonal forests, rain and montane forests, dry land forests, floodplain forests, woodlands and intra-Amazonian savannahs (Junk 1983, Ribeiro et al. 1999). The Brazilian intra-Amazonian savannah landscape encompasses a predominantly grassy-woody vegetation (e.g. grasses, sedges, and small herbs), with low arboreal-shrub density (Barbosa et al. 2007, Sarmiento 1984) and specific edaphic characteristics (Cavalcante et al. 2014, Sanaiotti et al. 2002). These savannahs are located in the extreme north of the Brazilian Amazon forest, mainly in the triple border between Venezuela, Brazil and Guyana (Barbosa et al. 2007, Barbosa & Fearnside 2005, Prance 1996). This eco-region known as Guyana's shield (Hubber 2006) comprises the largest contiguous area of intra-Amazonian savannah (around 54.000 km^2), of which approximately 72% are located in the northeastern region of the Roraima State in Brazil (Barbosa & Fearnside 2005, Barbosa & Campos 2011, Copobianco et al. 2001, Ferreira 2001).

Furthermore, those savannahs are regionally known as '*lavrado*' (Barbosa et al. 2007, Sanaiotti 1997), which means 'place where the trees are absent' (Vanzolini & Carvalho 1991) and reflects its typical non-forest vegetation.

Despite a review about the Phanaeini tribe (Pacheco & Vaz-de-Mello 2015), no work to our knowledge has reported the dung beetle fauna from the intra-Amazonian savannahs in Roraima. The dung beetles are a responsive taxonomic group (Bicknell et al. 2014), with more than 600 species recorded in Brazil (Vaz-de-Mello 2000) and distributed throughout all Brazilian terrestrial ecosystems. Regarding their diversity within Brazilian opened areas, studies have recorded between 13 and 66 species from the Brazilian southeastern savannahs (known as '*cerrado*') and pasturelands (Abot et al. 2012, Almeida et al. 2011, Durães et al. 2005, Gries et al. 2012, Milhomem et al. 2003, Silva & Audino 2011, Silva et al. 2010, Vieira & Silva 2012). Furthermore, 15 dung beetle species were reported from the intra-Amazonian savannahs near to *Alter do Chão* village, state of Pará, Brazil (Louzada et al. 2010, Matavelli & Louzada 2008). Hence, considering the dung beetles' ecological importance in many ecosystem processes (Nichols et al. 2008) and the poor knowledge about their fauna from the largest intra-Amazonian savannah area in Brazil, here we aimed to present the dung beetle species that were sampled within three *lavrado* savannahs of Roraima state, Brazil.

Materials and Methods

The city of Boa Vista in the state of Roraima has a humid tropical climate, characterized as a rainy summer, which extends from April to September, and a dry season from October to March. The average annual rainfall and temperature are respectively 1612 ± 400 mm and 27.4 °C (Barbosa & Fearnside 2005, Meneses et al. 2007). We used dung-baited pitfall traps to sample dung beetles during September 1996, July 1997, and November 2008 in three savannah areas near Boa Vista, Roraima, Brazil.

The first sampling period (1996) was carried out in a small savannah area in the municipality of Cantá (2°46' N 60° 38' W) located on the margin of the '*Rio Branco*' river. The region is a large *lavrado* area continuous with small anthropogenic areas and subjected to floods during the rainy season. We installed five pitfall traps in this area, separated at least 50 m apart from each other, baited with human dung and exposed for 48 h to the dung beetle community. In the second sampling period (1997), a large area of *lavrado* in the '*Serra da Moça*' region (north of Boa Vista, approx. 6°12' N 60°41' W) was sampled. We placed seven pitfall traps, located at least 50 m apart, baited with human dung and collected daily during five days with two exchanges of bait during the sampling period. In the third sampling period (2008), we sampled a large area of *lavrado* located on the opposite side of the *Rio Branco* river (02°62' N 60°72' W). We used seven pitfall traps, separated at least 50 m apart from each other, baited with human dung and left in the field for 48 h.

Pitfall traps were plastic containers (14 cm in diameter; 9 cm deep) buried in the ground with the opening at ground level, and with approximately 30 g of bait. We covered each pitfall with a lid to protect it from the rain and filled each one with 250 ml of a saline solution and detergent. After the exposition in the field, we collected, sorted, mounted and identified all dung beetles to the lowest possible taxonomic level. All voucher specimens were deposited in the Reference Collection of Neotropical Scarabaeinae in the Insect Ecology and Conservation Laboratory, Universidade Federal de Lavras and in the Entomology section of the Zoological Collection at Universidade Federal de Mato Grosso, Brazil. To further discussions about the geographical distribution and feeding habits of each genera and species here collected, we reviewed published and unpublished bibliographical references about the species ecology and distribution. Furthermore, we present an illustrated guide from each identified species we have found.

Results and Discussion

We collected 383 dung beetles belonging to ten species and eight genera (Table 1). From the collected species, only *Canthidium* sp. could not be identified and it is a possible new species. *Ontherus appendiculatus*, *Canthidium* aff. *humerale*, *Dichotomius nisus*, and *Pseudocanthon* aff. *xanthurus* were the most abundant species. As such, we have sampled six species without any previous occurrence from intra-Amazonian savannahs, as only the dung beetle species *O. appendiculatus*, *D. nisus*, *P.* aff. *xanthurus* and *C. mutabilis* have been previously recorded in these environments (Génier 1996, Louzada et al. 2010, Matavelli & Louzada 2008).

Most species we found belong to species-clusters that have been collected within dry, open and highly disturbed environments on the American continent, some of them with records from Argentina (Damborsky et al. 2015), Mexico (Novelo et al. 2007), Ecuador (Carpio et al. 2009), Venezuela (Lozano 2010), Colombia (Noriega et al. 2007) and Costa Rica (Padilla-Gil &

Table 1. Dung beetle species collected in three intra-Amazonian savannahs close to Boa Vista, Roraima, Brazil. In each sampling period, we sampled a different area.

Species	**Sampling period**			**Total individuals**
	1996	**1997**	**2008**	
Canthidium aff. *humerale* (Germar, 1813)	1	10	50	61
Canthidium sp.	5	0	0	5
Canthon (*Canthon*) aff. *scrutator* Balthasar, 1939	0	2	0	2
Canthon (*Canthon*) aff. *mutabilis* Lucas, 1959	0	5	0	5
Malagoniella astyanax (Oliver, 1789)	0	0	1	1
Pseudocanthon aff. *xanthurus* (Blanchard, 1846)	4	21	22	47
Dichotomius nisus (Olivier, 1789)	13	22	14	49
Ontherus appendiculatus (Mannerheim, 1829)	161	0	3	164
Onthophagus aff. *hirculus* Mannerheim, 1829	10	0	0	10
Coprophanaeus gamezi Arnaud, 2002	0	39	0	39

Halffter 2007). In Brazil, those have been registered within the semi-arid scrub forest (known as '*caatinga*') (Hernandéz 2007, Lopes et al. 2006, Silva et al. 2007), coastal sandy vegetation ('*restinga*') (Costa et al. 2014), coastal low land forests ('*Tabuleiro*' forests) (Endres et al. 2007) and native and exotic pasturelands (Almeida et al. 2011, Costa et al. 2009, 2013, Silva et al. 2010, Silva et al. 2011, 2014). In addition, the species reported here were also found within highly impacted Brazilian forests, such as northeastern fragments of Atlantic forest (Salomão & Iannuzzi 2015, Viegas et al. 2014), planted *Eucalyptus* sp. forests (Audino et al. 2011) and Amazonian secondary forests, savannahs and agricultural areas (Korasaki et al. 2012, Louzada et al. 2010, Matavelli & Louzada 2008).

The number of dung beetle species and individuals reported here was lower than in other intra-Amazonian savannahs (Louzada et al. 2010, Matavelli & Louzada 2008), southern *cerrado* (Abot et al. 2012, Almeida et al. 2011, Durães et al. 2005, Gries et al. 2012, Silva et al. 2010, Vieira & Silva 2012) and native grasslands of the '*Pampa*' region (Silva et al. 2011). We believe this lower species-rich sample can be due the historical isolation of the intra-Amazonian from the *cerrado* savannahs in central Brazil during the Pleistocene period (Sanaiotti et al. 2002), besides some natural specific habitat characteristics, such as edaphic factors, vegetation structure and fire occurrence (Barbosa & Fearnside 2005, Louzada et al. 2010). Henceforward, we will discuss the knowledge concerning the distribution and ecology of each identified species.

***Canthidium* Erichson (1847):** Considered as one of the most diverse dung beetle groups (Halffter & Martínez 1966), this genus needs urgent revision, which may result in the creation of new genera. It currently includes about 170 described species, mainly recorded with dung-baited pitfalls in Neotropical forests and savannahs (Gill 1991, Silva et al. 2014, Vaz-de-Mello & Louzada 1997, Vaz-de-Mello et al. 1998). There are also some records of species sampled with carrion-baited pitfalls or consuming rooting fruit, fungi and dead insects (Medri & Lopes 2001, Silva & Audino 2011, Silva et al. 2014). Hence, species have been suggested as myrmecophilous associated with nests of *Atta* ants Fabricius, 1804, probably exploiting rotting fungi (Falqueto et al. 2005). *Canthidium* aff. *humerale* (Figure 1A) belongs to a species-cluster that contains species considered as coprophagous (Silva et al. 2007) and distributed within many opened environments. Species in this cluster have been recorded in northeastern Brazilian grassland areas (Almeida et al. 2011, Costa et al. 2009, Silva et al. 2007), *Tabuleiro* forests (Endres et al. 2007), secondary regeneration zones between *caatinga* and *cerrado* (Lopes et al. 2006) and transitional regions between the Amazon forest and *cerrado* (Andrade et al. 2011). The other *Canthidium* species we found could not be identified accurately, thus no further comments are possible about its ecology and distribution.

***Canthon* Hoffmannsegg (1817):** Featuring approximately 200 species, this genus has been studied at a supraspecific level, except for some species that are not yet grouped into any subgenera. It is an American group, with species mainly found from Argentina to Canada (Vaz-de-Mello 2000). Although most species are considered as copro-necrophagous, other feeding habits, including fungi and debris feeders (Vaz-de-Mello 1999b) and ant predation (Hertel & Colli 1998, Vaz-de-Mello et al. 1998, Villalobos et al. 1998) were also recorded. The subgenus *Canthon* (*Canthon*) Hoffmannsegg, 1817 includes mainly coprophagous or necrophagous dung beetles, despite species preying on ants (Cantil et al. 2014, Forti et al. 2012, Villalobos et al. 1998) and feeding on dead insects and millipedes (Villalobos et al. 1998). *Canthon* (*Canthon*) aff. *scrutator* Balthasar, 1939 (Figure 1B) belongs to the *Canthon virens* species-group (Halffter & Martínez 1977), which is distributed throughout the northern Amazon Basin, Guyana and Atlantic Forest region. This species-group comprises copro-necrophagous dung beetles, also recorded consuming insect carcasses (Forti et al. 2012) or sampled with carrion-baited pitfall traps (Salomão & Iannuzzi 2015). We believe the species *Canthon* (*Canthon*) aff. *mutabilis* Lucas, 1859 (Figure 1C) needs urgent revision, given that individuals identified as *C. mutabilis* may comprise a complex group of different species. This species-group have been recorded within open environments in America, such as Colombia (Noriega et al. 2007), Costa Rica (Padilla-Gil & Halffter 2007), Argentina (Boito et al, 2009) and primary forests from Suriname (Larsen 2011). In Brazil, there are samples from flight intercept traps (Audino et al. 2011, Costa et al. 2009) and pitfalls baited with dung and carrion (Costa et al. 2013, 2014, Silva et al. 2007, 2014, Silva & Audino 2011).

***Malagoniella* Martínez, 1961:** Halffter & Martínez (1966) reviewed this genus, which includes nine colorful metallic dung beetle species distributed across the Neotropical region, from USA (Texas) to Argentina (Padilla-Gil & Halffter 2007). *Malagoniella astyanax* (Oliver 1789) (Figure 1D) belongs to a species complex that is currently being revised. It has been found in the Brazilian *caatinga* (Hernandéz, 2007, Silva et al. 2007, Vieira & Silva 2012), Ecuadorian Amazon (Carpio et al. 2009), Colombia (Escobar 1997), Costa Rica (Padilla-Gil & Halffter 2007), Mexico (Novelo et al. 2007), Venezuela (Ferrer-Paris et al. 2013), Bolivia (Vidaurre et al. 2008) and Guyana (F.Z. Vaz-de-Mello, unpublished data). Species in this group have been considered as nocturnal (Hernandéz 2007), sampled by pitfall traps baited with dung and carrion (Carpio et al. 2009, Hernandéz 2007, Novelo et al. 2007, Silva et al. 2007).

***Pseudocanthon* Bates, 1887:** This genus is small, including nine species distributed from the USA to Argentina and Antilles (Halffter & Matthews 1966, Padilla-Gil & Halffter 2007). Although small, it urgently needs taxonomic revision, at least for the continental species. The species *Pseudocanthon* aff. *xanthurus* (Figure 1E) is a complex of species, which is difficult to identify (Korasaki et al. 2012) and, as the genus, it needs taxonomic revision. Although extensively sampled with dung baited pitfalls, the species have been considered as generalist (Andrade et al. 2011), with records from open habitats in Colombia and Venezuela (Ferrer-Paris et al. 2013). In Brazil they have been reported within pastures and grasslands (Costa et al. 2009, Schiffler et al. 2015, Silva et al. 2014), *caatinga* (Lopes et al. 2006), degraded *restinga* (Costa et al. 2014), northeastern Atlantic forest (Costa et al. 2013, Salomão & Iannuzzi 2015), intra-Amazonian savannahs (Matavelli & Louzada 2008) and Amazonian agricultural areas (Korasaki et al. 2012).

***Dichotomius* Hope (1838):** According to the last taxonomic revision, this genus features approximately 165 valid species widely distributed from the USA to Argentina (Luederwaldt 1929),

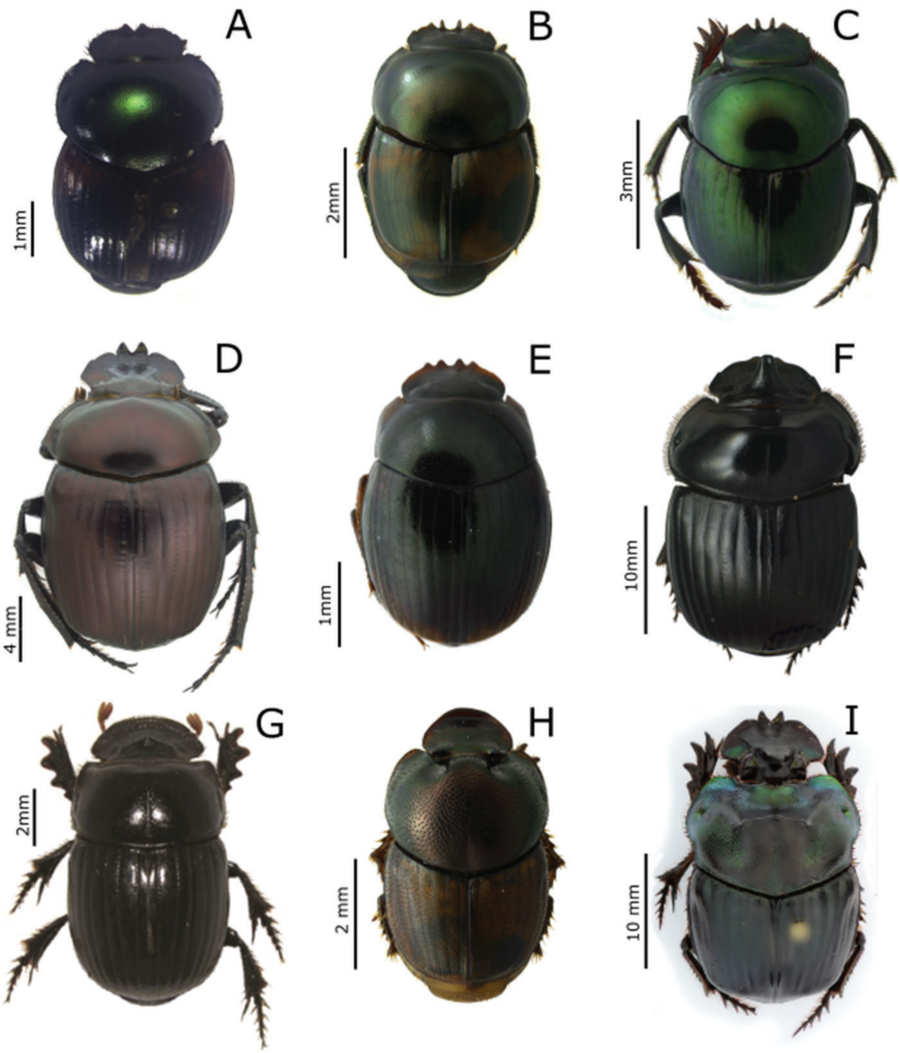

Figure 1. Dung beetle species sampled from intra-Amazonian savannahs in the state of Roraima: (A) *Canthidium* aff. *humerale*; (B) *Canthon* aff. *scrutator*; (C) *Canthon* aff. *mutabilis*; (D) *Malagoniella astyanax* (extracted from Vieira & Silva, 2012); (E) *Pseudocanthon* aff. *xanthurus*; (F) *Dichotomius nisus*; (G) *Ontherus appendiculatus* (extracted from Vidaurre et al., 2008); (H) *Onthophagus* aff. *hirculus*; (I) *Coprophanaeus gamezi* (extracted from Pacheco & Vaz-de-Mello, 2015).

especially in Neotropical forest and savannah areas (Vaz-de-Mello 1999b, 2000). Although most species are coprophagous, we believe there are some exceptions. *Dichotomius nisus* (Olivier 1789) (Figure 1F) is considered a nocturnal coprophagous-generalist species (Hernandéz 2007, Silva et al. 2007, Vieira et al. 2008), commonly occurring within opened and/or disturbed environments (Filgueiras et al. 2015, Nunes et al. 2012). It is widely distributed, with records from Guyana (Boilly & Vaz-de-Mello 2014), Argentinian *Chaco* (Damborsky et al. 2015), transitional forests in Bolivia (Vidaurre et al. 2008), Colombia Andes (*Putumayo region*) (Escobar et al. 2005) and Venezuelan dry forests and pastures (Ferrer-Paris et al. 2013, Lozano 2010). In Brazil, it has been sampled with both dung and carrion-baited pitfall traps within more than 17 states (Louzada et al. 2007). Accordingly, it has been extensively collected from the northern intra-Amazonian savannahs (Koller et al. 1999, Matavelli & Louzada 2008) to southern *Campanha* region (Silva et al. 2008), within non-native forests of *Eucalyptus* sp. (Audino et al. 2011). Furthermore, there are records from *restinga* (Costa et al. 2014, Schiffler et al. 2015, Vieira et al. 2008), *Tabuleiro* forest (Endres et al. 2007), *caatinga* (Hernandéz 2007, Medina & Lopes 2014, Santos et al. 2014, Vieira & Silva 2012), Atlantic forest fragments (Costa et al. 2013, Flechtmann et al. 2009, Salomão & Iannuzzi 2015, Silva et al. 2015, Viegas et al. 2014), *cerrado* (Almeida et al. 2011, Rodrigues et al. 2010) and many pasturelands and altered grasslands (Costa et al. 2009, Filgueiras et al. 2015, Louzada & Silva 2009, Louzada et al. 2007, Puker et al. 2013, Scheffler 2005, Silva et al. 2011).

***Ontherus* Erichson, 1847:** This genus is distributed from Mexico to Argentina and was recently reviewed by Génier (1996), which resulted in 56 species divided into three subgenera. We believe that most of the species are coprophagous; however, there are some species associated with sediment deposits within ant colonies of *Atta* Fabricius, 1804 and *Acromyrmex* Mayr, 1865 (Halffter & Halffter 2009). *Ontherus appendiculatus* (Mannerhein, 1829) (Figure 1G), although considered as typically coprophagous, has been collected also with carrion (Flechtmann et al. 2009, Rosa et al. 2011, Silva et al. 2007). Widely distributed in South America (Génier 1996), *O. appendiculatus* has been reported in Argentina, Bolivia, Brazil, Colombia, Ecuador, French Guyana,

Guyana, Paraguay, Uruguay and Venezuela (Génier 1996, Louzada et al. 2007, Vidaurre et al. 2008, Ferrer-Paris et al. 2013). In Brazil, it has a broad distribution, with records from intra-Amazonian savannahs (Matavelli & Louzada 2008), *Tabuleiro* forest (Lima et al. 2013) and Atlantic forest fragments (Silva et al. 2015). Furthermore, it has been recorded in transitional forests between *cerrado* and Amazon forest (Andrade et al. 2011), and *cerrado* within *Pantanal* regions (Louzada et al. 2007, Puker et al. 2013, Rodrigues et al. 2010).

***Onthophagus* Latreille, 1802:** It is a very diverse and cosmopolitan genus with more than 2000 species (Tarasov & Kabakov 2010). Although considered as coprophagous, there are species attracted by the defense secretions from millipedes (Brühl & Krell 2003, Schmitt et al. 2004) or associated with caves (Slay et al. 2012), bird nests (Kristofík et al. 2003) and rodents (Sánchez-Huerta et al. 2015). *Onthophagus* aff. *hirculus* Mannerheim, 1829 (Figure 1H) belongs to a complex of species that is taxonomically close to *O. hirculus* and needs urgent taxonomic revision. Those species have been considered as coprophagous and generalist (Hernandéz 2007, Silva et al. 2011), collected by pitfall traps baited with different types of dung, rotting fruits and carcass (Audino et al. 2011, Flechtmann et al. 2009, Puker et al. 2013, Rosa et al. 2011, Silva & Audino 2011, Silva et al. 2008). This species-complex have been recorded in South American open areas at altitudes <1000 m, such as Argentinian *Chaco* (Damborsky et al. 2015), Colombian secondary dry forests (Noriega et al. 2007) and Bolivian transitional forests (Vidaurre et al. 2008). In Brazil, they have been collected within pasturelands (Puker et al. 2013, Silva et al. 2010, Silva et al. 2014), *caatinga* (Hernandéz 2007, Santos et al. 2014, Silva et al. 2007, Vieira & Silva 2012) and *restinga* areas (Costa et al. 2014, Vieira et al. 2008). In addition, they have been recorded in Atlantic forest fragments (Silva et al. 2015) and transitional areas between the Amazon forest and *cerrado* (Andrade et al. 2011).

***Coprophanaeus* d'Olsoufieff, 1924:** Reviewed by Edmonds & Zidek (2010), this genus includes 38 species distributed among three subgenera and eight species recorded from Texas to Argentina. *Coprophanaeus gamezi* Arnaud, 2002 (Figure 1I) has been found in tropical dry forests in Colombia (Solís et al. 2011), the coast and provinces in Venezuela (Ferrer-Paris et al. 2013, Lozano 2010) and adjacent Amazon regions of Brazil, Colombia and Guyana (Edmonds & Zidek 2010). Accordingly, it has been suggested as preferring open habitats and readily invading pasturelands (Edmonds & Zidek 2010), and has already been reported in introduced pastures and banana plantations (Gámez & Acconcia 2009, Gámez 2010).

Here we reinforce the unique botanical and faunal characteristics that Amazonian savannahs exhibit, which are considered an important area of endemism within South America (Barbosa et al. 2007). Hence, the studies concerning the fauna of this region should aim to establish conservation strategies associated with this important environment. Our study was the first to document the dung beetle fauna from Roraima savannahs and we believe that knowing the biodiversity is the first step in developing conservation strategies. Thus, since human disturbances threaten these environments (Barbosa et al. 2007, 2011), what leads to biodiversity loss, we reinforce that efforts should be undertaken towards the conservation of intra-Amazonian savannahs. Furthermore, we suggest further studies aiming to understand the effects of human disturbances on the dung beetle diversity in the Brazilian intra-Amazonian savannahs.

Acknowledgments

We thank Lívia Audino, Ross Thomas, the editor and anonymous reviewers for constructive comments on earlier versions of the manuscript. We thank to Fausto França and Edna Macedo for logistical and financial support, also to Daniel Macedo for his invaluable field assistance. We also thank T. Pacheco, L. Vieira and T. Vidaurre for allowing us to use dung beetle photographs from their previous publications; and Amanda Arcanjo and Laís Maia for taking the dung beetle photographs we included in this work. Insect Ecology and Conservation Lab (UFLA) was funded by and CNPq-PELD site 23, and by FAPEMIG, CNPq and CAPES grants. F.F. was awarded a studentship by CAPES (BEX 5528/13-5). F.V.M. was granted by CNPq (405697/2013-9, 302997/2013-0, 484035/2013-4, 202327/2013-2) and thanks very especially to the Assis and Estevam families (especially Joana and Pedro Raimundo - in memoriam - and Pedro Heber), and Adrian Forsyth for logistical support.

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Received 30/03/2015
Revised 29/12/2015
Accepted 20/01/2016

Biota Neotropica 16(1): e20140085, 2016
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)

inventory

Butterflies (Lepidoptera: Papilionoidea and Hesperioidea) of the Private Reserve of Natural Heritage Fazenda Lontra/Saudade, Itanagra, Northern Coast of Bahia, Brazil

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PALUCH, M., MIELKE, O.H.H., LINHARES, L.M., SILVA, D.C. **Butterflies (Lepidoptera: Papilionoidea and Hesperioidea) of the Private Reserve of Natural Heritage Fazenda Lontra/Saudade, Itanagra, Northern Coast of Bahia, Brazil.** Biota Neotropica. 16(1): e20140085. http://dx.doi.org/10.1590/1676-0611-BN-2014-0085

Abstract: The Private Reserve of Natural Heritage Fazenda Lontra/Saudade (FLS), located in the Northern Coast of Bahia state, Brazil, is the largest (1,377.33 ha) preserved Atlantic Forest area between Paraguaçu and São Francisco rivers in Bahia and Sergipe, respectively. A list of 260 species belonging to six families of butterflies is presented herein, being recorded 4 species of Papilionidae, 16 of Pieridae, 29 of Lycaenidae, 41 of Riodinidae, 87 of Nymphalidae and 83 of Hesperiidae. The butterfly community was composed mainly by widespread species commonly found in open habitats. There were also many species typical of forested areas, as such *Morpho telemachus richardus* Fruhstorfer, 1898 (Nymphalidae: Morphini), a new record to the Northeastern Brazil.
Keywords: *Inventory, Conservation, Species richness, Atlantic Forest.*

PALUCH, M., MIELKE, O.H.H., LINHARES, L.M., SILVA, D.C. **As borboletas (Lepidoptera: Papilionoidea e Hesperioidea) da Reserva Particular do Patrimônio Natural Fazenda Lontra/Saudade, Itanagra, Litoral Norte da Bahia, Brasil.** Biota Neotropica. 16(1): e20140085. http://dx.doi.org/10.1590/1676-0611-BN-2014-0085

Resumo: A Reserva Particular do Patrimônio Natural Fazenda Lontra/Saudade (FLS), localizada no litoral norte do estado Bahia, Brasil, corresponde a maior área (1.377,33 ha) preservada de Mata Atlântica entre os rios Paraguaçu (Bahia) e São Francisco (Sergipe). Uma lista com 260 espécies de borboletas pertencentes a seis famílias é apresentada, sendo 4 espécies de Papilionidae, 16 de Pieridae, 29 de Lycaenidae, 41 de Riodinidae, 87 de Nymphalidae e 83 de Hesperiidae. A fauna foi composta principalmente por espécies de áreas abertas com ampla distribuição geográfica. Espécies típicas de áreas florestadas também estão presentes, uma delas, *Morpho telemachus richardus* Fruhstorfer, 1898 (Nymphalidae: Morphini), é um registro novo para a fauna de borboletas do nordeste do Brasil.
Palavras-chave: *Inventário, Conservação, Riqueza de espécies, Mata Atlântica.*

Introduction

The butterfly fauna of Northeastern Brazil was considered recently as largely unknown (Santos et al. 2008, Freitas & Marini-Filho 2011). However, important areas of the biome Caatinga have been studied in the last years, mainly in Pernambuco (PE) and Bahia (BA). The Catimbau National Park (PE) (Nobre et al. 2008); the Ecological Park João Vasconcelos Sobrinho (PE), "Brejo de Altitude" enclave of Atlantic Forest inserted in the semi-arid (Paluch et al. 2011); northern portion of the “Chapada Diamantina” (BA) (Zacca & Bravo 2012) and the “Serra da Fumaça” (BA) (Lima & Zacca 2014), together represent a significant inventory of butterflies for the Brazilian semi-arid region.

To Atlantic Forest of Northeastern Brazil, recently was published a list of 140 species of butterflies of the “Serra da Jibóia”, a mountainous complex in the “Recôncavo” region of Bahia (Zacca et al. 2011). But, more significant data for this biome are quite old and were obtained during more than five years of collecting by Cardoso (1949), who listed 218 species of butterflies in urban areas of Maceió, Alagoas (AL). Additionally, Kesselring & Ebert (1982) surveyed the urban fragment “Mata do Buraquinho” in João Pessoa, Paraíba (PB), and recorded 291 species. In this context, the present paper provides the first list of butterflies recorded in Itanagra, Northern Coast of Bahia, Brazil. It is expected that this list may offer subsidies for future conservation strategies in the region.

Material and methods

The study was conducted in the Private Reserve of Natural Heritage (Portuguese acronym, RPPN) “Fazenda Lontra/

Saudade" (FLS), Itanagra, located at the Northern Coast of Bahia (38° 0.00' W and 12° 15.00' S). According Birdlife International (2014) FLS is the largest particular protected area of Atlantic Forest with extension of 1,377.33 ha, located between the Paraguaçu (BA) and São Francisco (SE) rivers, with possibility of reconnection with others forest fragments of the region. In this area, 183 species of plants from 56 families already were recorded, mostly of Myrtaceae, Fabaceae, Rubiaceae, Melastomataceae, Mimosaceae, Sapotaceae and Flacourtiaceae. The local economy is based on forestry (pine and eucalypt), subsistence agriculture and extensive cattle. The region has undulating relief, and is drained by a complex network of aquifers. The average annual rainfall is 1,800 mm. The FLS is an example of environmental protection in the region, representing one of the most significant remnants of Atlantic Forest of Northern Coast of Bahia.

Butterflies were sampled between January to December 2012 (dry and wet seasons), totaling 12 field trips. Fieldwork was conducted from 9:00 to 15:00 h, during two days per month, with a total sampling effort of 288 hours. The samplings were carried out by two collectors along all habitats of the occidental side FLS.

The collected material was deposited in the entomological collections of the following institutions brazilian: Universidade Federal do Recôncavo da Bahia, Cruz das Almas (Laboratório de Sistemática e Conservação de Insetos - LASCI) and Departamento de Zoologia, Universidade Federal do Paraná, Curitiba (DZUP). Nomenclature follows Mielke (2005) (Hesperioidea) and Lamas (2004) (Papilionoidea), except for the genus *Morpho* Fabricius, 1807 (Morphini) according to Blandin (2007), and suprageneric categories of Nymphalidae modified after Wahlberg et al. (2009).

Results and discussion

A total of 260 butterfly species were recorded in the FLS. Of these, 177 (68%) are Papilionoidea and 83 (32%) Hesperioidea, with the following distribution: Papilionidae (4 spp., 1,5%), Pieridae (16 spp., 6%), Lycaenidae (29 spp., 11%), Riodinidae (41 spp., 16%), Nymphalidae (87 spp., 33,5%), and Hesperiidae (83 spp., 32% of the total) (Appendix 1). The butterfly fauna is composed by species commonly found in open areas and widely distributed in Brazil, and species more frequent in humid forests as well.

Four species of Papilionidae were recorded, and three of them were already expected for the area, *Heraclides anchisiades capys* (Hübner, [1809]), *Heraclides thoas brasiliensis* (Rothschild & Jordan, 1906) and *Battus polydamas polydamas* (Linnaeus, 1758) because they are very common and occur throughout the Brazilian coast, Caatinga, and also in the "Brejos de Altitude" (Tyler et al. 1994, Nobre et al. 2008, Paluch et al. 2011, Zacca & Bravo 2012). *Parides zacynthus* (Fabricius, 1793) has been considered restricted to the coastal plains, including "restingas" and lowland forests areas (Tyler et al. 1994). However, the subspecies *P. zacynthus polymetus* (Godart, 1819) was recently recorded in the Ecological Park João Vasconcelos Sobrinho, PE, about 100 km far from the coast (Paluch et al. 2011). In Bahia, this subspecies has been recorded to Salvador (Zacca 2009), but it was also collected in 15 km east of Lençóis, Bahia, about 300 km west from Salvador.

All sixteen species of Pieridae collected in FLS already were recorded in previous studies performed in Northeastern Brazil, and most of them are typically founded in open secondary forests, grasslands and more disturbed areas (Brown 1992). Only *Leucidia elvina* (Godart, 1819) (Coliadinae) and *Enantia lina versicolora* (Fruhstorfer, 1912) (Dismorphiinae) were collected in transects inside the forest.

Lycaenidae totaled 29 species in the FLS, same richness recorded for the Atlantic Forest of Maceió (AL) by Cardoso (1949). Kesselring & Ebert (1982) recorded 46 species in João Pessoa, in a forest fragment along the Atlantic coastline. However, data were gathered during more than five years of observations.

The Riodinidae richness of FLS was surprising similar to the number of species found by Kesselring & Ebert (1982). The presence of two sympatric subspecies of *Stalachtis phlegia* (Cramer, 1779), *Stalachtis phlegia phlegetontia* (Perty, 1833) and *Stalachtis phlegia susanna* (Fabricius, 1787) reveals an unusual taxonomic situation. Some authors consider *Stalachtis susanna* (Fabricius, 1787) as a valid species, for example Brown & Freitas (2000b). Both taxa are very common, and were observed in all months flying at the same time in FLS. This situation can be best elucidated by a review on the status of all five subspecies (Lamas 2004).

Nymphalidae and Hesperiidae were the richest families, with similar numbers reported in other important forest areas in Northeastern Brazil (Cardoso 1949, Kesselring & Ebert 1982). In general, Nymphalidae was represented by species widely distributed in different Brazilian biomes (from Amazonian borders to South Brazil).

Danaini (Danainae) is represented by two widespread species, previously mentioned for Bahia by Zacca et al. (2011) in the Atlantic Forest and Zacca & Bravo (2012), Lima & Zacca (2014) in the biome Caatinga. Ithomiini (Danainae) is represented by 7 species, same number recorded by Kesselring & Ebert (1982), and includes common species which may be found throughout the year, for example, *Mechanitis lysimnia nesaea* Hübner, [1820] and *Mechanitis polymnia casabranca* Haensch, 1905.

Haeterini and Satyrini (Satyrinae) represent 23 species; the other inventoried areas in Northeastern Brazil have on average 13 species. The Neotropical genus *Pierella* Westwood, 1851, so far, with four species in northeastern Brazil in the states Alagoas, Paraíba, Bahia and Pernambuco (Cardoso 1949; Kesselring & Ebert 1982; Zacca 2009; Paluch et al. 2011; Zacca et al. 2011), has revealed new taxa to the Northeastern Atlantic Forest, as *Pierella* sp. nov. in FLS described in Zacca et al. (in press) (Taxonomic revision of the "*Pierella lamia* species group"), as well as, *Pierella lena atlantica* Paluch, Zacca & Siewert, 2015 in Paluch et al. (2015).

Brassolini (Satyrinae) is represented by five common and widespread species and Morphini (Satyrinae) by three species. *Morpho helenor bahiana* Fruhstorfer, 1897 (Blandin 2007) was recently mentioned by Zacca et al. (2011) as *Morpho helenor achillaena* (Hübner, 1823]) from Serra da Jiboia. The record of *Morpho telemachus richardus* Fruhstorfer, 1898 in FLS was important to enlarge 700km to the east in the geographical distribution of this subspecies. The first and only known record is from southeastern Brazil, Minas Gerais, Teófilo Otoni. Seven mature larvae were collected in March on its hostplant – *Abuta* sp. (Menispermaceae), a rare plant in the region. The genus *Abuta* Aubl. is also known as hostplant of *Morpho telemachus martini* Niepelt, 1933 in San Martín, Peru (Gallusser et al. 2010). In a greenhouse, five specimens of *M. telemachus richardus* emerged in April.

Anaeini (Charaxinae) is represented by five species, *Hypna clytemnestra forbesi* Godman & Salvin, 1884 is a typical subspecies of the Caatinga biome (Nobre et al., 2008), however, also known in the Atlantic Forest remnants of the "Recôncavo" and southern coast of Bahia (Zacca 2009; M. Paluch, pers. obs.).

Biblidinae and Cyrestinae are represented by 16 species, the tribes Coeini, Kallimini and Melitaeini (Nymphalinae) are represented by three, four and two common and widespread species, respectively. *Anartia amathea amathea* (Linnaeus, 1758) (Kallimini) generally restricted in rainforests of Northeastern region (Cardoso 1949; Kesselring & Ebert 1982; Paluch et al. 2011), while *Anartia jatrophae jatrophae* (Linnaeus, 1763) is common in dry Caatinga, and also humid Atlantic Forest (Nobre et al. 2008; Zacca 2009; Zacca et al. 2011; Zacca & Bravo 2012).

Limenitidinae is represented by four species: *Adelpha cytherea cytherea* (Linnaeus, 1758), also reported in Maceió, Alagoas (Cardoso 1949) and seems to be restricted to the Atlantic Forest biome, while *Adelpha cytherea aea* (C. Felder & R. Felder, 1867) to the Semiarid region (Paluch et al. 2011, Zacca & Bravo 2012); *Adelpha leucates iphicleola* Fruhstorfer, 1915 was recently recorded in two areas of Caatinga: Catimbau National Park and the northern portion of the Chapada Diamantina (Nobre et al. 2008, Zacca & Bravo 2012). *Adelpha melona melona* (Hewitson, 1847) and *Adelpha plesaure plesaure* Hübner, 1823 are known from the Northeastern Atlantic Forest in Brazil (Cardoso 1949, Kesselring & Ebert 1982, Zacca et al. 2011).

Heliconiinae is represented by thirteen taxa widely distributed in all extension of the Atlantic Forest. The northern border of the distribution of *Heliconius ethilla narcaea* Godart, 1819 (Heliconiini) seems to be Maceió, Alagoas Cardoso (1949); this subspecies was also collected at the "Serra da Jiboia" (Zacca et al. 2011), northern part of the "Chapada Diamantina" and at FLS. *Heliconius ethilla flavomaculatus* Weymer, 1894 is endemic to Pernambuco and Paraiba. *Heliconius numata ethra* (Hübner, [1831]) was re-collected in Northeastern Brazil, after 63 years since its unique record to Maceió, Alagoas (Cardoso 1949). However, this subspecies was cited by Brown & Freitas (2000b) in Santa Teresa, Espírito Santo, near to the southern limits of Bahia. *Actinote pellenea pellenea* Hübner, [1821] (Acraeini) was previously recorded in southern Bahia (Jitaúna, Itanhém and Itamaraju); its northern subspecies *Actinote pellenea aulodea* Oberthür, 1917 is distributed in the Atlantic Forest of Alagoas, Pernambuco and Paraiba (Cardoso 1949, Paluch et al. 2011, Kesselring & Ebert 1982).

Hesperiidae is considered the dominant family of butterflies in most well sampled Brazilian sites (C. Mielke 1994, Brown 2005, Morais et al. 2007, Francini et al. 2011, Dolibaina et al. 2011). In FLS skippers represented 32% of all butterflies species, with 83 recorded species. FLS corresponds to the second largest richness of Hesperiidae in the Northeastern Brazil, close to the 110 species recorded by Kesselring & Ebert (1982).

Future studies can greatly enhance the richness of butterflies of the FLS, with sampling on the eastern side of the reserve, using "The Ahrenholz Technique", to attract species of skippers, Nymphalidae, Riodinidae and Pieridae (Lamas et al. 1993), together with "Van Someren-Rydon" traps, to capture others species of frugivorous butterflies, mainly of the subfamilies Satyrinae, Charaxinae and Biblidinae.

The FLS may be considered very important because it is one of the largest and best preserved remnants of Atlantic Forest in northeastern Brazil, this region is part of a biome with more than 95% of its original vegetation destroyed by human activities (Galindo-Leal & Câmara 2003, Tabarelli et al. 2005). Considering Nymphalidae as a surrogate (25-29%) of the total butterfly fauna (Brown & Freitas 2000a), the total richness in the FLS could reach 300 to 350 species, equivalent or higher to the total richness of "Mata do Buraquinho", João Pessoa, Paraiba, with a sampling effort of five years (Kesselring & Ebert 1982). Based on the present data and other inventories performed in this area, FLS should be considered as a priority area for biodiversity conservation in the Atlantic Forest. Among the priority actions for the FLS, ecological monitoring and management of the surrounding environments should be included, so the area can keep sustaining health forests.

Appendix I. Butterflies (Papilionoidea and Hesperioidea) from the Private Reserve of Natural Heritage Fazenda Lontra/Saudade, Itanagra, Northern Coast, Bahia, Brazil. Number of species are provided within parenthesis for higher taxa. Species recorded in other areas of Atlantic Forest Northeastern: 1 = Maceió, AL (Cardoso 1942); 2 = Mata do Buraquinho, João Pessoa, PB (Kesselring & Ebert 1982); 3 = Ecological Park João Vasconcelos Sobrinho (Enclave of Atlantic Forest), Caruaru, PE (Paluch et al. 2011); 4 = Serra da Jibóia, Santa Terezinha, BA (Zacca et al. 2011).

PAPILIONOIDEA (177)
Papilionidae (4)
Papilioninae (4)
Troidini (2)
    Battus polydamas polydamas (Linnaeus, 1758)[1,2,3,4]
    Parides zacynthus polymetus (Godart, 1819)[2,3]
Papilionini (2)
    Heraclides anchisiades capys (Hübner, [1809])[1,2,3]
    Heraclides thoas brasiliensis (Rothschild & Jordan, 1906)[1,2,3,4]

Pieridae (16)
Dismorphiinae (1)
    Enantia lina versicolora (Fruhstorfer, 1912)[3]
Coliadinae (12)
    Anteos clorinde (Godart, [1824])[1,2,3,4]
    Aphrissa statira statira (Cramer, 1777)[1,3]
    Eurema agave pallida (Chavannes, 1850)[3]
    Eurema albula albula (Cramer, 1775)[1,3,4]
    Eurema elathea flavescens (Chavannes, 1850)[3,4]
    Eurema phiale paula (Röber, 1909)[3, 4]
    Leucidia elvina (Godart, 1819)[1,3,4]
    Phoebis argante argante (Fabricius, 1775)[1,2,4]
    Phoebis philea philea (Linnaeus, 1763)[1,2,3,4]
    Phoebis sennae marcellina (Cramer, 1777)[3,4]
    Pyrisitia nise tenella (Boisduval, 1836)[1,2,3,4]
    Rhabdodryas trite banksi (Breyer, 1939)
Pierinae (3)
    Ascia monuste orseis (Godart, 1819)[1,2,3,4]
    Glutophrissa drusilla drusilla (Cramer, 1777)[1,4]
    Itaballia demophile nimietes (Fruhstorfer, 1907)[3]

Lycaenidae (29)
Polyommatinae (3)
    Hemiargus hanno hanno (Stoll, 1790)[2,3,4]
    Leptotes cassius cassius (Cramer, 1775)[3,4]
    Zizula cyna (W.H. Edwards, 1881)[2,3]
Theclinae (26)
    Arawacus ellida (Hewitson, 1867)[2]
    Calycopis caulonia (Hewitson, 1877)[3]
    Calycopis vesulus (Stoll, 1781)[1,2]
    Celmia celmus (Cramer, 1775)[2]

Evenus satyroides (Hewitson, 1865)[1]
Evenus sp.
Gargina gnosia (Hewitson, 1868)
Lamprospilus badaca (Hewitson, 1868)[4]
Ministrymon una (Hewitson, 1873)[1]
Ostrinotes tympania (Hewitson, 1869)
Panthiades hebraeus (Hewitson, 1867)[2]
Panthiades phaleros (Linnaeus, 1767)[1,2]
Pseudolycaena marsyas (Linnaeus, 1758)[1,2]
Rekoa meton (Cramer, 1779)
Rekoa palegon (Cramer, 1780)[2,3,4]
Strephonota ambrax (Westwood, 1852)[1]
Strephonota tephraeus (Geyer, 1837)[2]
Strymon bazochii (Godart, [1824])[2,4]
Strymon mulucha (Hewitson, 1867)[1,2,3,4]
Theclopsis gargara (Hewitson, 1868)
Theclopsis sp.
Theritas hemon (Cramer, 1775)[1,2,3,4]
Theritas lisus (Stoll, 1790)
Theritas triquetra (Hewitson, 1865)[1,2,4]
Tmolus echion (Linnaeus, 1767)[1,2]
Ziegleria syllis (Godman & Salvin, 1887)[3]

Riodinidae (41)
Euselasiinae (1)
Euselasiini (1)
Euselasia opalescens opalescens (Hewitson, [1855])
Riodininae (40)
Mesosemiini (7)
Hyphilaria parthenis (Westwood, 1851)
Leucochimona icare matatha (Hewitson, 1873)[1,4]
Mesosemia hesperina Buttler, 1874
Mesosemia methion methion Hewitson, 1860
Mesosemia nyctea lato Stichel, 1910
Perophthalma tullius (Fabricius, 1787)[2,3]
Semomesia geminus (Fabricius, 1793)
Eurybiini (2)
Eurybia halimede halimede (Hübner, [1807])[4]
Eurybia molochina hyacinthina Stichel, 1910
Riodinini (10)
Baeotis euprepes H.W. Bates, 1868
Calephelis braziliensis McAlpine, 1971[2,3]
Cyrenia martia androgyne Stichel, 1910
Isapis agyrtus sestus (Stichel, 1909)[1]
Melanis smithiae smithiae (Westwood, 1851)[1,2,3]
Metacharis ptolomaeus (Fabricius, 1793)
Panara jarbas jarbas (Drury, 1782)[2]
Rhetus periander (Cramer, 1777)
Syrmatia nyx (Hübner, [1817])
Themone pais pais (Hübner, [1820])
Symmachiini (6)
Mesene florus (Fabricius, 1793)[2]
Mesene phareus (Cramer, 1777)[1,2]
Mesene philonis Hewitson, 1874
Panaropsis inaria (Westwood, 1851)[1]
Pirascca sagaris satnius (Dalman, 1823)[1,2,4]
Symmachia menetas menetas (Drury, 1782)
Helicopini (1)
Anteros formosus (Cramer, 1777)[2]
Nymphidiini (8)
Calospila lucianus lucianus (Fabricius, 1793)[1,2]
Calospila parthaon (Dalman, 1823)
Juditha caucana (Stichel, 1911)
Nymphidium acherois erymanthus (Ménétriés, 1855)
Nymphidium lisimon attenuatum Stichel, 1929
Synargis calyce (C. Felder & R. Felder, 1862)[2,3]
Synargis gela (Hewitson, [1853])[1,2]
Synargis paulistina (Stichel, 1910)
Stalachtini (2)
Stalachtis phlegia phlegetontia (Perty, 1833)
Stalachtis phlegia susanna (Fabricius, 1787)
Incertae sedis (4)
Astraeodes areuta (Westwood, 1851)[1,2]
Calydna hiria (Godart, [1824])[2]
Calydna sturnula (Geyer, 1837)
Emesis fatimella fatimella Westwood, 1851[1]

Nymphalidae (87)
Danainae (9)
Danaini (2)
Danaus eresimus plexaure (Godart, 1819)[3]
Lycorea halia discreta Haensch, 1909[3,4]
Ithomiini (7)
Hypothyris euclea laphria (Doubleday, 1847)[1,2,4]
Hypothyris ninonia daetina (Weymer, 1899)[1,2,3]
Ithomia agnosia zikani d'Almeida, 1940[4]
Mechanitis lysimnia nesaea Hübner, [1820][1,2,3]
Mechanitis polymnia casabranca Haensch, 1905
Oleria astrea thiemei (Oberthür, 1879)
Scada reckia reckia (Hübner, [1808])[3,4]
Satyrinae (31)
Morphini (3)
Antirrhea archaea Hübner, [1822][4]
Morpho helenor bahiana Fruhstorfer, 1897[4]
Morpho telemachus richardus Fruhstorfer, 1898
Brassolini (5)
Brassolis sophorae laurentii Stichel, 1925
Caligo idomeneus ariphron Fruhstorfer, 1910
Caligo illioneus illioneus (Cramer, 1775)[2,3,4]
Eryphanis automedon (Cramer, 1775)[2,3]
Opsiphanes quiteria meridionalis Staudinger, 1887[2]
Haeterini (4)
Haetera piera diaphana Lucas, 1857
Pierella sp. nov.
Pierella lena atlantica Paluch, Zacca & Siewert, 2015
Pierella hyalinus (Gmelin, [1790])
Satyrini (19)
Caeruleuptychia brixius (Godart, [1824])
Chloreuptychia arnaca (Fabricius, 1776)[3]
Chloreuptychia chlorimene (Hübner, [1819])[1]
Chloreuptychia herseis (Godart, [1824])
Cissia myncea (Cramer, 1780)[3]
Erichthodes antonina (C. Felder & R. Felder, 1867)[1]
Godartiana sp.
Hermeuptychia hermes (Fabricius, 1775)[1,2,4]
Magneuptychia lea (Cramer, 1777)
Magneuptychia libye (Linnaeus, 1767)[2,3]
Pareuptychia ocirrhoe interjecta (d' Almeida, 1952)[1,3]
Paryphthimoides poltys (Prittwitz, 1865)[3]
Pharneuptychia romanina (Bryk, 1953)
Pharneuptychia sp.
Taygetis echo (Cramer, 1775)[2]
Taygetis laches laches (Fabricius, 1793)[1,3]
Yphthimoides affinis (Butler, 1867)[3]

  - *Yphthimoides manasses* (C. Felder & R. Felder, 1867)[1,3]
  - *Yphthimoides renata* (Stoll, 1780)[1,2,3,4]
- Charaxinae (5)
- Anaeini (5)
  - *Fountainea glycerium cratais* (Hewitson, 1874)[2]
  - *Fountainea ryphea phidile* (Geyer, 1837)[3]
  - *Hypna clytemnestra forbesi* Godman & Salvin, 1884
  - *Memphis acidalia victoria* (H. Druce, 1877)
  - *Memphis moruus stheno* (Prittwitz, 1865)
- Biblidinae (14)
  - *Biblis hyperia nectanabis* (Fruhstorfer, 1909)[4]
  - *Callicore astarte codomannus* (Fabricius, 1781)
  - *Dynamine agacles agacles* (Dalman, 1823)[1,3,4]
  - *Dynamine athemon athemaena* (Hübner, [1824])[3]
  - *Dynamine postverta postverta* (Cramer, 1779)[1,2,3]
  - *Ectima thecla thecla* (Fabricius, 1796)[1,3]
  - *Hamadryas amphinome amphinome* (Linnaeus, 1767)[1,3,4]
  - *Hamadryas arete* (Doubleday, 1847)[1,2,3]
  - *Hamadryas februa februa* (Hübner, [1823])[3]
  - *Hamadryas feronia feronia* (Linnaeus, 1758)[1,3]
  - *Mestra dorcas hypermestra* Hübner, [1825][1,2,3,4]
  - *Myscelia orsis* (Drury, 1782)[1,2,3]
  - *Nica flavilla flavilla* (Godart, [1824])[4]
  - *Pyrrhogyra neaerea ophni* Butler, 1870
- Cyrestinae (2)
  - *Marpesia chiron marius* (Cramer, 1779)[3,4]
  - *Marpesia petreus petreus* (Cramer, 1776)
- Nymphalinae (9)
- Coeini (3)
  - *Colobura dirce dirce* (Linnaeus, 1758)[1,2,3]
  - *Historis acheronta acheronta* (Fabricius, 1775)[1,2]
  - *Historis odius dious* Lamas, 1995[3]
- Kallimini (4)
  - *Anartia amathea amathea* (Linnaeus, 1758)[1,2,3]
  - *Anartia jatrophae jatrophae* (Linnaeus, 1763)[1,2,3,4]
  - *Junonia evarete evarete* (Cramer, 1779)[1,2,3,4]
  - *Siproeta stelenes meridionalis* (Fruhstorfer, 1909)[1,3,4]
- Melitaeini (2)
  - *Ortilia ithra* (W.F. Kirby, 1900)[2,3]
  - *Tegosa claudina* (Eschscholtz, 1821)[3,4]
- Limenitidinae (4)
  - *Adelpha cytherea cytherea* (Linnaeus, 1758)[1]
  - *Adelpha iphicleola leucates* Fruhstorfer, 1915[1]
  - *Adelpha melona melona* (Hewitson, 1847)[1,2,4]
  - *Adelpha plesaure plesaure* Hübner, 1823[1,4]
- Heliconiinae (13)
- Argynnini (1)
  - *Euptoieta hegesia meridiania* Stichel, 1938[3]
- Acraeini (1)
  - *Actinote pellenea pellenea* Hübner, [1821]
- Heliconiini (11)
  - *Agraulis vanillae maculosa* (Stichel, [1908])[2,3,4]
  - *Dione juno juno* (Cramer, 1779)[1,2,3,4]
  - *Dryadula phaetusa* (Linnaeus, 1758)[2,3]
  - *Dryas iulia alcionea* (Cramer, 1779)[2,3,4]
  - *Eueides aliphera* (Godart, 1819)[1,4]
  - *Eueides isabella dianasa* (Hübner, [1806])[1,2,3,4]
  - *Heliconius erato phyllis* (Fabricius, 1775)[1,2,3,4]
  - *Heliconius ethilla narcaea* Godart, 1819 [4]
  - *Heliconius numata ethra* (Hübner, [1831])[1]
  - *Heliconius sara apseudes* (Hübner, [1813])[2,3,4]
  - *Philaethria wernickei* (Röber, 1906)[1,4]

HESPERIOIDEA (83)

Hesperiidae (83)

- Eudaminae (25)
  - *Aguna asander asander* (Hewitson, 1867)[1,2,3,4]
  - *Aguna aurunce aurunce* (Hewitson, 1867)
  - *Astraptes anaphus anaphus* (Cramer, 1777)[1,2,3]
  - *Astraptes janeira* (Schaus, 1902)[1]
  - *Augiades crinisus* (Cramer, 1780)[2]
  - *Autochton neis* (Geyer, 1832)[2,3]
  - *Autochton zarex* (Hübner, 1818)[1,2,3,4]
  - *Chioides catillus catillus* (Cramer, 1779)[2,3]
  - *Drephalys oriander* (Hewitson, 1867)
  - *Entheus priassus pralina* Evans, 1952[1]
  - *Euriphellus euribates polygius* (Latreille, [1824])
  - *Phanus australis* L. D. Miller, 1965[3]
  - *Phanus marshalli* (W.F. Kirby, 1880)
  - *Phocides distans distans* (Herrich-Schäffer, 1869)
  - *Salatis salatis* (Stoll, 1782)[2]
  - *Typhedanus crameri* McHenry, 1960[1]
  - *Typhedanus undulatus* (Hewitson, 1867)[2]
  - *Udranomia kikkawai* (A.G. Weeks, 1906)[2]
  - *Udranomia orcinus* (C. Felder & R. Felder, 1867)[2]
  - *Urbanus cindra* Evans, 1952
  - *Urbanus dorantes dorantes* (Stoll, 1790)[1,2,3,4]
  - *Urbanus esta* Evans, 1952
  - *Urbanus proteus proteus* (Linnaeus, 1758)[1,2,3,4]
  - *Urbanus simplicius* (Stoll, 1790)[2,3,4]
  - *Urbanus virescens* (Mabille, 1877)[2,4]
- Pyrginae (24)
  - *Achlyodes busirus rioja* Evans, 1953[1]
  - *Anastrus neaeris narva* Evans, 1953
  - *Antigonus erosus* (Hübner, [1812])[2]
  - *Camptopleura janthinus* (Capronnier, 1874)
  - *Chiomara basigutta* (Plötz, 1884)[1,2]
  - *Cogia calchas* (Herrich-Schäffer, 1869)[2,3]
  - *Gesta gesta* (Herrich-Schäffer, 1863)[2,4]
  - *Helias phalaenoides palpalis* (Latreille, [1824])[3]
  - *Heliopetes alana* (Reakirt, 1868)[3,4]
  - *Heliopetes arsalte* (Linnaeus, 1758)[2,3,4]
  - *Heliopetes omrina* (Butler, 1870)[3,4]
  - *Mylon ander ander* Evans, 1953
  - *Nisoniades macarius* (Herrich-Schäffer, 1870)[2,3,4]
  - *Ouleus fridericus riona* Evans, 1953
  - *Pachyneuria duidae duidae* (Bell, 1932)
  - *Pyrgus orcus* (Stoll, 1780)[2,3,4]
  - *Pyrgus veturius* Plötz, 1884[2]
  - *Pythonides herennius lusorius* Mabille, 1891
  - *Pythonides limaea* (Hewitson, 1868)[2]
  - *Quadrus* sp.
  - *Sostrata festiva* (Erichson, [1849])
  - *Telemiades antiope* (Plötz, 1882)[2]
  - *Timochreon doria* (Plötz, 1884)[2]
  - *Xenophanes tryxus* (Stoll, 1780)[1,2]
- Hesperiinae (33)
  - *Anthoptus insignis* (Plötz, 1882)
  - *Artines* sp.
  - *Callimormus corades* (C. Felder, 1862)[2]
  - *Cobalus virbius hersilia* (Plötz, 1882)
  - *Corticea corticea* (Plötz, 1882)[3]
  - *Cymaenes distigma* (Plötz, 1882)
  - *Cymaenes tripunctus theogenis* (Capronnier, 1874)[4]
  - *Hylephila phyleus phyleus* (Drury, 1773)[1,2,3,4]

Justinia justinianus justinianus (Latreille, [1824])[2,4]
Mnaseas bicolor inca Bell, 1930
Mnasilus allubita (Butler, 1877)[2,3]
Morys compta compta (Butler, 1877)
Nyctelius nyctelius nyctelius (Latreille, [1824])[2,3]
Onophas columbaria (Herrich-Schäffer, 1870)[2]
Orses cynisca (Swainson, 1821)
Panoquina hecebolus (Scudder, 1872)
Paracarystus menestries menestries (Latreille, [1824])[4]
Perichares philetes adela (Hewitson, 1867)[2,3]
Phanes aletes (Geyer, 1832)[2]
Phanes almoda (Hewitson, 1866)
Pompeius pompeius (Latreille, [1824])[1,2]
Radiatus bradus Mielke, 1968
Saliana morsa Evans, 1955
Saturnus reticulata meton (Mabille, 1891)
Sodalia sodalis (Butler, 1877)
Talides sergestus (Cramer, 1775)[1,2]
Vacerra bonfilius bonfilius (Latreille, [1824])
Vehilius stictomenes stictomenes (Butler, 1877)[2,3]
Vettius artona (Hewitson, 1868)[2,3,4]
Vettius fantasos (Cramer, 1780)[1,2]
Vettius lafrenaye lafrenaye (Latreille, [1824])
Vettius phyllus prona Evans, 1955[1,3]
Zariaspes mys (Hübner, [1808])[2]

Pyrrhopyginae (1)
Pyrrhopyge phidias (Linnaeus, 1758)

Acknowledgements

We thank Dr. André Victor Lucci Freitas (UNICAMP) for their help in the identification of the species of Satyrini and Dr. Diego Rodrigo Dolibaina (UFPR) with the species of Lycaenidae and Riodinidae. We thank MSc. Thamara Zacca (UFPR) for reading and suggestions in the last version of the manuscript. Copener Florestal LTDA, Alagoinhas, Bahia for the permit of the inventory in the RPPN Fazenda Lontra/Saudade. This publication is part of the RedLep "Rede Nacional de Pesquisa e Conservação de Lepidópteros" SISBIOTA-Brasil/CNPq (563332/2010-7).

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Received 19/06/2014
Revised 19/09/2015
Accepted 21/12/2015

Biota Neotropica 16(1): e0166, 2016
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
article

Spatial and temporal distribution in two anuran communities in the Chapada do Araripe, Northeastern Brasil

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FERREIRA-SILVA, C., OLIVEIRA, D.B., OLIVEIRA, H.F., ÁVILA, R.W. **Spatial and temporal distribution in two anuran communities in the Chapada do Araripe, Northeastern Brasil.** Biota Neotropica. 16(1):e0166. http://dx.doi.org/10.1590/1676-0611-BN-2014-0166

Abstract: In this study, we report the temporal occurrence and habitat and microhabitat use by anurans in two areas located in one highland marsh (brejo-de-altitude) in northeastern Brazil. Fieldwork was carried out between September 2011 and September 2012. The recorded anurans belong to 14 species distributed in five families: Hylidae (six), Leptodactylidae (five), Bufonidae, Odontophrynidae and Pipidae (one each). Vocalization activity was seasonal and concentrated in the wetter and warmer months, but correlated to rainfall only in the top in the Chapada do Araripe. Richness and abundance of calling anurans were lower in the humid forest of the slope than in Cerradão area in the top of the Chapada do Araripe. *Scinax x-signatus* vocalized during nine months, and along with *Dendropsophus soaresi*, *Phyllomedusa nordestina* and *Physalaemus cuvieri* presented the longest periods of vocalization with the highest number of species vocalizing in at the height of the rainy season. Males were recorded vocalizing in nine different microhabitats, *Adenomera* sp. uses leaf litter and *P. cuvieri* the edge of water bodies as calling site both two sampled areas. Differences in richness and abundance of anurans between the two habitats are probably due to physical characteristics, such as presence of lentic environments.

Keywords: *Anurofauna, microhabitat use, seasonality.*

FERREIRA-SILVA, C., OLIVEIRA, D.B., OLIVEIRA, H.F., ÁVILA, R.W. **Distribuição espacial e temporal em duas comunidades de anuros na Chapada do Araripe, Nordeste do Brasil.** Biota Neotropica. 16(1):e0166. http://dx.doi.org/10.1590/1676-0611-BN-2014-0166

Resumo: Neste estudo são descritas a ocorrência temporal e o uso de habitat e microhabitat dos anuros de duas localidades em uma área de brejo de altitude no nordeste do Brasil. As amostragens foram realizadas entre setembro de 2011 e setembro de 2012. Foram registrados anuros pertencentes a 14 espécies distribuídas em cinco famílias: Hylidae (seis), Leptodactylidae (cinco), Bufonidae, Odontophrynidae e Pipidae (uma cada). A atividade de vocalização foi sazonal e concentrada nos meses mais úmidos e quentes, mas correlacionada somente com as chuvas no topo da Chapada do Araripe. A riqueza e abundância de anuros vocalizando foram menores na floresta úmida da encosta que na área de Cerradão do topo da Chapada do Araripe. *Scinax x-signatus* vocalizou durante nove meses, e juntamente com *Dendropsophus minutus, D. soaresi, Phyllomedusa nordestina* e *Physalaemus cuvieri* apresentou os períodos de vocalização mais prolongados, com maior abundancia de indivíduos vocalizando no ápice do período chuvoso. Machos de anuros foram registrados vocalizando em nove microhabitats diferentes, *Adenomera* sp. utiliza serrapilheira e *P. cuvieri* a margem dos corpos d'água como sítios de vocalização em ambas áreas amostradas. Diferenças na riqueza e abundância de anuros entre os dois habitats estudados estão associadas às características estruturais dos mesmos, como a presença de ambientes lênticos.

Palavras-chave: *Anurofauna, uso do micro-habitat, sazonalidade.*

Introduction

Anurans have a high diversity of species and life strategies (Wells 2007). This variety has stirred the attention of researchers in the field of anuran ecology with regard to the factors that structure their communities, especially patterns of spatial and temporal distribution (Toledo et al. 2003, Ponssa 2004, Conte & Machado 2005).

The use of different microhabitats, such as reproductive sites, facilitates spatial partitioning by anurans (Duellman & Trueb 1994). Temporal distribution, on the other hand, is directly related to the physical conditions of the region, such as environment temperature and availability of temporary water bodies (Bernarde & Anjos 1999). Besides these factors, risk of predation and competition between species are also determinant in the composition of anuran communities (Wellborn et al. 1996, Morin 1983, 2011).

The reproductive activity of anurans is strongly influenced by the availability of water bodies and mild temperatures (Vieira et al. 2009). In Brazil, the annual rainfall and structural complexity of vegetation are strong predictors of the richness of both species and reproductive modes (Vasconcelos et al. 2010, Xavier & Napoli 2011, Silva et al. 2012). Thus, species demonstrate behavioral strategies to avoid (or at least minimize) the adverse events of drought and high temperatures, and their reproductive periods coincide with the rainy period (Bertoluci & Rodrigues 2002).

In the Caatinga of Northeast Brazil, there are the so-called “brejos-de-altitude” (highland marshes), wetlands on the top of mountains over 600 m with humid forest remnants of the Atlantic Forest surrounded by the xeric Caatinga vegetation (Andrade-Lima 1982, Borges-Nojosa & Caramaschi 2003). According to Vasconcelos-Sobrinho (1971), there are 43 of these highland marshes (*sensu* Andrade- Lima 1982) distributed in the states of Ceará, Rio Grande do Norte, Paraíba and Pernambuco. The “brejos-de-altitude” occurs in plateaus and tablelands between 500 and 1.100 m (*e.g.*, Planalto da Borborema, Chapada do Araripe and Planalto da Ibiapaba), where the orographic rains provide precipitation levels over 1.200 mm/year (Andrade-Lima 1960, 1961).

Only nine of the “brejos-de-altitude” located in the states of Ceará and Pernambuco have available data of anuran richness: RESEC Serra Negra, Brejo dos Cavalos, Triunfo, Fazenda Buriti, PARNA Catimbau (Moura et al. 2011), Planalto da Ibiapaba (Loebmann & Haddad 2010), Serra do Baturité (Borges-Nojosa 2007), Chapada do Araripe (Ribeiro et al. 2015), and Serra da Aratanha (I.J. Roberto, unpublished data). Moreover data on temporal and spatial use by anurans for these highland marshes are absent.

The Chapada do Araripe region, located in the southern region of the Ceará state, is considered of high priority for conservation because of its faunistic and floristic diversity and level of vulnerability (MMA 2002). Our objective was to investigate the reproductive modes and patterns of spatial-temporal distribution by anurans of the Chapada do Araripe. Furthermore we compare the Chapada do Araripe anuran species composition with that of other brejos-de-altitude.

Methods

The present study was carried out in the Chapada do Araripe, which occupies an area of approximately 972.000 ha, over three states (Ceará, Piauí and Pernambuco) in Northeast Brazil (Campello et al. 2000, ICMBio 2015). The vegetation is composed of humid forest (semi-evergreen tropical cloud forest) and dry forest (semideciduous forest) on the slope, and Cerrado, Cerradão (xeromorphe semideciduous forest), and Carrasco (high dense shrubby xerophytic vegetation) areas at the top (Araújo et al. 1999, Borges-Nojosa & Caramaschi 2003).

Two areas were sampled: Trilha Ecológica do Clube Grangeiro (TECG, 07°16'47.0" S; 39°26'17.7" W, Alt. 691 m), Crato Municipality, located at the foothill of the Chapada and characterized by humid forest, and low soil permeability, and Fazenda Malhada Bonita (FMB, 7°21'55.55" S; 39°26'26.23" W, Alt. 912 m), Barbalha, located at the top of the Chapada do Araripe in the “cerradão” area, and exhibiting an table-like topography with accentuated drainage, due to sandy soil (Ribeiro et al. 2012) (Figure 1a). The mean annual precipitation of the region is 1121.25 mm, and the air temperature varies between 24 to 26° C, with the rainy season occurring from January to May (IPECE 2011). The rainfall data were obtained in a station at Lameiro, Crato (07°14'00" S; 39°25'00" W) within 10 km of the two localities (FUNCEME 2012).

Estimates of richness and abundance of the adult anuran species were carried out from September 2011 to August 2012 in TECG, and from October 2011 to September 2012 in FMB. Visual and acoustic encounter surveys were performed monthly, with one collection day for each sampled community. In the dry period (September to December 2011 and June to September 2012) recordings were made during shorter periods, approximately two to three hours sample effort, but in the rainy season (January to May 2012) they started approximately at 17:00 h and lasted until the end of vocalizations, with a total effort of 110 observer-hours. Three short-term samplings (one in TECG and two in FMB) were made on nights after heavy rains (Heyer et al. 1994), being added to the total sampling effort.

At FMB there were three water bodies, a permanent artificial pond with 1726.6 m^2 and depth up to 5 m in the rainy period and two temporary ponds: P1 with approximately 36 m^2 and 28 cm depth and P2 with approximately 18 m^2 and 39 cm depth. In FMB, the active search of anurans was performed in the margin of the permanent pond and adjacent vegetation during the sampling period. The same sampling was carried in the temporary ponds only during the rainy season, due to the short hydroperiod of these bodies of water. At TECG one perennial stream belonging to the Basin of Grangeiro River was sampled, with depth ranging from 20 cm to 85 cm. In TECG, four listening points were established, each consisting of a quadrant of 10 m, approximately 50 m from each other, with transect totaling 230 m (Figure 1b).

The abundance of species was estimated by acoustic records with the index adopted by the North American Amphibian Monitoring Program NAAMP (Royle 2004): (0) no individual vocalizing; (1) vocalizations sparse, without overlapping, and number of individuals estimated between 1 and 10; (2) vocalizations overlap, but it is still possible to individualize them and to estimate the number of individuals (11 - 35 individuals); and (3) formation of chorus in which the individual vocalizations are indistinguishable and the number of individuals cannot be determined (> 35) (Crouch & Paton 2002). Moreover total abundance was considered equal to that of the month with the highest abundance (Bertoluci & Rodrigues 2002, Vasconcelos & Rossa-Feres 2005).

In relation to seasonality, species were classified into three groups according to their reproductive pattern (vocalization activity) (*sensu* Wells 1977): (I) species that showed a prolonged reproductive period, with vocalization activity for more than five months; (II) species that displayed an intermediate reproductive period, with vocalization activity lasting three to four months; and (III) species with an explosive reproductive pattern, showing vocalization activity for some nights to two months.

The microhabitats and substrates utilized for the vocalizations were classified as: vegetation, on the ground, water, rocks and leaflitter. The reproductive modes were determined on the basis of the observation of the type of oviposition and amplexus, and classified according to Haddad & Prado (2005). For those species

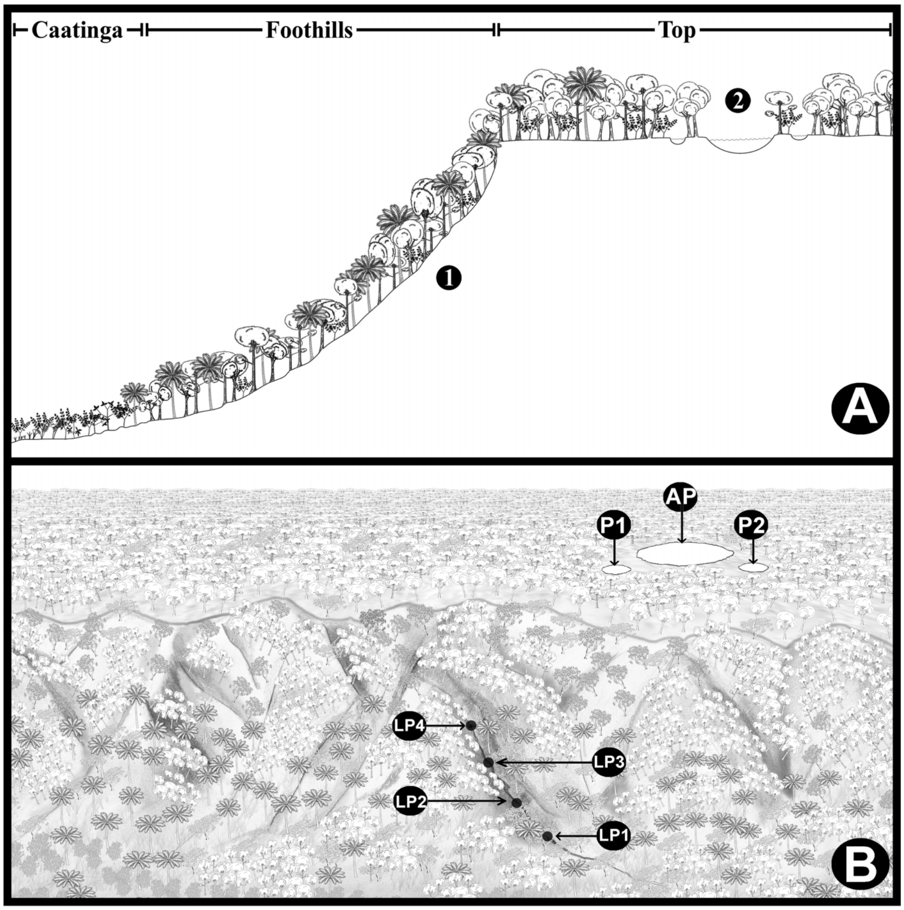

Figure 1. Schematic representation, observation without scale, of areas sampled in the Chapada do Araripe, Ceará. 1A) Representation of the two study areas: 1 – Foothills – Trilha Ecológica do Clube Grangeiro (TECG), 2 – Top – Fazenda Malhada Bonita (FMB); 1B) Representation of the collection points: LP – Listening points in TECG, AP – Artificial Pond, P1 and P2 – Temporary ponds in FMB.

whose reproductive modes could not be determined by field observations, it was used literature data. Monthly rainfall was obtained at FUNCEME (2012) and the temperature and humidity were obtained periodically during the collection of data through a digital termohygrometer.

Voucher specimens were collected manually, euthanized with 2% lidocaine solution, fixed in 10% formalin and later preserved in 70% ethanol (Auricchio & Salomão 2002). They are deposited in Coleção Herpetológica da Universidade Regional do Cariri - URCA-H (Appendix 1).

The relationship between the abundance of individuals vocalizing in the sampled months and the abiotic variables (temperature, humidity and rainfall) was tested with the Generalized Least Squares (GLS) test using the program Gretl (version 1.9.92). To compare the similarity of the Chapada do Araripe species composition with that of other "brejos-de-altitude" a cluster analysis was performed with 1.26 PAST software (Hammer et al. 2001), using a matrix of presence/absence of species per area and the Jaccard similarity index. To complement the matrix about the studied region, data on "Cerradão" and "humid forest" areas of Chapada do Araripe (CAR), present in Ribeiro et al. (2015), were added. For this analysis the following locations were used: RESEC Serra Negra (SNE), Brejo dos Cavalos (BCA), Triunfo (TRI), Fazenda Buriti (FBU), PARNA Catimbau (CAT), Planalto da Ibiapaba (PIB), Serrado Baturité (SBA), and Serra da Aratanha (SAR).

Results

1. *Richness*

Anurans of 14 species distributed in five families were found (Table 1). Hylidae presented the highest richness (six species, 42.86%), followed by Leptodactylidae (five species, 35.71%) and Bufonidae, Odontophrynidae and Pipidae, each one with one species (7.14%) Thirteen species were observed at TECG, while eleven species were recorded at FMB. Ten species were common to both environments whereas *Pipa carvalhoi* was only found in the FMB and *Corythomantis greeningi*, *Hypsiboas raniceps* and *Leptodactylus vastus* were found only in TECG.

The anurofauna of the Chapada do Araripe showed a higher similarity with the one from Planalto da Ibiapaba (0.59) and the "Brejos-de-altitude" of Ceará state formed a cluster distinct from the one formed by the "Brejos-de-Altitude" of Pernambuco. The coefficient of cophenetic correlation for the cluster analysis was 0.95 (Figure 2).

2. *Spatial distribution*

In FMB, nine species were registered in calling activity, four with terrestrial habits (*Adenomera* sp., *L. troglodytes, P. cuvieri,* and *R. jimi*), four with arboreal habits (*D. minutus, D. soaresi,* and *P. nordestina, S. x-signatus*) and one with aquatic habits

Table 1. Anuran species recorded in foothill (Trilha Ecológica do Clube Grangeiro – TECG) and top (Fazenda Malhada Bonita – FMB) of the Chapada do Araripe, Ceará state, from September 2011 to September 2012, with the relative abundance of the families. Reproductive modes sensu Haddad & Prado (2005). – = Reproductive mode no determined. Source of reproductive modes: * = this study, a = Arzabe 1999, b = Provete et al. 2011.

Relative abundance/ Families (%)	Species	TECG	FMB	Reproductive mode	Source
Bufonidae (7.14)	*Rhinella jimi* (Stevaux, 2002)	x	x	1	*
Hylidae (42.86)	*Corythomantis greeningi* Boulenger, 1896	x		1	*
	Dendropsophus minutus (Peters, 1872)	x	x	1	*
	Dendropsophus soaresi (Caramaschi & Jim, 1983)	x	x	1	*
	Hypsiboas raniceps (Cope, 1862)	x		1	a
	Phyllomedusa nordestina Caramaschi, 2006	x	x	24	*
	Scinax x-signatus (Spix, 1824)	x	x	1	*
Leptodactylidae (35.71)	*Adenomera* sp.	x	x	–	–
	Physalaemus cuvieri Fitzinger, 1826	x	x	11	*
	Leptodactylus mystaceus (Spix, 1824)	x	x	13	b
	Leptodactylus troglodytes A. Lutz, 1926	x	x	30	*
	Leptodactylus vastus A. Lutz, 1930	x		11	*
Odontophrynidae (7.14)	*Proceratophrys aridus* Cruz, Nunes & Juncá, 2012	x	x	1	*
Pipidae (7.14)	*Pipa carvalhoi* (Miranda-Ribeiro, 1937)		x	15	*

(*P. carvalhoi*). The microhabitats used as vocalization sites were: a) leaf litter, under dead leaves generally in the forest at a distance over 15 m from streams for *Adenomera* sp.; b) subterranean holes by *L. troglodytes*; c) ground, generally associated with grass, by *S. x-signatus;* d) edges of water bodies, by *P. cuvieri* and also *D. minutus* (depth <1 cm); e) water, with the members underwater by *R. jimi* (depth 23 to 80 cm); f) marginal vegetation, perched at a height varying from 2 cm to 2.04 m from the ground with a distance of approximately 5 m from the water edges, utilized by arboreal species (height from the ground: *D. minutus* 30 cm to 2.04 m, *D. soaresi* 40 cm to 1.5 m, *P. nordestina* 10 cm to 1.93 m); and g) water with depth <1 m used by *P. carvalhoi* (Figure 3).

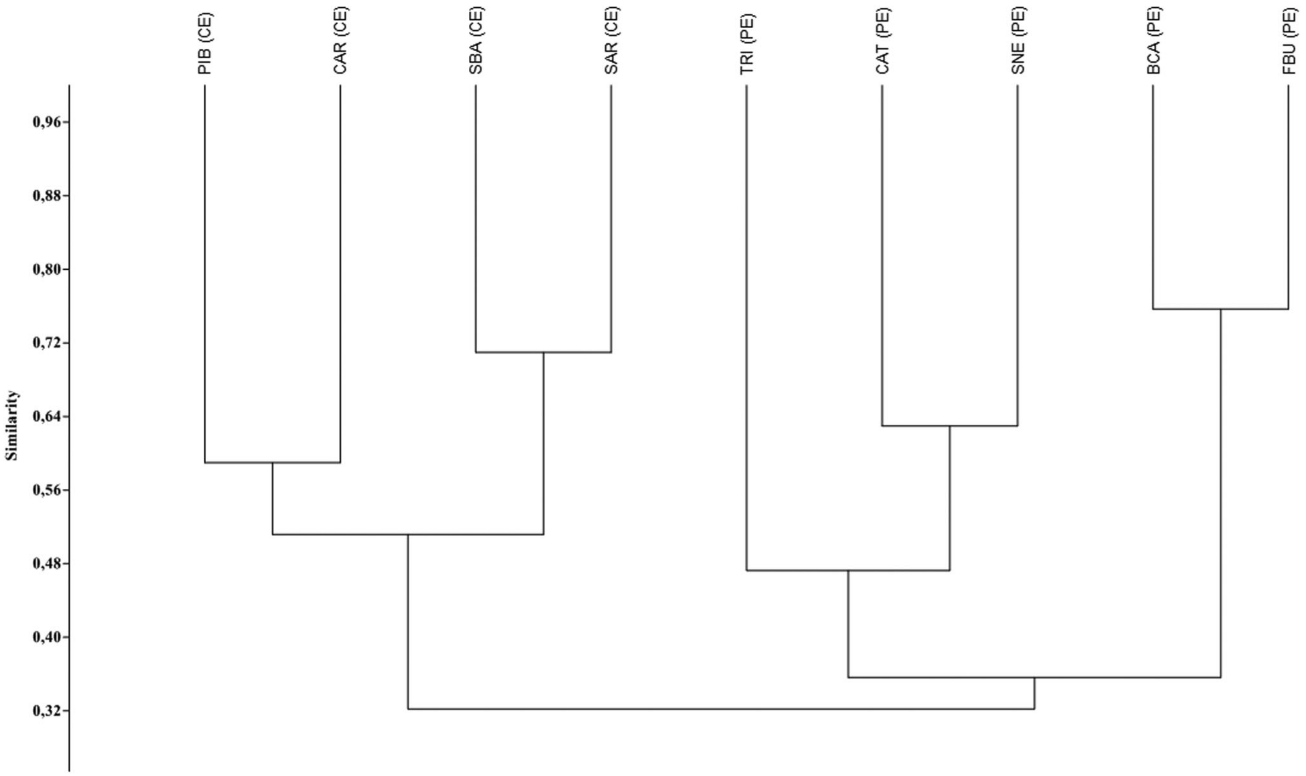

Figure 2. Dendrogram of similarity in anuran composition between the Chapada do Araripe with areas of "Brejos-de-altitude", based on the Jaccard index. Chapada do Araripe = CAR, RESEC Serra Negra = SNE, Brejo dos Cavalos = BCA, Triunfo = TRI, Fazenda Buriti = FBU, PARNA Catimbau = CAT, Planalto da Ibiapaba = PIB, Serra de Baturité = SBA, and Serra da Aratanha = SAR.

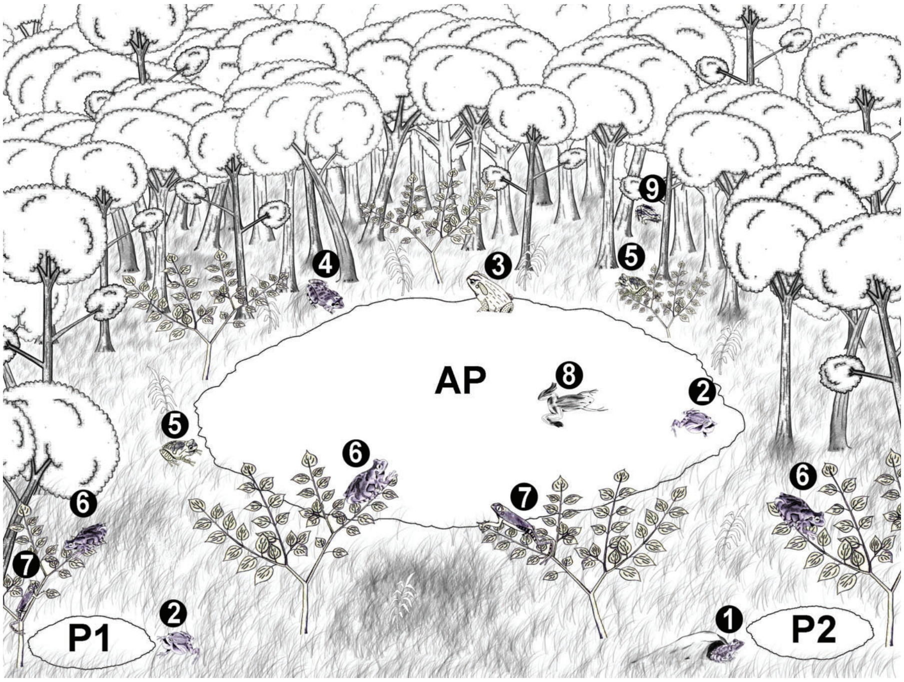

Figure 3. Schematic representation (without scale) of anuran spatial distribution at Fazenda Malhada Bonita, Chapada do Araripe: 1) *Leptodactylus troglodytes*; 2) *Physalaemus cuvieri*; 3) *Rhinella jimi*; 4) *Scinax x-signatus*; 5) *Dendropsophus minutus*; 6) *Dendropsophus soaresi*; 7) *Phyllomedusa nordestina*; 8) *Pipa carvalhoi*; 9) *Adenomera* sp.; AP = Artificial Pond; P1, P2 = Temporary ponds.

In TECG, five species were registered in calling activity (*Adenomera* sp., *L. vastus, P.aridus,* and *P. cuvieri* of terrestrial habits and the arboreal species *C. greeningi*). The substrates utilized by these were the following: a) ground, with a distance of 30 cm from streams, by *P. aridus*; b) leaflitter, under dead leaves generally in the forest at a distance over 15 m from streams by *Adenomera* sp.; c) rocks, inside cracks, for *C. greeningi*; d) and water margins of small running streams utilized by *P. cuvieri* and *L. vastus* (Figure 4).

Six reproductive modes were recorded, according to field observations and literature data (Table 1): Mode 1, with egg laying

Figure 4. Schematic representation (without scale) of anuran spatial distribution at Trilha Ecológica do Clube Grangeiro, Chapada do Araripe: 1) *Proceratophrys aridus*; 2) *Corytomantis greeningi*; 3) *Adenomera* sp.; 4) *Physalaemus cuvieri;* 5) *Leptodactylus vastus*.

and development of tadpoles in lentic water, was the most common, occurring in seven species of the families Bufonidae, Odontophrynidae and Hylidae; Mode 11, where there is the construction of foam nests on the water surface and the development of the tadpoles in lentic water, was the second most representative with two Leptodactylidae species; Mode 13, foam nest floating on water accumulated in constructed basins, exotrophic tadpoles in ponds (one Leptodactylidae species); Mode 15, with eggs deposited in depressions on the dorsum of the female with indirect development in the water, (one Pipidae species); Mode 24, with egg laying on the vegetation above the water and aquatic larval development (one Hylidae species); Mode 30, with spawning in foam nests in subterranean chambers, (one Leptodactylidae species).

The terrestrial species exhibited four reproductive modes (modes 1, 11, 13 and 30), the arboreal species two (1 and 24) and the aquatic species one (mode 15). For *Adenomera* sp. no oviposition, amplexus, tadpoles or recently metamorphosed juveniles were observed. The reproductive modes of *H. raniceps* and *L. mystaceus* were identified from the literature.

3. *Temporal distribution*

Nine species were observed in calling activity in FMB (Adenomera sp., D. minutus, D. soaresi, L. troglodytes, P. carvalhoi, P. cuvieri, P. nordestina R. jimi and S. x-signatus), while, five species vocalized in TECG (Adenomera sp., C. greeningi, L. vastus, P. aridus, P. cuvieri). Two species (H. raniceps and L. mystaceus) vocalized outside the sampled water bodies and thus their reproductive period was not determined. Pipa carvalhoi presents aquatic vocalization activity (Weygoldt 1976), which prevents the determination of its reproductive period.

The majority of the species showed vocalization activity during the most humid and warm months of the year (October to March; Table 2). However, *R. jimi* was found in vocalization activity during the driest months. Males of *S. x-signatus* vocalized for ten months in the dry as well as in rainy season, and *P. nordestina* and *D. minutus* showed a period of vocalization that started at the end of the dry season and continued throughout the rainy season.

The abundance of vocalizing anurans was greater in FMB than in TECG. In TECG, there was a maximum of three species per night of observation, with an estimated number of individuals between 1 and 10. Meanwhile in FMB, there was up to seven species per night of observation in March, and great abundance, specially of *D. soaresi*, *P. nordestina, P. cuvieri* and *S. x-signatus,* with more than 35 calling individuals during some nights.

Despite the greater number of species vocalizing from October to March in TECG, corresponding to rainy season, there was no correlation between the abundance of individuals vocalizing and the abiotic variables. At FMB, on the other hand, the monthly abundance of individuals vocalizing was influenced only by rainfall (Table 3).

In the studied areas, many species vocalized at the same time (Table 4), and it was possible to identify two temporal vocalization patterns: (a) dusk until midnight (*C. greeningi, P. aridus, Adenomera* sp., *L. troglodytes*); (b) dusk until dawn (*D. minutus, D. soaresi, P. nordestina, P. cuvieri, R. jimi,* and *S. x-signatus*).

Discussion

1. *Richness*

In the past few years, the number of studies focusing anuran species composition in the Caatinga domain has increased (Rodrigues 2003, Albuquerque 2012). Even so, there is still a need for information about natural history and ecology, scant for the majority of Neotropical species, especially in Caatinga (Borges-Nojosa & Caramaschi 2003).

The richness of anurans in the southern region of Ceará state is well inventoried. Ribeiro et al (2012) pointed 31 species of anurans for the Bioregion of Araripe, which includes the Chapada do

Table 2. Anuran calling patterns, categories of seasonal distribution (I = Extended, II = Intermediate, III = Explosive), Trilha Ecológica do Clube Grangeiro (TECG) from September 2011 to August 2012 and top Fazenda Malhada Bonita (FMB) from October 2011 to September 2012, at Chapada do Araripe, Ceará.

Locality	Species	S	O	N	D	J	F	M	A	M	J	J	A	S	Category
FMB	*Rhinella jimi*										■			■	III
	Dendropsophus minutus		■	■	■	■	■	■	■						I
	Dendropsophus soaresi					■		■							III
	Phyllomedusa nordestina		■	■	■	■	■	■	■						I
	Scinax x-signatus		■	■	■	■	■	■	■	■		■		■	I
	Adenomera sp.				■	■		■							II
	Physalaemus cuvieri			■				■							III
	Leptodactylus troglodytes		■				■	■							II
Temperature (°C)			23.2	23.5	22.4	20.1	22.5	22.1	20.7	23.6	19.1	18.4	19.5	24.8	
Humidity (%)			63.4	62.2	64.1	80.9	64	73.1	58.8	65.6	87.7	60.3	46	36.8	
TECG	*Corythomantis greeningi*					■									III
	Adenomera				■	■		■							II
	Physalaemus cuvieri					■	■	■							II
	Leptodactylus vastus				■										III
	Proceratophrys aridus		■		■										III
Temperature (°C)		27	23	24.8	24.6	24.2	23.1	23.8	23.5	24.6	25.2	24.1	22.6		
Humidity (%)		62.1	62	63.5	54	69.7	70	69	59	64.8	61.2	61.5	49		
Rainfall (mm)		0	195	83	121	77	188	269	119	44	15	0	0	0	

http://dx.doi.org/10.1590/1676-0611-BN-2014-0166

Table 3. Correlation of the abundance of anurans of two locations (TECG and FMB) in Chapada do Araripe with abiotic data.

Localities	R^2_{GLS}	AICc	p	Rainfall		Temperature		Humidity	
				Std. Error	p	Std. Error	p	Std. Error	p
TECG	-0.09	60.54	0.04	0.009	0.09	0.44	0.43	0.14	0.60
FMB	0.27	135.69	0.23	0.25	0.05	4.27	0.29	0.56	0.89

Araripe and regions of adjacent Caatinga. This same author and collaborators (Ribeiro et al. 2015), in a recent study recorded 25 species of anurans only for the Chapada do Araripe.

The composition of the Chapada do Araripe anuran community was similar to that of the Planalto da Ibiapaba, both being “brejos” that receive strong influence of xeric environments (Loebmann & Haddad 2010). This influence is related to historical processes of forest decline occurred in the Quaternary, which promoted the existence of these islands of rainforest surrounded by the xeric Caatinga vegetation (Ribeiro et al. 2015).

The clustering of the “brejos-de-altitude” of Ceará, in a group apart from those of Pernambuco, suggests that, as stated by Santos et al. (2007) based on analysis of floral composition the “brejos-de-altitude” did not comprise a single biogeographical entity. It is possible that the “brejos-de-altitude” of Ceará form a particular center of endemism (I. J. Roberto, unpublished data).

2. *Spatial distribution*

The coexistence of several anuran species is possible due to the exploitation of microhabitats with distinct characteristics (Cardoso et al. 1989, Pombal Jr. 1997, Vasconcelos & Rossa-Feres 2005, Kopp & Eterovick 2006, Maffei & Jim 2011), where the occupation of different sites of reproduction by synchronopatric species of anurans can function as a mechanism of isolation (Andrade 1994, Ávila & Ferreira 2004, Vieira et al. 2007). However, other factors may have an influence in species segregation, such as differentiation in advertisement calls (Pombal Jr. 1997), morphological and behavioral features (Crump 1974, Toft 1985), historical factors (Eterovick & Fernandes 2001), seasonality, habitat and predation (Eterovick & Sazima 2000) and stochastic processes (Bonner et al. 1997).

The number of microhabitats used was greater in FMB than in TECG, and the majority of species utilized terrestrial microhabitats as vocalization sites. It was also observed the vertical stratification of the hylids, which utilized the same substrate (vegetation) at different heights (Prado & Pombal Jr. 2005). *Dendropsophus soaresi, P. nordestina, L. troglodytes* and *P. cuvieri* utilized the artificial lake as well as the temporary ponds for call and oviposition, indicating their plasticity with respect to the type of habitat utilized in reproduction. *Scinax x-signatus* and *P. nordestina* were the most abundant species in FMB, and are considered common species to the Caatinga.

A higher diversity of reproductive modes can be found in environments with complex vegetation structure, which provides moist microhabitats necessary to reproduction (Xavier & Napoli 2011). In the present study, we found few reproductive modes at the two sites, being species with the mode 15 exclusively found at FMB. The majority of the species observed laid their eggs directly in the water, one of the more primitive strategies utilized by anurans. Arzabe (1999) when studied the anurans in Maturéia, a high altitude region, found similar results about the reproductive modes, with greater number of species utilizing mode 1.

Some species presented reproductive modes where the eggs are deposited in foam nests. The maintenance of eggs or larvae in development inside foam nests increases their protection against predators and desiccation (Heyer 1969). Nests in subterranean chambers usually constructed by males, can be a refuge also for adults, besides serving as a place for oviposition (Arzabe & Almeida 1997, Arzabe & Prado 2006).

3. *Temporal distribution*

Reproduction in anurans is commonly limited to certain periods of the year, and this reproductive seasonality is mainly conditioned by rain precipitation and temperature (Cardoso & Martins 1987). The Caatinga is an environment with high temperatures, low relative humidity levels, low cloudiness and mainly low and irregular rainfall, limited in most of the area to

Table 4. Turn of vocalization (17:00 to 06:00) of anuran species at Chapada do Araripe, from September 2011 to September 2012. NAAMP: 0 (no individual vocalizing); 1 (1 – 10 individuals vocalizing); 2 (11 – 35 individuals vocalizing); 3 (> 35 individuals vocalizing).

Species	17:00 18:00	18:01 19:00	19:01 20:00	20:01 21:00	21:01 22:00	22:01 23:00	23:01 00:00	00:01 01:00	01:01 02:00	02:01 03:00	03:01 04:00	04:01 05:00	05:01 06:00
R. jimi	1	1	1	1	1	1	1	1					
C. greeningi		1	1	1									
D. minutus	1	1	1	1	1	1	1	1					
D. soaresi	1	3	3	3	3	3	3	3	3	3	3	2	1
P. nordestina	1	3	3	3	3	3	3	3	3	2	2	2	1
S. x-signatus	1	2	2	3	3	3	3	3	3	3	2	1	1
Adenomera sp.	1	1	1	1									
P. cuvieri	1	3	3	3	3	3	3	3	3	3	3	2	1
L. troglodytes		1	1	1	1								
L. vastus		1	1	1									
P. aridus		1	1	1	1								

a very short period of the year (Reis 1976). Accordingly, the majority of species reproduce in restricted periods of the year (Arzabe 1999, Vieira et al. 2007), since the larvae need an aquatic environment to develop.

In FMB, there was greater abundance of vocalizing anurans compared with TECG, possibly due to the presence of lentic water bodies, such as the artificial reservoir and temporary ponds, which shows greater stability, thereby providing higher richness of species and greater abundance of individuals (Vasconcelos & Rossa-Feres 2005). On the other hand, in TECG the presence of lotic water body, forming streams, are subject to abrupt changes in water regime in the rainy period, which can represent risk to the integrity of egg clutches and tadpoles that can be carried away by strong flows to places not suitable to their development (Grandinetti & Jacobi 2005).

In TECG, anuran reproductive activity was recorded only during the rainy season, because in this period there is the formation of small flooded areas where the anurans can deposit their eggs. However, March, the month with the greatest volume of rainfall (269 mm), did not presented the highest number of species vocalizing. According to Moreira & Barreto (1997), climatic effects on anurans are known in various populations, where annual variations in precipitation generally affect the hydroperiod of the ponds, influencing the number of individuals that reproduce there.

The species *C. greeningi, P. aridus, Adenomera* sp. and *L. troglodytes* displayed relatively short periods of diel calling activity, which end up to 22:00 h, probably due to the small number of males vocalizing, because according to Cardoso & Haddad (1992) the greater the number of active individuals the greater would be the shift time. Although some species had demonstrated vocalization throughout the night, all species showed a vocalization peak in the first half of the night (earlier in the cold months and later in the warm months). This pattern, which appears to be common, remains without adequate explanation (Cardoso & Martins 1987). Perhaps this pattern occurs because females approach reproduction sites in the beginning of the night, since they would have more time for spawning in them, avoiding predation by visually oriented animals (Pombal Jr. 1997). Another factor that can have an influence is temperature, which is higher in the first half of the night, thereby being more suitable for vocalization, while in the second half of the night, the temperature decreases, which can limit the activity of the anurans (Cardoso & Martins 1987, Cardoso & Haddad 1992, Pombal Jr. 1997).

The composition of anurans of Chapada do Araripe showed greater similarity to the Planalto da Ibiapaba and the number of reproductive modes was similar to the study conducted in the municipality of Maturéia (a high altitude area). The majority of species vocalized on the ground and the reproductive period was relatively short, coinciding with the rainy period.

Acknowledgments

We are grateful to IBAMA for logistical support, Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) for collecting permits (number 31162-1), the Conselho Nacional de Desenvolvimento Científico (CNPq) for the scholarship granted for Scientific Initiation to D.B.O and C.F.S. (process: 146839/2001-0), for a research grant to RWA (process # 303622/2015-6) and financial support (process 475107/2011-0). Fundação Cearense de Apoio ao Desenvolvimento Científico e Tecnológico (FUNCAP) for awarding a research grant to RWA (BPI-0067-00006.01.00/12), and master fellowship to Deivid B. Oliveira. Coordenação de aperfeiçoamento de Pessoal de Nível Superior (CAPES) for a master fellowship to Cristiana Ferreira-Silva. To Universidade Regional do Cariri for logistical support and to the staff of the Laboratório de Herpetologia for field assistance. Dr. A. Leyva helped with English editing of the manuscript.

Appendix 1

Voucher specimens of amphibians collected at FMB in municipality of Barbalha and TECG in Municipality of Crato, Ceará

Adenomera sp. (URCA 1130), *Corythomantis greeningi* (URCA 267), *Dendropsophus minutus* (URCA 031), *Dendropsophus soaresi* (URCA 1054), *Hypsiboas raniceps* (URCA 030), *Leptodactylus mystaceus* (URCA 1133), *Leptodactylus troglodytes* (URCA 093), *Leptodactylus vastus* (URCA 1431), *Pipa carvalhoi* (URCA 1437), *Phyllomedusa nordestina* (URCA 089), *Physalaemus cuvieri* (URCA 266), *Proceratophrys aridus* (URCA 083), *Rhinella jimi* (URCA 268), *Scinax x-signatus* (URCA 090).

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Received 18/07/2014
Revised 9/10/2015
Accepted 16/10/2015

Biota Neotropica 16(1): e20140130, 2016
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
article

Leguminosae in an altitudinal gradient in the Atlantic Forest of Serra do Mar State Park, São Paulo, Brazil

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SILVA, E.D., TOZZI, A.M.G.A., MEIRELES, L.D. **Leguminosae in an altitudinal gradient in the Atlantic Forest of Serra do Mar State Park, São Paulo, Brazil.** Biota Neotropica. 16(1): e20140130. http://dx.doi.org/10.1590/1676-0611-BN-2014-0130

Abstract: Studies on floristic and structural variations of forests in relation to altitude have contributed to the knowledge of patterns and causes of spatial distribution of plants in the Atlantic Forest. Geographical variables such as latitude, longitude and altitude result in different vegetation types, which limits newly established are not consensus. In the north coast of São Paulo state altitudes vary from the Restinga Forest, near the sea level, to the vegetation at the top of Cuscuzeiro Mountain at 1,279 m altitude. In order to evaluate the richness, taxonomic diversity, floristic similarity and the potential indicator of Leguminosae in the characterization of different vegetation types of Atlantic Forest on the northern coast of São Paulo, a matrix with the presence and absence of 142 species, in 15 different altitudinal belts was built. The greatest species richness was observed in the Restinga Forest (0-10 m), with 84 species, and in Montane Forest (500-1,200 m), with 69 species. The altitudinal belt with the highest number of tree species was 10-50 m, with 34 species. In the higher altitudes that number was significantly lower with six species of 1,100-1,200 m, and no species above this quota. The cluster analysis (Jaccard index) showed dissimilarity of the belts 0-10 m and 1,100-1,200 m in relation to the intermediate belts. The Lowland Forest and Submontane share the largest number of species (25). Some species characterize certain formations or have their preferred environment located at a specific elevation, as is the case of *Abarema brachystachya* and *Inga subnuda* (0-20 m), *Inga lanceifolia*, *Inga mendoncaei* and *Ormosia minor* (800-1,200 m). Distinguished for occupying all the phytophysiognomies: *Abarema langsdorffii* and *Senna macranthera*. Leguminosae, although well adapted to the first colonization and exploration of diverse environment, was poorly represented above 1,100 m altitude.

Keywords: *Ombrophilous Dense Forest, Fabaceae, phytophysiognomies, vegetation types.*

SILVA, E.D., TOZZI, A.M.G.A., MEIRELES, L.D. **Leguminosae em um gradiente altitudinal na Floresta Atlântica do Parque Estadual da Serra do Mar, São Paulo, Brasil.** Biota Neotropica. 16(1): e20140130. http://dx.doi.org/10.1590/1676-0611-BN-2014-0130

Resumo: Estudos sobre variações florísticas e estruturais da floresta em relação à altitude têm contribuído para o conhecimento dos padrões e causas da distribuição espacial de plantas na Floresta Atlântica. Variáveis geográficas como latitude, longitude e altitude resultam em diferentes fitofisionomias, cujos limites recentemente estabelecidos não são um consenso. No litoral norte do estado de São Paulo as altitudes variam desde a Floresta de Restinga, próximo ao nível do mar, até a vegetação do topo do morro do Cuscuzeiro a 1.279 m de altitude. Para avaliar a riqueza, a diversidade taxonômica, similaridade florística e o potencial indicador de Leguminosae na caracterização das diferentes fitofisionomias da Floresta Ombrófila Densa no litoral norte de São Paulo foi construída uma matriz com a presença e ausência de 142 espécies em 15 diferentes faixas altitudinais. A maior riqueza de espécies foi observada na Floresta de Restinga (0-10 m), com 84 espécies, e na Floresta Montana (500-1.200 m), com 69 espécies. A faixa altitudinal com maior número de espécies arbóreas foi a de 10-50 m, com 34 espécies. Nas maiores altitudes esse número foi expressivamente menor, seis espécies de 1.100-1.200 m e nenhuma acima dessa cota. A análise de agrupamento (índice de Jaccard) revelou dissimilaridade das faixas 0-10 m e 1.100-1.200 m em relação às faixas intermediárias. A Floresta de Terras baixas e a Submontana compartilham o maior número de espécies (25). Algumas espécies caracterizam certas formações ou têm o seu ambiente preferencial localizado em uma altitude específica, como é o caso de *Abarema brachystachya* e *Inga subnuda* (0-20 m), *Inga lanceifolia*, *Inga mendoncaei* e *Ormosia minor* (800-1.200 m). Destacam-se por ocupar todas as fitofisionomias: *Abarema langsdorffii* e

Senna macranthera. Leguminosae, embora bem adaptada à primeira colonização e exploração de diversos ambientes, está pobremente representada acima de 1.100 m de altitude.

Palavras-chave: *Floresta Ombrófila Densa, Fabaceae, fitofisionomias, tipos de vegetação.*

Introduction

The Atlantic Forest, the second largest rain forest in South America and one of the world's richest in biodiversity and endemism (Mori et al. 1981, Joly et al. 1999, Myers et al. 2000), is located along the Brazilian coast occupying approximately 16,377,472 ha or 11.7% of its original formation, which was 150 million hectares (Ribeiro et al. 2009). Most continuous remnants of Atlantic Forest are located primarily in the state of São Paulo and Paraná coast in southeastern Brazil. In São Paulo, where there is only 5% of native forests with little anthropic action, the mountainous regions stand out, especially the facade of the Serra do Mar (Kronka et al. 2003). The Serra do Mar is a set of festooned scarps with about 1,000 km stretching from Rio de Janeiro to the north of Santa Catarina, where it ceases to exist as an orographic unit of scaped rim plateau and falls apart in strands of parallel mountain ranges and isolated mountains drained directly into the sea, especially by the basin of Itajaí River (Almeida & Carneiro, 1998).The flora of the Atlantic Forest have been inventoried and patterns of richness and diversity described and interpreted, especially at the level of communities. Distribution patterns of the most representative families, however, have been little explored.

The Leguminosae (or Fabaceae) is the second largest family of eudicotyledons and is comprised of approximately 727 genera and 19,327 species (Lewis et al. 2005). It presents a wide geographical distribution and is characterized by high species richness in various vegetation types in different regions of the world, from peaks of high mountains to the sandy coastline, tropical rainforest to deserts. There are even aquatic species (Lewis 1987). In Brazil about 212 genera and 2,722 species (Lima et al. 2012) were cataloged, which occurrence is very significant in most vegetation types, especially the Atlantic Forest, where the family has high representation among the elements of the tree layer (Lima 2000). Recent estimates of Lima et al. (2009) lists 945 species of Leguminosae for the Atlantic Forest, and 391 would be unique to that phytogeographic domain.

Floristic inventories and phytosociological studies conducted in various regions of the Atlantic Forest from Bahia to Paraná (Mantovani 1991, Marques et al. 1997, Silva 1998, Assis 1999, Tabarelli & Mantovani 1999, Oliveira Filho & Fontes 2000, Pereira & Assis 2000, Scudeller et al. 2001, Lacerda 2001, Borém & Oliveira-Filho 2002, Mamede et al. 2004, Peixoto et al. 2005, Schmidlin 2005, Amorim et al. 2009, Meireles 2009, Assis et al. 2011) are already providing evidence of the importance of the Leguminosae family in the composition and structure of this forest. For the Atlantic Forest of São Paulo, however, where there is an expressive representativity of the family, floristic surveys in different remaining areas are scarce, especially surveys on the Caesalpinioideae and Mimosoideae subfamilies.

Analysis of plant diversity in tropical forest altitudinal gradients (Richards 1996, Gentry 1988, Kitayama 1992, Vasquez & Givnish 1998) suggest that the main trend observed with increasing altitude is the decrease in number of species, mostly trees. Rich families in trees as Leguminosae, Sapotaceae, Myristicaceae, Meliaceae, Sapindaceae, Burseraceae and Chrysobalanaceae are poorly represented in neotropical montane forests (Gentry 1988). Factors such as altitude and topography create different microsites, causing heterogeneous distribution of species and structural differences in communities (Whitmore 1984). In most studies in gradients this heterogeneity is associated with precipitation levels, soil physicochemical characteristics, differences in temperature, changes in air humidity, wind speed, fog and luminosity.

Research on floristic and structural changes in arboreal vegetation in relation to elevation performed in the Atlantic Forest (Rodrigues & Shepherd 1992, Roderjan 1994, Lacerda 2001, Custódio Filho 2002, Blum & Roderjan 2007, Bertoncello 2009) have contributed to the knowledge of patterns and causes of spatial variability of plants in Brazilian forests. However, there is not sufficient information on how the main families of angiosperms are distributed in relation to altitude.

Studies conducted in altitudinal gradients in Serra do Mar (Roderjan 1994, Lacerda 2001, Custódio Filho 2002, Bertoncello 2009) have shown that species richness decreases at higher altitudes, however, due to the small number of studies and differences among methods of analysis and sampling area, these issues are not fully understood yet.

The main objectives of this study were to investigate: which altitudinal zones present higher riches for the species of Leguminosae; if the genera, tribes or subfamilies of Leguminosae are equally distributed along the gradient or if there is an evident differentiation within these groups; what is the altitudinal amplitude of each species along the found phytophysiognomies; if there are species that could be indicators of local vegetation formations in this part of Serra do Mar; if substitution of species occurs along the gradient; what are the altitudinal zones with higher floristic similarity within the studied range.

Material and methods

The study area is located in the northeastern region of São Paulo state, in Picinguaba and Santa Virgínia Nucleus, Serra do Mar State Park (Figure 1). The Picinguaba Nucleus is located in Ubatuba and Santa Virgínia Nucleus covers the municipalities of São Luis do Paraitinga (70%), Cunha (20%) and Ubatuba (10%).

In the Picinguaba Nucleus three areas of study were utilized. The first is located near the headquarters of the Nucleus, in the single portion of the Serra do Mar State Park that reaches the coastline, where we can find the Restinga Forest. Restinga, considering here the botanical (Rizzini 1997, Assis et al. 2004) and geomorphological (Suguio & Tessler 1984) concepts, is a vegetation complex with strong marine influence which develops in Quaternary sandy sediments resulting from variations in sea level that occurred during the Holocene. The second, is located to the west of the headquarter of the Nucleus where the Ombrophilous Dense Forest prevails (according to Veloso et al. 1991, recently updated et IBGE 2012). The third is located near the central-south headquarter in the city of Ubatuba where the Ombrophilous Dense Forest

http://dx.doi.org/10.1590/1676-0611-BN-2014-0130

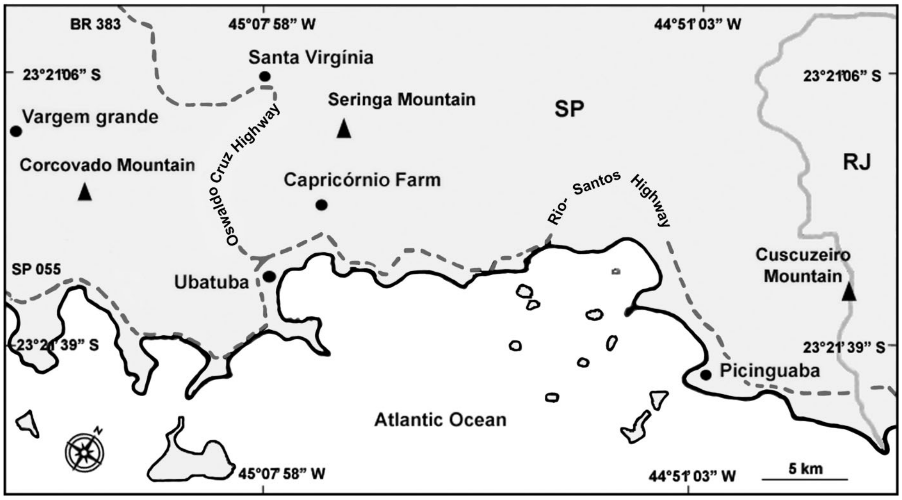

Figure 1. Location of the study area in Picinguaba and Santa Virgínia Nucleus, Serra do Mar State Park. (adapted from MMA/IBGE 2004, SOS Mata Atlântica/INPE 2010, MMA 2012).

also occurs. The climate in Picinguaba is tropical humid (Setzer 1966), with no dry season, with average annual precipitation exceeding 2,200 mm. The soils, in a study conducted by Lacerda (2001) on the coastal plain up to 1,000 m altitude, showed up acid, poor in nutrients, with high levels of aluminum and organic matter and low fertility.

In the surrounding areas of the Picinguaba Nucleus collections were carried out at altitudes that range from the Restinga Forest, near the sea level up to the vegetation at the top of Cuscuzeiro Mountain at 1,279 m altitude (Figure 1). The areas near the south-central base comprise the ones located at altitudes ranging from 25 m near the Capricórnio Farm to the top of the Seringa Mountain at 1,090 m altitude. In Santa Virgínia Nucleus collections were also carried out in two areas of the Ombrophilous Dense Forest. The first, located near the headquarter of the nucleus at altitudes which vary from 850-1,100 m, and the second near the Vargem Grande headquarter from 819 m altitude up to the vegetation at the top of Corcovado Mountain at 1,168 m altitude. Collections along highway Oswaldo Cruz, which connects the city of Ubatuba to the head office in Santa Virgínia Nucleus at the top of Serra do Mar were also carried out. The weather in the region of Santa Virgínia is tropical temperate (Setzer 1966) with no dry season, with average annual precipitation greater than 2,000 mm.

The floristic survey involved the collection of shrubs (including vine), trees and lianas. Herbaceous plants were not found. The classification as for the habit followed the model proposed by Whittaker (1975). The trips to the study area were taken monthly between 2006 and 2009 going through trails in different vegetation types. All material collected is incorporated into the collection of the UEC Herbarium. Voucher material was selected and the name and number of the collector, followed by the herbarium acronym, was inserted after the name of the species (Table 1). The terminology used to indicate the native, alien or naturalized species is the one proposed by Pysek et al. (2004). Information concerning the origin of these taxa were obtained in the List of Species of Brazilian Flora (2015). In the same table, codes were inserted concerning the environment in which each species was found in the study area (native forest, anthropized forest or both). The final list was complemented with other botanists collections previously conducted in the study area and deposited in herbaria. The identification of specimens was based on literature consultation and on the comparison of materials deposited in the herbaria in São Paulo state (UEC, SP, SPF, ESA and HRCB, which acquis has the Flórula Picinguaba collection) in herbaria from other states (HB, MBM, R and RB) and foreign herbaria (US and NY).

Distribution data used in the discussion is the result of the collected information on reviews and theses, herbarium material and geographical distribution sites (ILDS Legume Database 2012, Species link 2013 and List of Species of Brazilian Flora 2015). To verify the distribuition of taxa of Leguminosae along a gradient, a matrix of presence and absence of species was elaborated and applied to 15 different belts. The altitudinal amplitude of each belt, just after Lowland, is 100 m and have as its main objective to find out the extent of altitudinal variation of each specie along the phytophysiognomies. The data relating to location and altitude was obtained through the use of GPS. In some cases, when the altitude reading by the GPS was impossible, estimates from known points were made. These phytophysiognomies were adapted from the classification system proposed by Veloso et al. (1991) and adopted by IBGE (Brazilian Institute of Geography and Statistics), recently updated et IBGE 2012, in which the Ombrophilous Dense Forest, in the domain area of the Atlantic Forest, has been subdivided into four zones ordered according to the latitudinal and altimetric variations. The Restinga-Lowland transition, which occurs up to five meters in the IBGE system, was extended to 10 meters in this study as we observed that many known species of Restinga occur beyond five meters.

To study the distribution of species along the altitudinal gradient, cluster analysis and ordination with all tree species were conducted. With a matrix of presence and absence of each specie per altitudinal belts a similarity matrix between altitudinal belts using the Jaccard index was calculated. It was used the hierarchical clustering method - UPGMA to produce a dendrogram with the similarity matrix to verify if the forest formations would form well established groups. To check for substitution of species along the altitudinal belts we carried out a correspondence analysis (CA). An analysis using

Table 1. Species of Leguminosae found in altitudinal gradient (from sea level to 1,279 m altitude) in the Atlantic Forest of the Picinguaba and Santa Virgínia Nucleus. No species were found above 1,200 m altitude. non bold: native species, in bold: alien species, underlined: naturalized species, ☐ native forest, ○ anthropized forest (forest edge, roads or tracks with low to moderate human impact), ◇ both forests.

		Restinga	Lowland	Submontane					Montane							
Species names/collecting data	**Habit**	**0-10 m**	**10-50 m**	**50-100 m**	**100-200 m**	**200-300 m**	**300-400 m**	**400-500 m**	**500-600 m**	**600-700 m**	**700-800 m**	**800-900 m**	**900-1,000 m**	**1,000-1,100 m**	**1,100-1,200 m**	**1,200-1,279 m**
Caesalpinioideae																
Bauhinia forficata Link (Silva 989 UEC) ○	tree		x	x	x	x	x	x	x	x	x	x	x			
Chamaecrista desvauxii (Collad.) Killip (Silva 1109 UEC) ○	shru	x										x	x			
Chamaecrista glandulosa Greene (Silva 1068 UEC) ○	shru	x										x	x			
Chamaecrista nictitans Moench (Silva 744 UEC) ○	shru	x														
Chamaecrista rotundifolia (Pers.) Greene (Silva 818 UEC) ○	shru	x										x	x			
Copaifera langsdorffii Desf. (Silva 1030 UEC) ☐	tree		x	x	x	x	x	x	x	x	x	x	x			
Copaifera trapezifolia Hayne (Silva 883 UEC) ☐	tree		x	x	x	x	x	x	x	x						
Hymenaea courbaril L. (Campos 974 UEC) ☐	tree		x	x	x	x	x									
Phanera angulosa (Vogel) Vaz (Silva 647 UEC) ☐	lian		x	x	x	x	x	x	x	x	x	x	x	x		
Phanera microstachya (Raddi) L.P. Queiroz (Silva 1035 UEC) ☐	lian		x	x	x	x	x	x	x	x						
Poincianella pluviosa DC. (Silva 769 UEC) ○	tree											x	x			
Schizolobium parahyba (Vell.) S.F. Blake (Silva 1028 UEC) ◇	tree	x	x													
Senna macranthera (DC. ex Collad.) H.S. Irwin & Barneby (Silva 709 UEC) ◇	tree		x	x	x	x	x	x	x	x	x	x	x	x		
Senna multijuga (Rich.) H.S. Irwin & Barneby (Silva 712 UEC) ◇	tree	x	x									x	x	x		
Senna pendula (Humb. & Bonpl. ex Willd.) H.S. Irwin & Barneby (Silva 726 UEC) ☐	shru	x														
Senna tropica (Vell.) H.S. Irwin & Barneby (Silva 987 UEC) ☐	shru					x							x			
Tachigali denudata (Vogel) Oliveira-Filho (Silva 850 UEC) ☐	tree	x	x	x	x											
Tachigali friburgensis (Harms) L.F.G.Silva & H.C.Lima (Padgurschi 359 UEC) ☐	tree													x		
Tachigali multijuga Benth. (Silva 655 UEC) ☐	tree		x	x	x											
Mimosoideae																
Abarema brachystachya (DC.) Barneby & J.W. Grimes (Silva 732 UEC) ☐	tree	x														
Abarema langsdorffii (Benth.) Barneby & J.W. Grimes (Silva 990 UEC) ☐	tree					x	x	x	x	x	x	x	x	x		
Albizia pedicellaris (DC.) Kleinh. (Silva 315 UEC) ◇	tree	x														
Anadenanthera colubrina (Vell.) Brenan (Silva 1155 UEC) ◇	tree		x									x	x			
Anadenanthera peregrina (L.) Speg. (Silva 390 UEC) ○	tree		x													
Inga barbata Benth. (Silva 985 UEC) ☐	tree											x	x			
Inga capitata Desv. (Silva 882 UEC) ◇	tree		x	x	x	x	x									
Inga cauliflora Willd. (Prata 450 UEC) ☐	tree		x	x	x											
Inga edulis Mart. (Silva 356 UEC) ◇	tree	x	x	x	x											
Inga flagelliformis (Vell.) Mart. (Silva 604 UEC) ☐	tree		x													
Inga hispida Schott ex Benth. (Silva 1169 UEC) ☐	tree		x	x	x	x	x	x	x	x	x	x	x	x	x	
Inga lanceifolia Benth. (Silva 1170 UEC) ☐	tree											x	x	x	x	
Inga marginata Willd. (Silva 711 UEC) ◇	tree	x	x	x	x	x	x						x	x		
Inga mendoncaei Harms (Silva 951 UEC) ☐	tree								x	x	x	x				
Inga schinifolia Benth. (Silva 877 UEC) ☐	tree				x	x	x	x	x	x	x	x				
Inga sessilis (Vell.) Mart. (Silva 366 UEC) ◇	tree											x	x	x	x	

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http://dx.doi.org/10.1590/1676-0611-BN-2014-0130

Table 1. Continued.

Species names/collecting data	Habit	Restinga	Lowland	Submontane					Montane							
		0-10 m	10-50 m	50-100 m	100-200 m	200-300 m	300-400 m	400-500 m	500-600 m	600-700 m	700-800 m	800-900 m	900-1,000 m	1,000-1,100 m	1,100-1,200 m	1,200-1,279 m
Inga striata Benth. (Silva 967 UEC) ◇	tree		x	x	x	x	x	x								
Inga subnuda Salzm. ex Benth. (Silva 685 UEC) ◇	tree	x														
Inga vera Willd. (Silva 723 UEC) ○	tree	x														
Inga vulpina Mart. ex Benth. (Silva 1178 UEC) ○	tree												x	x		
Mimosa bimucronata (DC.) Kuntze (Silva 311 UEC) ◇	tree	x														
Mimosa debilis Humb. & Bonpl. ex Willd. (Silva 571 UEC) ○	shru	x														
Mimosa diplotricha C. Wright ex Sauvalle (Silva 1111 UEC) ○	shru	x											x			
Mimosa elliptica Benth. (Silva 409 UEC) ○	shru	x														
Mimosa invisa Mart. ex Colla (Silva 1192 UEC) ○	shru	x														
Mimosa pudica L. (Silva 506 UEC) ○	shru	x														
Mimosa quadrivalvis L. (Silva 799 UEC) ○	shru	x														
Mimosa ramosissima Benth. (Silva 392 UEC) ○	shru													x		
Mimosa scabrella Benth. (Silva 364 UEC) ◇	tree											x	x	x		
Mimosa velloziana Mart. (Silva 741 UEC) ○	shru	x														
Mimosa sp1 (Silva 369 (UEC) ○	tree												x			
Piptadenia adiantoides (Spreng.) J. F. Macbr. (Silva 1146 UEC) ○	lian	x	x	x	x							x	x	x		
Piptadenia gonoacantha (Mart.) J.F. Macbr. (Silva 653 UEC) ◇	tree	x	x													
Piptadenia paniculata Benth. (Silva 631 UEC) ◇	tree		x	x	x	x	x	x	x	x	x	x	x	x		
Pseudopiptadenia leptostachya (Benth.) Rauschert (Silva 1158 UEC) □	tree		x	x	x	x	x	x	x	x	x	x	x	x		
Pseudopiptadenia warmingii (Benth.) G.P. Lewis & M.P. Lima (Silva 1138 UEC) □	tree		x	x	x	x	x									
Senegalia grandistipula (Benth.) Seigler & Ebinger (Silva 555 UEC) ◇	shru	x														
Senegalia lacerans (Benth.) Seigler & Ebinger (Silva 629 UEC) ◇	lian										x	x	x	x		
Senegalia martiusiana (Steud.) Seigler & Ebinger (Silva 775 UEC) ◇	lian	x														
Senegalia miersii (Benth.) Seigler & Ebinger (Silva 891 UEC) □	lian		x													
Senegalia paniculata (Willd.) Killip (Silva 1084 UEC) ○	lian	x	x	x	x	x	x									
Senegalia sp1 (Silva 365 UEC) ○	lian											x	x	x		
Papilionoideae																
Aeschynomene brasilianna (Poir.) DC. (Silva 736 UEC) ○	shru	x														
Aeschynomene elegans Schltdl. & Cham. (Silva 399 UEC) ○	shru	x														
Aeschynomene falcata (Poir.) DC., Prodr. (Silva 803 UEC) ○	shru	x														
Aeschynomene paniculata Willd. ex Vog., Linnaea (Silva 739 UEC) ○	shru	x														
Aeschynomene sensitiva Sw (Silva 539 UEC) ○	shru	x														
Andira fraxinifolia Benth. (Silva 667 (UEC) □	tree	x	x													
Andira ormosioides Benth. (Garcia et al. 490 HRCB) □	tree	x	x	x	x	x	x									
Cajanus cajan (L.) Millsp. (Silva 1118 UEC) ○	shru										x					
Calopogonium mucunoides Desv. (Silva 780 UEC) ○	shru	x														
Centrosema arenarium Benth. (Silva 427 UEC) ○	shru	x														
	shru	x														

Continued on next page

Table 1. Continued.

Species names/collecting data	Habit	Restinga	Lowland	Submontane					Montane							
		0-10 m	10-50 m	50-100 m	100-200 m	200-300 m	300-400 m	400-500 m	500-600 m	600-700 m	700-800 m	800-900 m	900-1,000 m	1,000-1,100 m	1,100-1,200 m	1,200-1,279 m
Centrosema virginianum (L.) Benth. (Silva 593 UEC) ○																
Clitoria fairchildiana Howard (Silva 584 UEC) ○	tree	x														
Clitoria falcata Lam. (Silva 672 UEC) ○	shru	x														
Clitoria laurifolia Poir. (Silva 564 UEC) ◇	shru	x														
Crotalaria breviflora DC. (Silva 375 UEC) ○	shru												x	x		
Crotalaria incana L. (Silva 773 UEC) ○	shru	x														
Crotalaria juncea L. (Silva 1148 UEC) ○	shru											x	x			
Crotalaria lanceolata E. Mey. (Silva 1071 UEC) ○	shru												x	x		
Crotalaria micans Link (Silva 610 UEC) ○	shru												x	x		
Crotalaria pallida Aiton (Silva 563 UEC) ○	shru	x														
Crotalaria stipularia Desv. (Silva 473 UEC) ○	shru	x														
Crotalaria velutina Benth. (Silva 1083 UEC) ○	shru	x														
Crotalaria vitellina Ker Gawl. (Silva 312 UEC) ○	shru	x	x	x	x								x			
Crotalaria sp1 (Silva 1069 UEC) ○	shru													x		
Dahlstedtia pinnata (Benth.) Malme (Silva 708 UEC) □	tree	x	x	x	x	x	x	x	x	x	x	x	x	x		
Dalbergia brasiliensis Vogel (Silva 1054 UEC) □	tree												x	x		
Dalbergia ecastaphyllum (L.) Taub. (Silva 596 UEC) □	shru	x														
Dalbergia frutescens (Vell.) Britton (Silva 1110 UEC) ◇	lian	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Dalbergia lateriflora Benth. (Silva 876 UEC) □	lian		x	x	x	x	x	x	x	x	x	x				
Desmodium adscendens (Sw.) DC. (Silva 615 UEC) ○	shru	x										x				
Desmodium affine Schltdl. (Silva 616 UEC) ○	shru											x				
Desmodium axillare (Sw.) DC. (Silva 976 UEC) ○	shru	x														
Desmodium barbatum (L.) Benth. & Oerst. (Silva 543 UEC) ○	shru	x														
Desmodium incanum DC., Prodr. (Silva 415 UEC) ○	shru	x														
Desmodium leiocarpum (Spreng.) G. Don (Silva 340 UEC) ○	shru	x														
Desmodium uncinatum (Jacq.) DC. (Silva 719 UEC) ○	shru												x			
Dioclea grandistipula L.P. Queiroz (Silva 1166 UEC) □	lian						x	x	x	x	x					
Dioclea rufescens Benth.(Silva 1117 UEC) ◇	lian	x											x			
Dioclea wilsonii Standl. (Silva 382 UEC) ◇	lian	x														
Erythrina speciosa Andrews (Silva 318 UEC) ◇	tree	x														
Galactia latisiliqua Desv. (Silva 465 UEC) ○	shru	x														
Indigofera suffruticosa Mill. (Silva 541 UEC) ○	shru	x										x				
Lonchocarpus cultratus (Vell.) A.M.G. Azevedo & H.C. Lima (Silva 1033 UEC) ◇	tree	x	x	x	x	x	x	x	x							
Machaerium aculeatum Raddi (Silva 656 UEC) □	lian	x	x	x	x	x	x	x	x	x	x					
Machaerium debile (Vell.) Stellfeld (Silva 1145 UEC) ◇	lian		x	x	x	x	x	x	x	x	x	x	x	x	x	
Machaerium declinatum (Vell.) Stellfeld (Silva 316 UEC) ◇	lian	x	x	x	x	x	x									
Machaerium lanceolatum (Vell.) J.F. Macbr. (Silva 918 UEC) □	lian							x	x	x	x	x				
Machaerium nictitans (Vell.) Benth. (Silva 1019 UEC) ◇	tree		x	x	x	x	x	x	x	x	x	x	x			
Machaerium oblongifolium Vogel (Garcia 197 UEC) □	tree	x														
Machaerium scleroxylon Tul.(Silva 1156 UEC) ◇	tree											x	x	x		
Machaerium triste Vogel (Silva 687 UEC) ○	tree	x														
Machaerium uncinatum (Vell.) Benth. (Silva 686 UEC) ◇	lian	x	x	x	x	x	x	x	x	x	x	x	x			

Continued on next page

Table 1. Continued.

		Restinga	Lowland	Submontane					Montane							
Species names/collecting data	**Habit**	**0-10 m**	**10-50 m**	**50-100 m**	**100-200 m**	**200-300 m**	**300-400 m**	**400-500 m**	**500-600 m**	**600-700 m**	**700-800 m**	**800-900 m**	**900-1,000 m**	**1,000-1,100 m**	**1,100-1,200 m**	**1,200-1,279 m**
Machaerium vellosianum Benth. (Silva 1027 UEC) ○	lian	x														
Macroptilium atropurpureum (DC.) Urb. (Silva 1186 UEC) ○	shru	x														
Macroptilium lathyroides (L.) Urb. (Silva 743 UEC) ○	shru	x														
Mucuna japira A. M. G. Azevedo, Agostini & Sazima (Silva 774 UEC) ◇	lian	x														
Mucuna urens (L.) Medik. (Silva 605 UEC) ◇	lian	x	x													
Myrocarpus frondosus Allemão (Silva 901 UEC) □	tree		x	x	x	x	x	x	x	x	x	x	x			
Ormosia arborea (Vell.) Harms (Sanchez & Pedroni 378 UEC) □	tree	x	x	x	x	x	x									
Ormosia minor Vogel (Silva 617 UEC) □	tree											x	x	x	x	
Ormosia monosperma (Sw.) Urb. (Silva 844 UEC) □	tree													x	x	
Platymiscium floribundum Vogel (Silva 1126 UEC) □	tree		x													
Pterocarpus rohrii Vahl (Silva 486 UEC) ◇	tree	x	x	x	x	x	x	x	x	x	x	x	x	x		
Rhynchosia phaseoloides (Sw.) DC. (Romero et al. 23 HRCB) ○	shru	x														
Sophora tomentosa L. (Silva 317 UEC) □	shru	x														
Stylosanthes guianensis (Aubl.) Sw. (Silva 1154 UEC) ○	shru	x										x				
Stylosanthes viscosa (L.) Sw. (Silva 1182 UEC) ○	shru	x										x				
Swartzia acutifolia Vogel (Silva 843 UEC) □	tree													x	x	
Swartzia flaemingii Raddi (Silva 1174 UEC) □	tree													x		
Swartzia langsdorffii Raddi (Silva 1082 UEC) ○	tree						x	x	x	x	x	x	x			
Swartzia oblata R.S. Cowan (Silva 1094 UEC) ◇	tree		x	x	x											
Swartzia simplex (Sw.) Spreng. (Silva 505 UEC) ◇	tree	x	x													
Vigna adenantha (G. Mey.) Maréchal, Mascherpa & Stainier (Silva 451 UEC) ○	shru	x														
Vigna caracalla (L.) Verdc. (Silva 1144 UEC) ◇	lian	x	x										x			
Vigna luteola (Jacq.) Benth. (Silva 731 UEC) □	shru	x														
Vigna vexillata (L.) A. Rich. (Silva 660 UEC) ○	shru	x														
Zollernia glabra (Spreng.) Yakovlev (Romero et al. 167 HRCB) □	tree	x														
Zollernia ilicifolia (Brongn.) Vogel (Silva 893 UEC) □	tree		x	x	x	x	x	x	x							
Zornia curvata Mohlenbr.(Silva 1081 UEC) ○	shru	x														
Zornia glabra Desv. (Silva 737 UEC) ○	shru	x														
Zornia latifolia Sm. (Silva 740 UEC) ○	shru	x														
Total		84	48	36	37	32	33	26	26	24	24	41	45	31	8	0

divisive clustering - TWINSPAN was carried out with the tree species to verify which species could be indicators of these forest formations. These analyses were performed using Fitopac 1.6.4 program (Shepherd 2006).

Results

A total of 142 species of Leguminosae belonging to 45 genera were found in the studied altitudinal gradient (0-1,279 m), being 62 trees, 58 shrubs and 22 lianas (Table 1). No species were found above 1,200 m of altitude. The Papilionoideae subfamily showed higher species richness (81 spp), followed by Mimosoideae with 42 species (Table 1). Considering the tree species only, Mimosoideae appears with the greatest number of species being the best represented group inside the Forest.

Restinga Forest showed higher species richness (84), being 23 trees, 48 shrubs and 13 lianas. From the total of species, 52 were exclusive to Restinga Forest (Table 2). The Montane Forest was the second formation greater in number of species (69, being 25 exclusive). It is noteworthy that the high number of species found in Montane Forest is due to the presence of shrubs and even lianas that grow in open areas. In the Lowland Forest, 48 species were found, being 3 exclusive. The phytophysiognomy with the lowest number of species was the Submontane Forest, where 43 species were found, it was not registered the presence of any exclusive species. The absence of exclusive species in the Submontane Forest may be associated to the fact that, in general, these species also occur below the established quota for this phytophysiognomy in the Lowland, or immediately above, in Montane Forest. It is worth considering that, despite the fact that the Montane Forest appears second in total number of species, the Leguminosae family is best represented in this phytophysiognomy only from 800-1,000 m altitude. There is a clear decrease in the number of species in the higher quotas of this formation, from 1,000-1,279 m (Table 1).

The analysis of the distribution of the habits of Leguminosae species in relation to altitude (Figure 2) revealed a higher richness tree species in the quota that represents the Lowland (10-50 m) with 34 species. The shrubs were more abundant in the Restinga Forest (48 spp.), completely disappearing from 300 to 700 returning to occur from 800-1,100 m in open areas. The increase in the number of species in Montane Forest (69 spp.) is mainly due to the reappearance of shrub species, but also due to a significant number of tree species that occur only in those quotas. The number of lianas remained constant in almost all quotas, with a significant reduction between 1,100-1,279 m. The number of species and their respective altitudinal quotas by habits are shown in Table 2.

Analyzing the occurrence of species of Leguminosae in different altitudes (Table 1), we can see that no specie of the Caesalpinioideae subfamily was found occupying all phytophysiognomies. However, *Bauhinia forficata*, *Copaifera langsdorffii*, *Copaifera trapezifolia*, *Phanera angular* and *Senna macranthera*, only are not present at Restinga (0-10 m) and can be found very often in other formations, mainly between 50 and 1,100 m altitude. *Bauhinia forficata*, however, was not found inside the forest, but only at the edge of forests, along roads and highways or in other altered areas. *Bauhinia microstachya*, frequently found in the Lowland (10-50 m) and Submontane (50-500 m), was not found above 700 m. Some Caesalpinioideae characterize certain formations or have their preferred environment located at a specific altitude, as is the case of *Schizolobium parahyba*, which was only found between 0-100 m, *Tachigali denudata* and *Tachigali multijuga* that reach up to 200 m altitude and *Hymenaea courbaril* found in Lowland and Submontane Forest (10-500 m).

For the Mimosoideae subfamily, we observed that only two species were found in all phytophysiognomies (*Inga marginata* and *Piptadenia adiantoides*). The two species, however, are not equally

Table 2. Number of species, genera, tribes and habits of Leguminosae by phytophysiognomies of the Atlantic Forest in Picinguaba and Santa Virgínia Nucleus.

		Taxa (exclusive)			**Habits (exclusive)**		
	Phytophysiognomies	**Species**	**Genera**	**Tribes**	**Tree**	**Shrubs**	**Lianas**
Caesalpinioideae	Restinga (0-10 m)	8 (2)	3 (0)	2 (0)	3 (0)	5 (0)	0
	Lowland (10-50 m)	11 (0)	6 (0)	4 (0)	9 (0)	0	2 (0)
	Submontane (50-500 m)	10 (0)	5 (0)	4 (0)	7 (0)	1 (0)	2 (0)
	Montane (500-1,200 m)	14 (2)	7 (1)	4 (0)	8 (2)	4 (0)	2 (0)
	total	19	8	4	11	6	2
Mimosoideae	Restinga (0-10 m)	19 (13)	6 (1)	3 (0)	8 (5)	8(7)	3 (0)
	Lowland (10-50 m)	16 (2)	5 (0)	3 (0)	13 (2)	0	3 (0)
	Submontane (50-500 m)	13 (0)	5 (0)	3 (0)	11 (0)	0	2 (0)
	Montane (500-1,200 m)	19 (10)	7 (0)	3 (0)	14 (7)	2 (1)	3 (1)
	total	42	8	3	27	9	6
Papilionoideae	Restinga (0-10 m)	57 (37)	26 (10)	8 (0)	12 (5)	35 (29)	10 (3)
	Lowland (10-50 m)	21 (1)	14 (1)	6 (0)	12 (1)	1 (0)	8 (0)
	Submontane (50-500 m)	20 (0)	12 (0)	6 (0)	11 (0)	1 (0)	8 (0)
	Montane (500-1,200 m)	36 (13)	16 (1)	8 (0)	13 (5)	14 (4)	9 (1)
	total	81	29	8	24	43	15
Leguminosae	Restinga (0-10 m)	84 (52)	35 (1)	13 (0)	23 (10)	48 (35)	13 (3)
	Lowland (10-50 m)	48 (3)	25 (1)	13 (0)	34 (3)	1 (0)	13 (0)
	Submontane (50-500 m)	43 (0)	22 (0)	13 (0)	29 (0)	2 (0)	12(0)
	Montane (500-1,200 m)	69 (25)	30 (2)	15 (0)	35 (14)	20 (5)	14 (2)
Total	142	45	15	62	58	23	

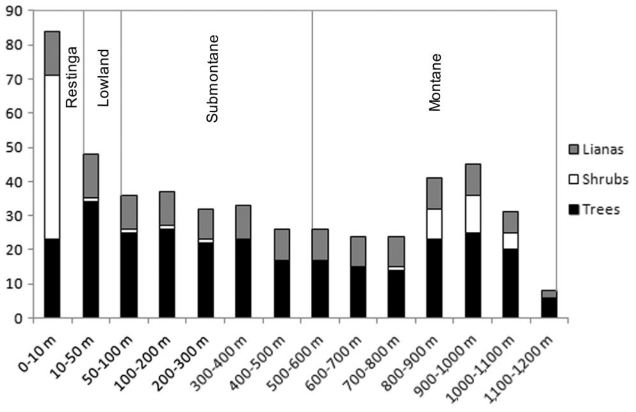

Figure 2. Distribution of habits of Leguminosae species in relation to altitude in Atlantic Forest of Serra do Mar State Park.

distributed, since *P. adiantoides* occurs almost continuously throughout the gradient, while *I. marginata* is present in abundance only within the Restinga and Lowland Forest, being little found in the Submontane and Montane Forest, where it was found only in open areas, along rivers and forest edges. Thirteen species were found only in the Restinga Forest (Table 2), standing out *Abarema brachystachya*, *Balizia pedicellaris* and *Inga subnuda* that were found most frequently. Also well represented in Restinga, extending to the Lowland, were found *Inga edulis* and *Piptadenia gonoacantha*; from Restinga to Submontane (*Inga striata*, *Pseudopiptadenia warmingii* and *Senegalia paniculata*) and from the Lowland to Montane (*Inga hispida* and *Pseudopiptadenia leptostachya*). In the Montane Forest, 10 exclusive species were found, occurring more precisely from 700 to 1,100 m (*Inga barbata*, *Inga lanceifolia*, *Inga mendoncaei*, *Inga sessilis*, *Inga vulpina*, *Mimosa ramosissima*, *Mimosa scabrella*, *Mimosa* sp1, *Senegalia lacerans* and *Senegalia* sp1). At that altitude we highlight the presence of *Inga lanceifolia* and *Inga sessilis* by the large number of individuals inside the forest. It is also important to emphasize the presence of *Abarema langsdorffii* that although also present in the Submontane Forest, is very well represented in Montane as well as *Inga hispida* and *Pseudopiptadenia leptostachya*, species that are not exclusive to Montane, but are well represented in number of individuals in this phytophysiognomy.

Six species of Papilionoideae were found in all phytophysiognomies, from the sea level to about 1,000 m. Four are lianas (*Dalbergia frutescens*, *Machaerium aculeatum*, *Machaerium dimorphandrum* and *Machaerium uncinatum*) and two are trees (*Dahlstedtia pinnata* and *Pterocarpus rohrii*). All these species grow inside the forest, where they are well represented in number of individuals, or on forest edges and areas where the forest is reestablishing. In Restinga Forest, 37 exclusive species were found (Table 2). Abundant in the Restinga Forest, but extending to the Lowland, include: *Andira fraxinifolia*, *Mucuna urens*, *Platymiscium floribundum* and *Swartzia simplex*. Six species are present from the Restinga to the Submontane Forest, one of them occurring up to 200 m (*Swartzia oblata*) and the remaining from the sea level to about 500 m altitude (*Andira ormosioides*, *Lonchocarpus cultratus*, *Machaerium declinatum*, *Ormosia arborea* and *Zollernia ilicifolia*). In the Montane Forest, 13 species were found. The species of *Dalbergia brasiliensis*, *Machaerium scleroxylon*, *Ormosia minor*, *Ormosia monosperma*, *Swartzia acutifolia* and *Swartzia flaemingii* stand out for occurring only in this formation mainly above 800 m altitude. Standing out by the large number of individuals, found between 900 and 1,000 m, are the species of *Machaerium scleroxylon* and *Ormosia minor*, and by its rarity, the specie of *Swartzia flaemingii* found just above this quota.

Cluster analysis (UPGMA), which included here only tree species of Leguminosae, revealed some relations for the sample units (phytophysiognomies), highlighting the dissimilarity between the Restinga Forest (0-10 m) and Montane Forest (1,100-1,200 m) in relation to the others (Figure 3). At least three distinct groups showed greater similarity between quotas, one of 10-400 m, which corresponds to the Lowland + Submontane; another 400-800 m which encompasses the Submontane + Montane Forest, and another of 800-1,100 m, which corresponds to Montane. The lower altitude quotas of Montane Forest (600-800 m) showed greater similarity with

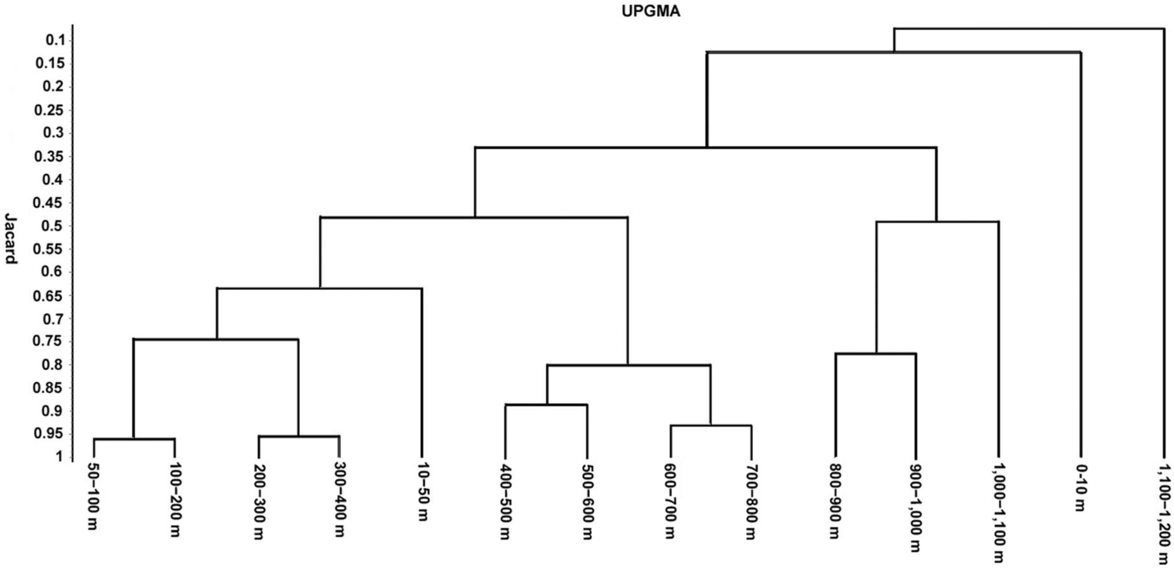

Figure 3. Similarity analysis among different altitudes in Atlantic Forest of Serra do Mar State Park using Jaccard index with Group Average Clustering (UPGMA). Only tree species.

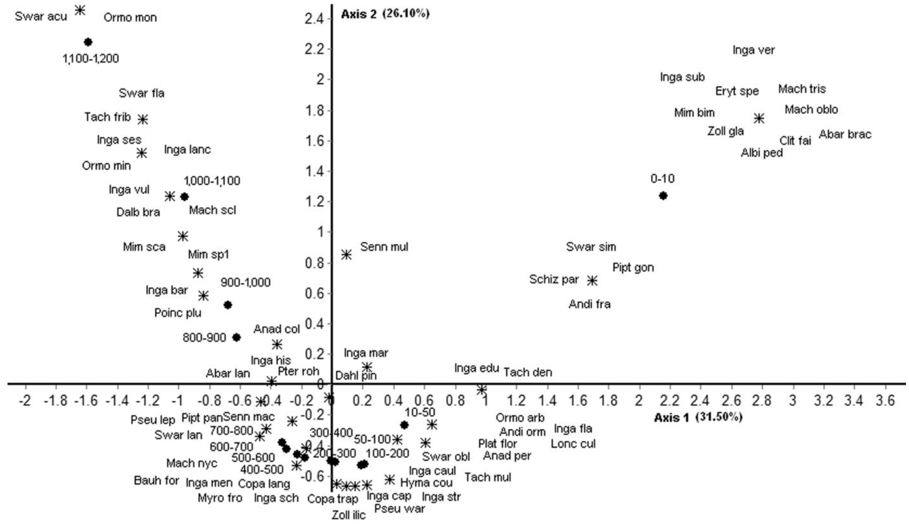

Figure 4. Ordination analyses among different altitudes in Atlantic Forest of Serra do Mar State Park using Correspondence Analysis (CA). Only tree species.

higher quotas of Submontane (400-500 m) than with the higher altitudinal quotas. This can be happening due to a restricted set of species restricted to higher altitudes of Montane Forest.

Correspondence analysis (CA) of the tree species (Figure 4) suggested a high turnover of species along the gradient, with 51.6% of inertia. The analysis also showed that there is greater similarity between the higher quotas of Montane Forest (800-1,000 m) and that the lower quotas of this formation (600-800 m) are more related to those higher of Submontane (400-500 m) as evidenced in the previous analysis (UPGMA).

The largest share of species (Figure 5) occurred between Lowland Forest and Submontane (25 spp.) and the lowest between the Restinga Forest and Montane Forest (5 spp.).

The TWINSPAN showed a similar grouping to that obtained by UPGMA. In the first division there was a separation of altitudes quotas of 800-1,200 m (Montane Forest) from the remaining quotas being *Inga lanceifolia*, *Inga sessilis* and *Ormosia minor* species indicated for this track separation (eigenvalue 0.520). The second division separated the Restinga Forest from other quotas of 10-800 m, with an eigenvalue of 0.501, being *Abarema brachystachya*, *Inga subnuda* and *Inga vera*, indicated species for this separation. A third division of low eigenvalue was also obtained in Lowland and in the beginning of the Submontane Forest, with different groups of 10 to 200 m (*Inga cauliflora*, *Inga edulis*, *Swartzia oblate, Tachigali denudata*, *Tachigali multijuga*) and 200-800 m (*Abarema langsdorffii*, *Inga mendoncaei*, *Inga schinifolia*, *Swartzia langsdorffii*).

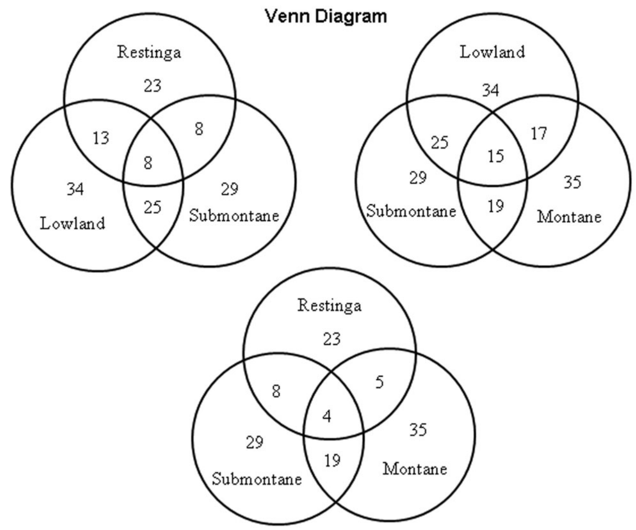

Figure 5. Sharing of species among phytophysiognomies in Atlantic Forest of Serra do Mar State Park using Venn Diagram. Only tree species.

Discussion

Among the vegetation types that comprise the Atlantic Forest domain on the northern coast of São Paulo, the Restinga Forest has been the poorest in numbers of tree species, especially when compared to the Lowland (Lacerda 2001, Assis et al. 2011). Specifically for the Leguminosae family, this trend was also observed in the study area, with 34 tree species present in the Lowland and only 23 in Restinga (Table 2). The physico-chemical differences of soil, temperature and precipitation have been identified as the main causes of lower tree species richness in Restinga. Lacerda (2001) suggests that, in the plain, different patterns of precipitation and temperature, the water excess, during periods of upwelling of groundwater, and consequent salinity salt spray carried by breezes and deposited in the soil by rain are factors that can be limiting the establishment of many slope species at Restinga. Despite the lower tree species richness in Restinga, some species are well represented in number of individuals on this formation. In a survey conducted in a block of 1 ha (100 × 100 m) in Restinga in Picinguaba (Assis *et al.* 2011), which included trees with diameter at breast height $\geq$ 4.8 cm, 22 individuals of the *Andira fraxinifolia* and 29 of *Inga subnuda* were found.

This formation, however, is richer than the Lowland when considering all the habits of the Leguminosae family. Some species of shrubs seem well adapted to the environmental conditions present in Restinga, as they also occur in other areas of such formation in São Paulo coast, as *Dalbergia ecastaphyllum*, *Senna pendula*, *Sophora tomentosa* and *Vigna luteola*. Data

Table 3. Number of Leguminosae species found in the Phytosociological studies carried out in altitudinal gradients in the Serra do Mar.

		Lacerda (2001)		Custódio-Filho (2002)		Bertoncello (2009)		Roderjan (1994)		
Altitude	**Phytophysiognomies**	**Total spp**	**Leguminosae**	**Total spp**	**Leguminosae**	**Total spp**	**Leguminosae**	**Total spp**	**Leguminosae**	**Leguminosae (%)**
2 m	Restinga	88	9							10.22
50 m	Lowland			56	5					8.92
100 m	Submontane	98	18							18.36
200 m	Submontane			95	5					5.26
300 m	Submontane	107	7							6.54
400 m	Submontane			91	6					6.59
600 m	Montane	106	9							8.49
600 m	Montane			88	7					7.95
800 m	Montane			78	7					8.97
820 m	Montane					87	4			4.59
970 m	Montane					71	6			8.45
1,000 m	Montane	91	8							8.79
1,000 m	Montane			69	6					8.69
1,120 m	Montane					61	2			3.27
1,150-1,200 m	Upper-Montane							43	1	3.32
1,200 m	Montane					39	2			5.12
1,200-1,300 m	Upper-Montane							43	0	0.00
1,270 m	Montane					21	0			0.00
1,300-1,400 m	Upper-Montane							25	0	0.00
Location study area		Serra do Mar, north São Paulo state, 2322’ S and 44 48’ W, 2 a 1,000 m altitude	Serra de Paranapiacaba, south São Paulo state; 24?00’ S and 48?00’ 50 a 1,000 m altitude	Serra do Mar, north São Paulo state, 23 18’ 14” S and 44 47’ 16” W, 820 a 1,270 m altitude	Serra do Mar, Paraná state, 2521-26’ S and 4900’ W, 1,150 a 1,400 m altitude					
Study Methodology		Plots of 0.18 ha (300, 600 e 1,000 m), 0.4 ha (100 m) e 0.48 ha (0 m). PBH ≥ 15 cm	Plots of 0.2 ha in all studied quotas. DBH ≥ 10 cm	Plots of 0.4 ha (820, 970 e 1,120 m) DBH ≥ 4.8 cm; (1,200 e 1,270 m) DBH ≥ 3.2 cm	Plots of 0,16 ha (1,300-1,400 m); 0.26 ha (1,200-1,300 m); 0.16 ha (1,150-1,200 m) DBH ≥ 4.88 cm					

comparing the species richness of the Lowland with the other formations are scarce and hampered by differences in the methodology used in the studies.

Phytosociological studies carried out in altitudinal gradients in Serra do Mar (Roderjan 1994, Lacerda 2001, Custodio Filho 2002, Bertoncello 2009) have shown that species richness decreases at higher altitudes. To Leguminosae, however, the data from these studies show that the percentual of species is very similar up to 1,000 m altitude and only decreases considerably after this quota (Table 3), except for the differences that hinder comparisons between areas, such as the methodology used in the study, size of the sample area, preserving levels of each area, difficult access to collection sites, delimitation of the parameters to include the individual in the sample.

In the study area, excluding the Restinga Forest (0-10 m), which is a distinctive vegetation type, we realize that up to 1,000 m the tree species of the Leguminosae family is very similar, taking into account the full amplitude established for each formation. In the Lowland (10-50 m) 34 species were found, in the Submontane (100-500 m) 29 were found and in Montane (500-1,200 m) 35 species occurred (Table 2). It is interesting to note that this similar number is maintained by different species and more evident when we look at the distribution by belt (Table 1). It seems, therefore, to occur species replacement along the gradient as shown in CA analysis. Legume species would then be occupying specific altitudinal zones within the forest. Genera well represented in our sample such as *Inga*, *Machaerium* and *Swartzia*, are present throughout the whole gradient by species that are occupying different altitudes. Many species of Leguminosae, therefore, characterize certain formations or have their preferred environment located at a specific altitude and thus being species indicator of phytophysiognomies.

The analysis of data by established quota shows that there are differences in the number of tree species, being the belt of transition between the plain and the slope represented by Lowland Forest (10-50 m), the richest in number of species (34) and the belt of 1,100-1,200 m, which is Montane Forest, the one that has the lowest number of species (6) showing the most commonly observed tendency in studies involving the distribution of species in altitudinal gradients.

The distribution of Leguminosae species at different altitudes may be related to environmental variables such as nutrient availability and soil depth, luminosity, temperature, precipitation and humidity. The interaction between increased precipitation and the decreasing of temperature with altitude has been associated with the reducing on the number of species in altitudinal gradients (Gentry 1982, Richards 1996, Gentry 1988). The decreasing of temperature with altitude may also be influencing a decrease in the rates of decomposition of organic matter preventing some nutrients from being returned to the soil. Ashton (1977) and Gartlan et al. (1986) suggested that phosphorus, magnesium and potassium are among the nutrients which levels are more related to diversity in the tropic plant community. To Grubb (1977), the slow rate of decomposition caused by the decrease in temperature at higher altitudes makes the soils of montane forests poor in nitrogen and phosphorus.

These variables would be exerting a selection of species per altitudinal belts since there are few species of the family that are adapted to a broader range of these environmental variables occurring in all altitudinal groups studied (two Mimosoideae and seven Papilionoideae).

For Lacerda (2001), the decrease of the richness presented above 1,100 m in Picinguaba can be related to the decrease in temperature and the presence almost daily of haze, which can interfere in other variables such as insolation and air humidity. According to Rambo (1953), the worsening of environmental conditions above 1,000 m of altitude, mainly due to edaphic and climatic aspects, dramatically affects the forest vegetation. Above this altitude the trees reduce in height and diameter and the vegetation becomes dense with floristic structure extremely impoverished. These formations are common and very similar to all the coastal mountains from the Brazilian southeast, defined by the same author as "matinhas nebulares" for being constantly submitted to dense fogs (Rambo 1953).

In the study area, these and other variables may be influencing the distribution of species of Leguminosae. The fact that no species of Caesalpinioideae have been found occupying all phytophysiognomies, but some of them (*Bauhinia forficata*, *Copaifera langsdorffii, Copaifera trapezifolia, Phanera angulosa* and *Senna macranthera*) are not present only in the Restinga (0-10 m) and above 1,100 m, may indicate that these two formations would somehow be limiting the development of these species. The absence of *Bauhinia microstachya* above 700 m, as shown in our results, however, should be viewed with caution, because data in the literature (Vaz 1993) and herbarium material showed that these species may occur up to 1,000 m altitude. *Poincianella pluviosa*, which according to Ulibarri (1996), is a specie that occupies areas inside forests, was only found in open areas of the Santa Virgínia Nucleus which may mean that this plant is disappearing from the Atlantic Forest on the north coast of São Paulo. Found only in the Restinga Forest, *Senna pendula* is a typical specie of this vegetation type as found in herbarium specimens and data from other studies conducted in São Paulo coast (Barros et al. 1991, Mamede et al. 2004).

The Mimosoideae subfamily, by having only two species present throughout the gradient, seems not to respond to different environmental conditions imposed by the different altitudes. In the study area, as elsewhere in the Atlantic Forest in the states of São Paulo, Paraná, Rio de Janeiro and Espírito Santo, *Abarema brachystachya*, *Balizia pedicellaris* and *Inga subnuda* seem well adapted to the Restinga Forest where they are found very often. Nonetheless, *Inga subnuda* also occurs in the Lowland (Garcia 1998) and *Balizia pedicellaris* is not restricted to Restinga vegetation, occupying areas of other vegetation types in the “Chapada Diamantina” and the Amazon region (Barneby & Grimes 1996). As for other species found in the Restinga Forest, there are records that indicate their occurrence in different vegetation types and altitudes, not only in the state of São Paulo, but also in areas of the central plateau in the states of Minas Gerais, Goiás and Bahia. Of the 11 exclusive species of Montane Forest (Table 1), except *Senegalia lacerans*, in that herbarium material was recorded to occur at lower altitudes (30 m) and *Abarema langsdorffii* which can also occur in the Restinga Forest at sea level (Barneby & Grimes 1996) it can be stated that these species characterize well this formation in Picinguaba and Santa Virgínia. Still on the species that clearly represent the Montane Forest it is also important to clarify that those belonging to the genera *Mimosa* occur only in open areas, often disturbed.

The number of species of Papilionoideae occurring in all vegetation types (6 spp.) corroborates the hypothesis that the taxa of this subfamily are more adapted to a wider range of environmental variations in the gradient studied. These species, however, do not occur over 1,000 m in Montane Forest. The high number of exclusive species of Restinga Forest (Table 1) does not necessarily mean an affinity with this vegetation type since most of these species are shrubby, have a wide geographical distribution and occupy different altitudes, among which the species of the genera *Vigna* (3 spp.), *Zornia* (3 spp.), *Crotalaria* (4 spp.), *Desmodium* (4 spp.) and *Aeschynomene* (5 spp.) are outstanding. Of the 38 species of Papilionoideae exclusive to Restinga, only five are really restricted to this formation and do not develop into other phytophysiognomies in the Atlantic Forest (*Centrosema virginianum, Dalbergia ecastaphyllum*, *Machaerium vellosianum*, *Mucuna japira* and *Sophora tomentosa*). Besides these five species, we could say that also characterize the vegetation of Restinga, by the number of individuals present and their occurrence in other areas of the Atlantic Coast (*Dioclea wilsonii*, *Erythrina speciosa* and *Vigna luteola*). Some genera of Papilinoideae contribute significantly to the diversity of the species distributed in the different levels along the gradient, among which are *Andira*, *Dalbergia*, *Machaerium*, *Ormosia* and *Swartzia* species, showing a good ability of these taxa to adapt to changes imposed by altitude. The presence of *Machaerium* and *Swartzia* in the list of genera with highest number of species in a survey conducted by Oliveira Filho & Fontes (2000) on the tree flora of 102 areas of Atlantic Forest corroborates the statement that the contribution of these genres for diversity in tropical forests is quite significant.

Regarding habits, shrubby legume species were not found within the forest. The predominance of arboreal habit within the forest was also demonstrated in a study by Guilherme et al. (2004) in Lowland Forest (86-130 m) in Intervales, São Paulo. In this study, the Leguminosae family contributed with four species (*Copaifera trapezifolia*, *Pseudopiptadenia warmingii*, *Pterocarpus rohrii*, *Schizolobium parahyba*) of the 12 with the highest importance (VI) in a vertical strata with trees $\geq$ 26 m tall. In the vertical strata with plants $\leq$ 8 m tall, Leguminosae species were not found, being Arecaceae, Lauraceae, Myrtaceae, Rubiaceae, Monimiaceae the richest families.

For Richards (1996), tropical forests exhibit a vertical stratification. These strata are composed of various species of plants with different occupation capacities resulting from an adaptive response to the different light conditions. Leguminosae probably should not be adapted to the low incidence of lighting in the lower strata of the forest. The presence of many species of the family at the edges of forest formations is possibly related to high rates of luminosity present in these areas.

The participation of subfamily Mimosoideae as the best represented in tree species in most altitudes (Table 2) is mainly due to the presence of many species of the genera *Inga*, neotropical group of expressive representation in Ombrophilous Forests.

The dissimilarity of Restinga Forest (0-10 m) and Montane Forest (1,100-1,200 m), relative to other phytophysiognomies highlighted in the results of the cluster analysis (Figure 3), can be explained by the large number of species restricted to these vegetation types. The greatest similarity found between the sets 10-400 m (Lowland + Submontane), 400-800 m (Submontane + Montane) and 800-1,100 m (Montane) indicates that closer altitudes share a certain number of species. This sharing, however, does not occur significantly at the extremes of the gradient as evidenced in CA, where the lower altitudes of Montane Forest (600-800 m, for example) showed greater similarity with higher quotas of Submontane (400-500 m) than with the immediately higher (900-1,000 m), due to a number of restricted species of these higher altitudes. The notable species replacement along the altitudinal gradient, with 51.6% of inertia shown in CA, suggests that there are other ecological variables influencing the distribution of Leguminosae species in the study area. The largest share of species that occur between Lowland Forest and Submontane, evidenced in the Venn diagram, may be linked to the fact that the Lowland presented higher tree species richness, and part of these species still occur just above the altitude established to this formation and, with increasing altitude, these taxa are gradually being replaced by others. The lowest share observed between the Restinga Forest and Montane was expected, because these phytophysiognomies hold a large number of restricted species.

Although the data presented in this study may add information about the distribution of legumes species in an altitudinal gradient, it is important to note that the richness of species can also change with latitudinal variation, which is a well known ecological pattern. The increase or decrease in temperature towards the lower or higher latitudes may be able to change the vegetation types due to the appearance and disappearance of some species.

The altitudinal limits of the phytophysiognomies that comprise the Atlantic Forest present in the current official Brazilian vegetation classification system (Veloso et al. 1991) should also be seen with reservations. According to Joly et al. (1999), there is an academic debate about the limits of the forest subtypes of the Atlantic Forest complex. For Leguminosae, the boundaries between the lower and upper Montane Forest, in the study area, also indicate that those limits may not be well established. Maybe there are numerous small areas with clear floristic differentiation occurring throughout the whole forest that do not allow a very precise separation of these limits. The separation of the highest part of Montane (1,100-1,200 m), in the study area, seem to coincide with the data obtained by Bertoncello et al. (2011). These authors admit the existence of a different vegetation type in the highest part of Cuscuzeiro Mountain (1,120-1,270 m). This vegetation type, called cloud forests, was also found in the southern region by Rambo (1953) and Klein (1980).

Despite the many efforts made in recent decades to understand how plant species are distributed along the surface of the earth, the almost continental dimensions of some phytogeographic areas make it considerably difficult the obtainment of data that can contribute to this understanding. The study of specific plant groups, conducted in smaller areas, may be a way to make this understanding possible. The biodiversity knowledge, allied to the knowledge of how these organisms are distributed, can be an important tool for the conservation of these environments and the organisms that live in them.

Acknowledgments

The authors thank São Paulo Research Foundation - FAPESP (Project Biota Functional Gradient - 03/12595-7), the Fund to Support Teaching, Research and Extension – FAEPEX/UNICAMP for financial support; the management and employees of the Forestry Institute - Picinguaba and Santa Virgínia for hosting and support throughout the research; the administrators and employees of Capricórnio Farm for permission and assistance during the collections; the herbaria curators by loans of materials; the two anonymous reviewers for valuable suggestions and corrections

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Received 28/08/2014
Revised 10/09/2015
Accepted 9/02/2016

Biota Neotropica 16(1): e0109, 2016
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)
article

Potential ecological distribution of alien mollusk *Corbicula largillierti* and its relationship with human disturbance in a semi-arid reservoir

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

Abstract: The introduction of exotic mollusk species has resulted in loss of biodiversity in semi-arid neotropical aquatic ecosystems. This study aims to relate the presence and density of *Corbicula largillierti* species to human disturbance, providing data for the conservation and management of aquatic ecosystems. Specimens were collected at Epitácio Pessoa reservoir in December 2011 and June 2012, presenting densities of 20.96 and 62.89 individuals per square meter, respectively. Anthropic disturbance metrics were calculated considering the presence, type and intensity of disturbance in littoral, riparian and flood zones. The occurrence of *C. largillierti* was mainly associated to the variables total phosphorus (261.05 ± 342.22 μg/L) and total nitrogen (440.79 ± 103.77 μg/L), near to tributaries. The occurrence of exotic mollusk species is evidence of the need for freshwater ecosystem conservation and management, particularly in reservoirs used for water supply.

Keywords: *Corbiculidae, anthropic disturbance, environmental quality.*

AZEVÊDO, E.L., BARBOSA, J.E.L., VIDIGAL, T.H.D.A., MARQUES, J.C., CALLISTO, M., MOLOZZI, J. **Potencial ecológico de distribuição do molusco alienígena *Corbicula largillierti* e sua relação com perturbação humana em um reservatório no semiárido.** Biota Neotropica. 16(1): e0109. http://dx.doi.org/10.1590/1676-0611-BN-2015-0109

Resumo: A introdução de espécies exóticas de moluscos resulta em perda de biodiversidade em ecossistemas aquáticos semiáridos neotropicais. Este estudo tem o objetivo de relacionar a presença e densidade da espécie *Corbicula largillierti* ao distúrbio humano, fornecendo dados para a conservação e manejo de ecossistemas aquáticos. Os espécimes foram coletados no reservatório Epitácio Pessoa em dezembro de 2011 e junho de 2012, com densidades de 20,96 e 62,89 indivíduos por metro quadrado, respectivamente. Métricas de perturbação antrópica foram calculadas considerando a presença, tipo e intensidade de perturbação nas zonas litorânea, ribeirinha e de inundação. A ocorrência de *C. largillerti* esteve associada às variáveis fósforo total (261,05 ± 342,22 μg/L) e nitrogênio total (440,79 ± 103,77 μg/L), em locais próximos aos afluentes. A ocorrência de espécies exóticas de moluscos evidencia a necessidade de conservação e manejo de ecossistemas de água doce, principalmente em reservatórios utilizados para abastecimento de água.

Palavras-chave: *Corbiculidae, distúrbio antrópico, qualidade ambiental.*

Introduction

Biological invasions threaten native species, as they modify interspecific interactions, community structure and ecosystems' natural processes (Emer & Fonseca 2011), and thus are considered the second main cause of biodiversity loss on a global scale (Darrigran et al. 2011).

Potentially invasive exotic species typically present high growth rates, ability to develop in a wide range of habitats and high ecological plasticity (Darrigran & Damborenea 2011). Considering that 10 to 20% of exotic species become invasive (Mcclaughlin 2002), the development of better tools for determining in advance where introduced species might become a threat is of the utmost importance. Identifying geographical distribution and the environmental factors which determine the occurrence of exotic species and forecasting species expansion are important conservation strategies (Oliveira et al. 2010, Jackson & Britton 2013).

Freshwater bivalves are among the exotic species with high invasion potential. They have been found in ecosystems worldwide (Darrigran et al. 2011, Franco et al. 2012, Wittmann et al. 2012). Three species of such bivalves from south-eastern Asia reached the neotropic ecozone during the 1960s: *Corbicula fluminea* (Muller 1774), *Limnoperna fortunei* (Dunker 1857) and *Corbicula largillierti* (Philippi 1844) (Darrigran 2002). Since then, these species have invaded several aquatic ecosystems in South America. *C. largillierti* belongs to the *Corbiculidae* family (Bivalvia, Heterodonta, Veneroida), originary to China's Yangtze Kiang lake system (Mansur et al., 2004). In South America, it was recorded for the first time on the La Plata River, on the outskirts of Buenos Aires, during the 1960s (Ituarte 1981). In Brazil, it was initially recorded on the Mato Grosso Pantanal (wetlands) (Callil & Mansur 2002), and on the Sinos River basin at Rio Grande do Sul (Mansur & Pereira 2006), followed by recordings in hydrographical basins at Minas Gerais, Espírito Santo, Santa Catarina and north-eastern Brazil (Ceará) (Silva & Barros 2011, Santos et al. 2012) and Paraíba (Azevêdo et al. 2014).

Stronger presence of exotic species in aquatic ecosystems is usually associated with human disturbance and lower environmental quality (Olenin et al. 2007). Some species are highly tolerant to physical and chemical variations, and colonize new habitats in reservoirs as they present high reproduction rates and adapt easily to different types of environment (Ruse 2010). In this semi-arid region, aquatic ecosystems present particular dynamics because of the following features: (1) distinct climatic and geomorphological characteristics; (2) highly variable precipitation both in time and in space; (3) low temperature variation (temperatures above 25°C); (4) high potential evapotranspiration, which promotes hydric deficit for about nine months per year; (5) shallow soil; (6) hydrographic basins with intermittent flow; and (7) deciduous vegetation coverage at the Caatinga biome (Barbosa et al. 2012).

Another issue that threatens conservation is the emerging diversion of water from the São Francisco River (born in Minas Gerais and extends by the states of Bahia, Sergipe, Alagoas and Pernambuco) to Paraíba River (state of Paraíba), a project by the Federal Government. Local ecological impacts, such as increased total phosphorus concentrations and proliferation of green algae are imminent (Li et al. 2013). In addition, the change of direction of the water will change the regime of flooding of the Paraíba River, from flood periods variables to permanent flooding, potentially causing loss of habitat and native fauna (Kingsford 2000), such as fish, birds and benthic macroinvertebrates.

These features strongly influence aquatic ecosystems, adding to the anthropic effect, which needs the development of management plans accommodating the human use of the watershed (Pereira et al. 2013). In order to assess the interaction between human activities and the characteristics of habitats on the littoral zone of reservoirs, the United States Environmental Protection Agency (US-EPA) has developed a protocol for evaluating physical habitats (US-EPA 2011, 2012). This protocol enables the calculation of disturbance metrics for reservoirs' riparian and flood zones by considering both the extension and the intensity of anthropic disturbances (Kaufmann et al. 2014a, Kaufmann et al. 2014b).

This study relates to the presence and density of *C. largillierti* in Paraíba River's hydrographic basin with human disturbances, thus providing information that can be used in other reservoirs to establish management and conservation programs.

Material and Methods

The study area comprised the Epitácio Pessoa reservoir in the Paraíba River hydrographic basin, part of the Brazilian semi-arid region. This region's annual pluviometric index is typically lower than 400 mm, with an aridity index of up to 0.5 and a drought risk over 60%. Also, the Brazilian semi-arid region has an area of 969.589.4 km^2 and a population of over 22 million people, and is the world's most populated semi-arid region (Pereira-Junior 2007). The Epitácio Pessoa reservoir (7° 28'4"- 7° 33' 32" S, 36° 8'23" - 36° 16'51" W) was built in 1956 and has a hydric capacity of over 418 million m^3, its residence time is three to five years (AESA 2013) because of long dry periods, which favours the retention of nutrients and sediments from its drainage basin (Freitas et al. 2011).

C. lagillierti specimens were collected in sediment samples from 20 sampling sites in the reservoir's littoral zone with a Van Veen grab sampler (477 cm^2) in December 2011 and June 2012, periods with higher and lower water volume, respectively. Taxonomic identification was performed according to shell characterization provided by Mansur et al. (2004) and Pereira et al. (2012). Identified material was later stored at the Laboratory of Malacology and Molecular Systematics at Universidade Federal de Minas Gerais (lots 3582 and 3583).

In order to apply the physical habitat characterization protocol, the methodology provided by Kauffman et al. (2014a, 2014b) was used. For each of the 20 sampling sites, the protocol was applied along 150 meters of the river bank, on ten consecutive 15 meter wide transects, thus adding up to 200 applied protocols, 10 for each site. Each sampling unit was composed of continuous littoral (15 x 10 m), riparian (15 x 15 m) and flood (15 x Y m) zone sections, where Y stands for flood zone length, which varied according to the bank angle at each site (Figure 1). Disturbance metrics were calculated according to the method applied by the US Environmental Protection Agency (Kaufmann et al. 2014a, Kaufmann et al. 2014b). For this study, human disturbance extension and intensity indices were calculated for the riparian zone (*RDix_IX*, Riparian human disturbance index) and the flood zone (*RDix_IX* inund). Twelve types of disturbance or human activities were considered for the riparian disturbance index (*RDix_IX*). Four of these were related to agriculture (plantation, pasture, orchard, parks/grasslands) and

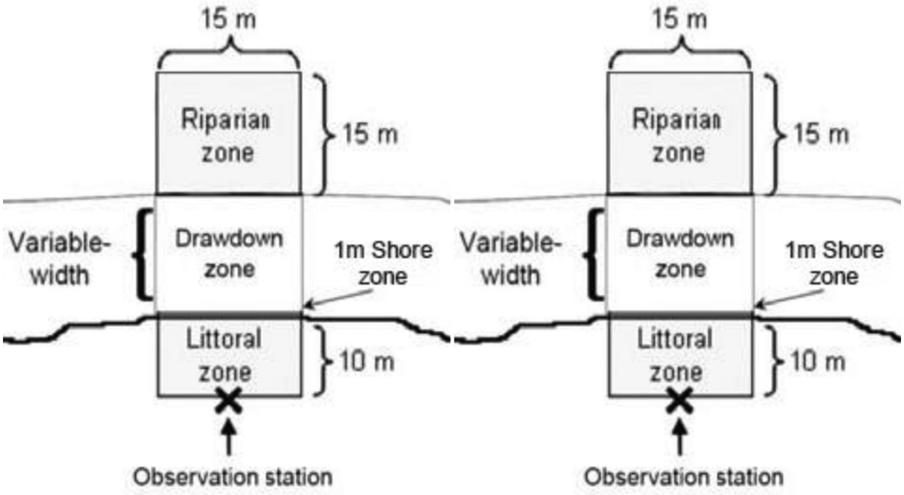

Figure 1. Outline of the observation area for application of the protocol characterization of physical habitat (US-EPA 2011.2012).

eight represented other activities which cause disturbance (buildings, commerce, ramp/artificial beach, docks/boats, walls/dams, garbage/debris, roads/railways, transmission lines). Disturbance metrics weighted disturbance according to its location in relation to the site as follows: absent disturbance had weight 0.0, disturbance inside the site had weight 1.0 and disturbance adjacent to the site had weight 0.5. The obtained values were then used for calculating a weighted mean. Metric indices presented final values which ranged from zero to one, with lower values representing low disturbance and higher values pointing to more intense disturbance. Flood zone metrics were calculated in the same manner. As there were two values for each site (riparian and flood zones), an arithmetical mean was calculated in order to obtain a single value using each zone's index (riparian zone and flood zone indexes).

Some variables were measured to assess water quality: temperature, pH, electrical conductivity, turbidity, oxygen, total dissolved solids, and salinity, these measurements were performed with the aid of a multi-analyzer Horiba/U-50 and water transparency using the Secchi disk. Nutrient concentration, total phosphorus (P-total), orthophosphate (PO_4), total nitrogen (N-total), nitrate (NO_3), nitrite (NO_2), ammonia (NH_4) and alkalinity were analysed according to the Standard Methods for the Examination of Water and Wastewater (APHA 2005). Granulometric composition was assessed by sieving, according to the methodology provided by Suguio (1973) and modified by Callisto & Esteves (1995). Sediment organic matter percentages were determined by gravimetric analysis.

Using the disturbance metrics of riparian and flood zones was performed a cluster analysis by using Euclidean distance. The metric values were the same for December 2011 and June 2012, because the evaluated human disturbances not show significant changes in such/short period of time, different from the physical and chemical parameters. After the formation of sampling site groups composed of disturbance metrics, a PERMANOVA (Dissimilarity/distance-based analysis of univariate or multivariate data in response to ANOVA experimental/sampling designs; Anderson 2001, Anderson & Braak 2003) was performed. Another PERMANOVA analysis was used to evaluate the differences between environmental variables between the years 2011 and 2012. This analysis assesses whether formed groups differ significantly. A single factor was selected: anthropogenic disturbance (with two levels: greater disturbance and lesser disturbance); with 999 permutations and a significance level ($\alpha \leq 0.05$). In order to identify which environmental variables influenced *C. largillierti* distribution, distance-based linear models were applied (DistLM) (Legendre & Anderson 1999). This analysis assesses the relation between one or more predictive variables for a group of biological data from a dissimilarity matrix. To determine variables, the "Best" test was performed. This test relates environmental variables to community structure by eliminating spatial effects; thus, the method searches for the best subgroup of environmental variables capable of explaining the community structure. The "Best" test was associated with the AIC criterion, as better AIC values indicate better models. Also, for assessing the occurrence of *C. largillierti*, anthropogenic disturbance levels for each site and site locations where the bivalve was found were organized in a bar-line combination chart (Legendre & Anderson 1999). All statistical tests were performed with PRIMER-6 + PERMANOVA softwares, Systat Software, Cranes Software International Ltd. (Ansderson et al. 2008).

Results

In 2011, *C. largillierti* was observed on a single location close to a tributary's confluence, presenting a density of 20.96 ind/m^2. In June 2012, specimens were recorded in six locations with densities of 62.89 ind/m^2 (sites 16 and 19); 41.92 ind/m^2 (sites 17 and 20); 20.96 ind/m^2 (sites 10 and 18), also close tributaries (Figure 2).

Average values for disturbance metrics in flood and riparian zones were separated into two main groups: the first one contained the lowest values, indicating areas with lower disturbance, and the second group contained the highest values (Figure 3), indicating more disturbance sites. Sites with lowest and highest disturbance values were significantly different (PERMANOVA: Pseudo-$F_{1.19}$ = 52.61; p = 0.001). Sites with less anthropogenic disturbance presented values ranging from 0.0 to 0.3, whereas more disturbance sites presented values over 0.3. Accordingly, 20% of the sites were classified as having lesser anthropogenic disturbance, and the remaining 80% as

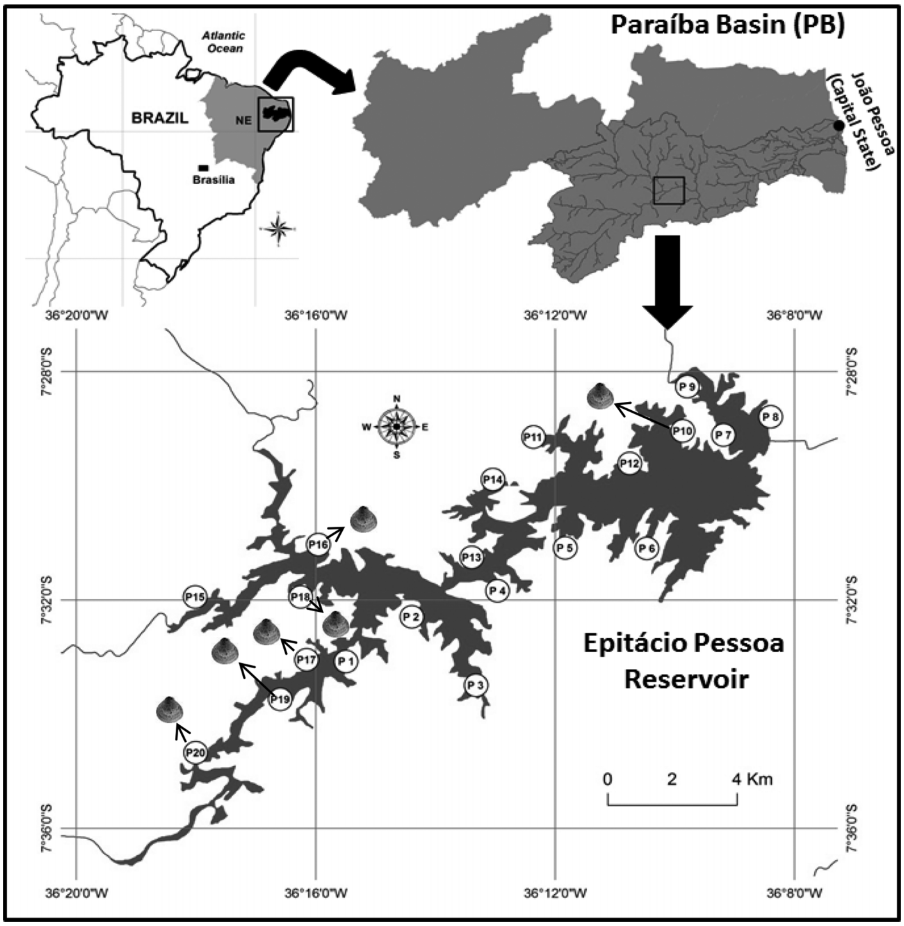

Figure 2. Distribution of *Corbicula largillierti* Epitácio Pessoa reservoir.

having greater disturbance. Of these last, 25 % showed *C. largillierti* occurrence. As regards sites close to tributaries, two sites (17 and 20), although classified as having low disturbance (disturbance < 0.3), showed *C. largillierti* (Figure 4).

DistLM analysis indicated that P-total and organic matter have determined *C. largillierti* distribution with a higher percentage (71%) on the sampling sites (Table 1). The model has also shown that P-total values significantly influenced the

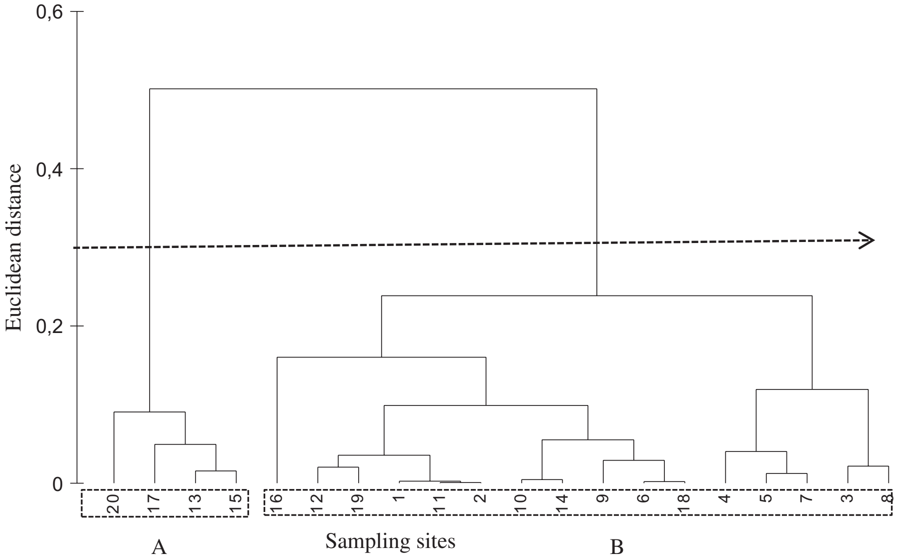

Figure 3. Dendrogram showing the clustering of the average values of the metrics of human disturbance on the sampling sites in the Epitácio Pessoa reservoir. (A) sites with lower values of metric disturbance and (B) places with higher metric disturbance.

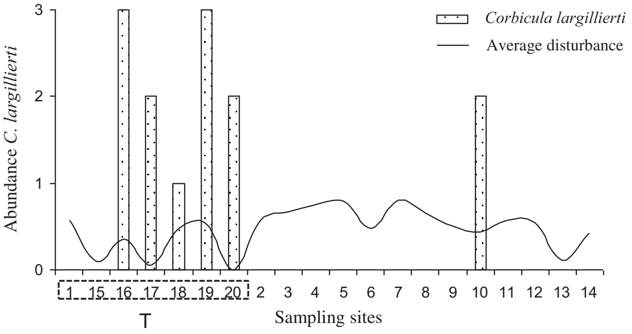

Figure 4. Sampling sites and occurrence of *C. largillierti*. Places near tributaries have a higher number of occurrences (T represents the nearby tributaries).

bivalve distribution (49%) when it was related to other environmental variables (Table 1).

The averages calculated for environmental variables demonstrated that groups classified as being of lesser disturbance by cluster analysis also presented lower nutrient concentration averages between the years, such as orthophosphate, total nitrogen, nitrate and nitrite (PERMANOVA: Pseudo-$F_{1,39} = 23.05$; $p = 0.001$) (Table 2).

Discussion

The occurrence of exotic species has increased over time because of habitat degradation and changes caused by human action (Sargent et al. 2011). *C. largillierti* recordings have shown that this mollusk species has reached reservoirs through tributaries, as most of the specimens were observed near confluences.

Recordings of increase in density and in the number of sampling sites with *C. largillierti* showed colonization progression in only six months (December 2011 to June 2012). Differently from other freshwater bivalve genera, *Corbiculidae* present high ecological and physiological plasticity, enabling their survival in a wide range of habitat conditions (Lucy et al. 2012), particularly in disturbed environments. Colonization progress in a short time is a cause for concern, as mollusks may impact the local benthic community (Santos et al. 2012, Torre & Reyna 2013), affecting different trophic levels (Jackson & Britton 2013) and provoking algae proliferation and substrate alteration (Everaert et al. 2011).

The *C. largillierti* prefers sites with sandy sediments, as observed in this study and also by Darrigran (2002) in studies performed on La Plata River. *C. largillierti* was mainly recorded on sites with thick sand sediments, indicating that the mollusk is still at an early stage of colonization; this can be inferred from the fact that interspecific competition will increase together with population and individuals will move to sites where the bottom is muddy (Torre & Reyna 2013). Species colonization is favoured by resource availability, such as high nutrient concentration (which is generally better for exotic species) (Darrigran et al. 2011, Darrigran 2002) given that *C. largillierti* is a filter feeder species. This hypothesis is supported by higher concentrations of nutrients in sites with greater disturbance, and in 2012, including some sites near the tributaries. These regions showed variables that facilitate the emergence of mollusk (total N and organic matter), these variables indicate disturbance together explained 71% of species distribution along the reservoir.

In studies performed in reservoirs located in tropical climate regions in Brazil, the presence of the exotic species *Melanoides tuberculata* (Müller 1774) (Caenogastropoda, Thiaridae) has been recorded in sites which presented maximum ecological potential (Molozzi et al. 2013). However, affected sites have near 97% more *M. tuberculata* individuals (Schirmel & Buchholz 2013). A similar observation was made in this work, whereby the exotic species *C. largillierti* was found in sites with good environmental conditions.

Sites with higher anthropogenic disturbance levels favour exotic species (Sargent et al. 2011). Apart from altering abiotic conditions and taxonomic composition, invasive species modify functional diversity, which is reflected in alterations of ecosystem functions and changes in productivity. These have consequences for ecosystem services (Schirmel & Buchholz 2013) such as hindering water self-purification capacity (Lorenz & Pusch 2013).

The occurrence of this mollusk makes it difficult to devise conservation efforts, especially given the transfer of water from the São Francisco River and the history of environmental degradation of the Caatinga biome (Oliveira et al. 2012). Transposition can bring new exotic species and promote the spread of *C. largillierti* to other ecosystems (Brasil 2004). A study conducted by Oliveira et al. (2010) predicted risk of exotic mollusk *L. fortunei* range the basin of the Rio São Francisco. In October 2015 the forecast has been confirmed, with record mollusk in the low-medium São Francisco river and transposition channel (north axis), according to Centro de Bioengenharia de Espécies Invasoras de Hidrelétricas (CBEIH 2015). This study provides an important methodology that should be considered for the management of the watershed studied, considering that the clam can reach other reservoirs in the basin, as well as natural ecosystems.

Niche modelling studies (Peterson & Vieglais 2001), assessment of limiting factors, predicting the potential risk of introducing exotic species (Darrigran et al. 2011, Oliveira et al. 2010), and management and handling to reduce impacts caused by invasive species should be conducted to support management measures and conservation of aquatic ecosystems. It is important to know when an invader has higher odds of

Table 1. Results of the DistLM (distance-based linear models) analysis, and the environmental variables which contributed to the distribution of *C. largillierti*). Df (degree of freedom), P (p-value, significance), R^2 (total percentage variation).

Variables	**Df**	**p**	**R^2**
Total phosphorus	5	0.04	0.49
Total phosphorus / Organic matter	5	0.04 / 0.13	0.71
Total phosphorus / Nitrate / Gravel	5	0.04 / 0.05 / 0.15	0.82
Temperature / Oxi-redox potential / Organic matter / Grit	5	0.45 / 0.004 / 0.13 / 0.01	0.90
Turbidity / Alkalinity / Total nitrogen / Organic matter / Grit	5	0.37 / 0.08 / 0.20 /0.13 / 0.01	0.96

Table 2. Mean and standard deviation values of physical and chemical variables in the sampling sites of minor and greatest disturbance, * It represents variables that showed significant differences ≤ 0,01, between the years 2011 and 2012.

	2011		2012	
	Minor disturbance	**Greatest disturbance**	**Minor disturbance**	**Greatest disturbance**
*Water temperature (°C)	29.58 ± 0.75	28.35 ± 0.80	27.09 ± 0.93	26.37 ± 0.73
*pH	8.22 ± 0.63	7.92 ± 0.57	9.87 ± 0.82	9.04 ± 0.51
*Oxi-redox potential (mV)	185.50 ± 34.81	203.50 ± 19.16	86.50 ± 28.54	113.68 ± 19.83
*Electrical conductivity (mS/cm)	0.80 ± 0.08	0.75 ± 0.02	0.88 ± 0.02	0.85 ± 0.02
Turbidity (NTU)	132.82 ± 142.98	120.78 ± 193.90	117.77 ± 153.23	21.17 ± 20.16
Dissolved oxygen (mg/L^{-1})	8.97 ± 1.36	7.69 ± 1.90	8.71 ± 0.37	8.34 ± 1.44
*Total dissolved solids (g/L^{-1})	0.51 ± 0.05	0.48 ± 0.016	0.56 ± 0.01	0.54 ± 0.01
Alkalinity ($CaCo_3$ mg/L^{-1})	17.50 ± 5.91	14.81 ± 4.73	16.00 ± 1.14	16.43 ± 2.06
*Total phosphorus -P-total ($\mu g/L^{-1}$)	1230.0 ± 214.39	996.25 ± 154.09	150.49 ± 29.85	207.68 ± 270.69
*Orthophosphate -PO_4 ($\mu g/L^{-1}$)	40.25 ± 16.00	57.12 ± 89.19	119.10 ± 9.84	127.35 ± 6.96
*Total nitrogen - N-total ($\mu g/L^{-1}$)	373.57 ± 53.77	313.25 ± 114.18	433.07 ± 73.13	452.38 ± 95.13
Ammonia-NH_4 ($\mu g/L^{-1}$)	93.77 ± 136.49	215.69 ± 175.21	609.13 ± 868.63	158.32 ± 46.98
*Nitrate-NO_3 ($\mu g/L^{-1}$)	42.73 ± 14.49	47.42 ± 12.52	31.81 ± 2.02	30.69 ± 4.80
*Nitrite-NO_2 ($\mu g/L^{-1}$)	3.68 ± 1.075	4.49 ± 3.36	9.61 ± 1.43	11.54 ± 1.24
Organic matter (% P.S)	8.34 ± 5.81	7.26 ± 4.53	7.10 ± 2.73	8.21 ± 3.6
Gravel % (2–64mm)	13.89 ± 18.88	18.84 ± 19.02	44.95 ± 22.75	66.61 ± 132.06
*Grit % (1–0.50mm)	21.37 ± 14.93	23.62 ± 7.70	95.38 ± 30.27	76.64 ± 52.42
*Medium sand % (0.250–1mm)	10.69 ± 6.31	20.01 ± 9.80	36.20 ± 16.72	46.43 ± 21.78
*Fine sand % (0.250–0.062mm)	13.86 ± 13.28	17.07 ± 10.57	41.71 ± 17.37	48.37 ± 21.06
*Silt / clay % (<0.062mm)	16.87 ± 15.75	20.44 ± 13.37	154.28 ± 167.41	77.51 ± 64.04

reaching a new environment and which places have favourable conditions for housing invasive species in order to facilitate management and conservation (Ferrari et al. 2014). Biomonitoring programs should include metrics of human disturbance, as performed in this study, and functional metrics, given that exotic species promote changes in ecosystem functioning (Lopes-Lima et al. 2014, Silva et al. 2014).

Acknowledgments

We thank the Coordenacão de Aperfeiçoamento de Pessoal de Nível Superior (Capes) for the provision of a masters scholarship that enabled the development of this work, the Universidade Estadual da Paraíba (UEPB), colleagues from the Laboratório de Ecologia de Bentos (UFMG) and Laboratório de Ecologia Aquática (UEPB). MC was awarded research productivity grants CNPq (No. 302960/2011-2) and Minas Gerais researcher grant FAPEMIG PPM-77/13 and PPM IX-02/2015.

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Received 10/09/2015
Revised 22/12/2015
Accepted 20/01/2016

Biota Neotropica 16(1): e20140195, 2016
www.scielo.br/bn

biotaneotropica
ISSN 1676-0611 (online edition)

short communication

Checklist and description of three new chromatic patterns of *Pachycoris torridus* (Scopoli, 1772) (Hemiptera: Scutelleridae)

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Abstract: In the present paper, 27 chromatic patterns of the specie *Pachycoris torridus* (Scopoli, 1772) were grouped and three new patterns are described. Because of this high phenotypic polymorphism, *P. torridus* already been registered eight times as a new specie, highlighting the importance of the application of different tools to assist in taxonomy of this hemipterous of economic importance.

Keywords: *Insect, Heteroptera, polymorphism, agricultural pest.*

SOUZA-FIRMINO, T.S., ALEVI, K.C.C., PEREIRA, L.L., BANHO, C.A., SILVA JUNIOR, F.C., SOUZA, E.R.S., ITOYAMA, M.M. **Checklist e descrição de três novos padrões cromáticos de Pachycoris torridus (Scopoli, 1772) (Hemiptera: Scutelleridae).** Biota Neotropica. 16(1): e20140195. http://dx.doi.org/10.1590/1676-0611-BN-2014-0195

Resumo: No presente artigo, 27 padrões cromáticos da espécie *Pachycoris torridus* (Scopoli, 1772) são agrupados e três novos padrões são descritos. Devido a esse grande polimorfismo fenotípico, *P. torridus* já foi registrado oito vezes como espécie nova, o que ressalta a importância da aplicação de diferentes ferramentas para auxiliar na taxonomia desse hemíptero de importância econômica.

Palavras-chave: *Insecta, Heteroptera, polimorfismo, peste agrícola.*

Introduction

The insects of the Scutelleridae family are popularly known as shield-backed bug, due to its scutellum which covers the whole body (Grazia & Schwertner 2011). A striking feature of Scutelleridae is intraspecific phenotypic variability, as can be observed in the species *Poecilocoris lewisi* (Distant, 1883), *Pachycoris klugii* (Burmeister, 1835) and *Pachycoris torridus* (Scopoli, 1772) (Miyamoto & Kosaku 2002, Peredo 2002). *Pachycoris* species are very similar to each other, although few differences exist among their genitalia and measure of scutellum and head (Peredo, 2002).

The stink bug *P. torridus* is phytophagous and polyphagous that has great prominence as an agricultural pest, with records of their attacks in 16 vegetable crops (Marques et al., 2012), with emphasis on the cultures of physic nut (*Jatropha curcas* Linnaeus 1753), raw material for the production of biodiesel (Borges Filho et al. 2013). This hemipterous is longevous and can live out to 600 days (Gabriel & Franco, 2012), with wide distribution in the Neotropical region. Shows a wide variation in chromatic patterns, characteristic that made *P. torridus* be registered several times as a new species (Costa Lima 1940), getting names like: *Tetyra schousboei* (Fabricius, 1803), *Pentatoma fabricii* (Tigny 1801), *Scutellera decorate* (Perty, 1833), *Pachycoris Klungii* (Burmeister, 1835), *Pachycoris linaei* (Westwood in F. W. Hope 183), *Pachycoris Aquila* (Herrich-S. 1839), *Pachycoris stallii* (Uhler 186) and *Poecilocoris aeneiventris* (Vollenhoven, 1863) (Maes 1994).

Monte (1937) initiated the descriptions of stains patterns of this stink bug and registered 13 different patterns, terming standard 1 to 13. The author highlights the pattern 13 (Figure 1) as the basic for *P. torridus*. Currently, there are 27 chromatic patterns described for this hemipterous in different scientific articles (Monte 1937, Sanchez-Soto 2004, Santos et al. 2005, Pikart 2011, Souza et al. 2012). Thus, in this study we performed a checklist of all the patterns of stains described in the literature for *P. torridus* and we describe three new (Figure 2).

Material and Methods

The checklist of twenty-seven chromatic patterns described for *P. torridus* was compiled from the literature (Monte 1937, Sanchez-Soto 2004, Santos et al 2005, Pikart 2011, Souza et al. 2012). For description of three new patterns, specimens of *P. torridus* were collected in Brotas, Sao Paulo, Brazil (22°14'17.6" S, 48°07'56.0" W) in *Jatropha curcas* Linnaeus (1753). The description was based on

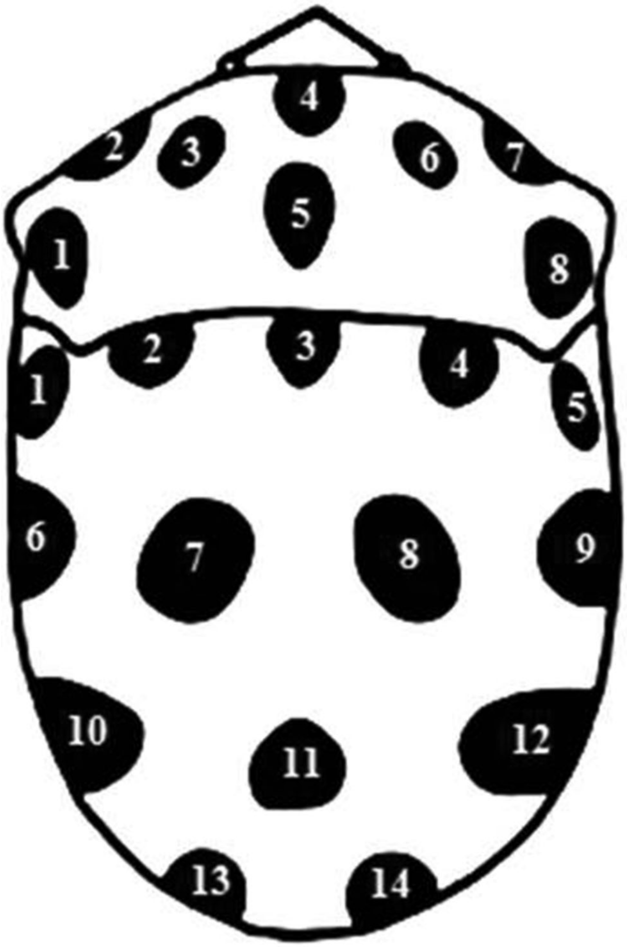

Figure 1. Basic pattern of *P. torridus* described by Monte (1937), with 22 spots, being 8 on pronotum and 14 on scutellum.

basic pattern of spots described by Monte (1937). Vouchers were deposited in the collection of the Laboratory of Cytogenetics and Molecular of Insects, of Institute of Biosciences, letters and the Exact Sciences (UNESP/IBILCE), Sao Jose do Rio Preto, Sao Paulo, Brazil.

Results

The stink bugs of the specie *Pachycoris torridus* are globular, with scutellum very developed, showing different patterns of stains and colors of its body, the coloring of the spots vary of yellow to red. In this checklist, 27 chromatic patterns identified for this species are detailed and ilustrated (Figure 3), according to the information of its publication, classified with pattern 1 to 27th in the order which they were reported. Three new chromatic patterns are described on this paper, totalizing one list with 30 chromatic patterns for this insect.

Pattern 1. Features 15 spots. Pronotum with six, being two near the head, two on the sides and two in the posterior region, and scutellum with nine, arranged in four rows, respectively 2, 4, 2 and 1 spots starting from the base to the apex (Monte 1937).

Pattern 2. Features 4 spots. Pronotum and scutellum with two spots, both of paired (Monte 1937).

Pattern 3. Features 8 spots. Pronotum with four, being two in the middle region disposed in parallel and two on the sides, and scutellum with four, arranged in three rows, being the last with two spots (Monte 1937).

Pattern 4. Features 16 spots. Pronotum with six, arranged in two rows with 2 and 4 stains, respectively, and scutellum with ten spots, arranged in four rows of 2, 2, 4 and 2 spots each, starting from the base to the apex (Monte 1937).

Pattern 5. Features 14 spots. Pronotum with four, being two rows with two spots each, and scutellum with ten, arranged in four rows of 2, 2, 4 and 2 spots, respectively, from base to apex (Monte 1937).

Pattern 6. Features 12 spots. Pronotum with six, being two near the head, two on the sides and two in the posterior region, and scutellum with six, arranged in three rows of 1, 4, 1 stains, being one big spot next to the base region (Monte 1937).

Pattern 7. Features 15 spots. Pronotum with six, being two near the head, two on the sides and two in the posterior region, and scutellum with nine, arranged in four rows with 2, 4, 2 and 1 spots, respectively, from base to apex (Monte 1937).

Pattern 8. Features 7 spots. Pronotum with two big spots, and scutellum with five, being one big in the region near the base, two on the sides and two near the apex (Monte 1937).

Pattern 9. Features 2 spots. Pronotum and scutellum with one big spot on each, featuring the spaces that would be the spots on basic pattern (Figure 1) (Monte 1937).

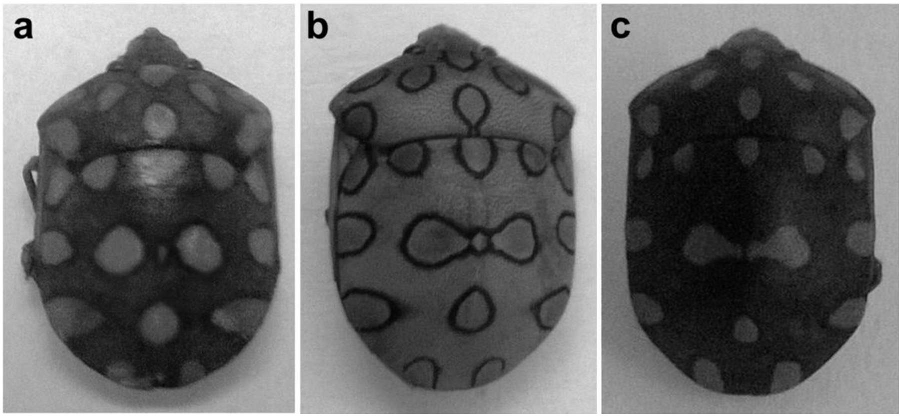

Figure 2. New chromatics patterns observed in the present work. a) Pattern 28; b) Pattern 29; c) Pattern 30.

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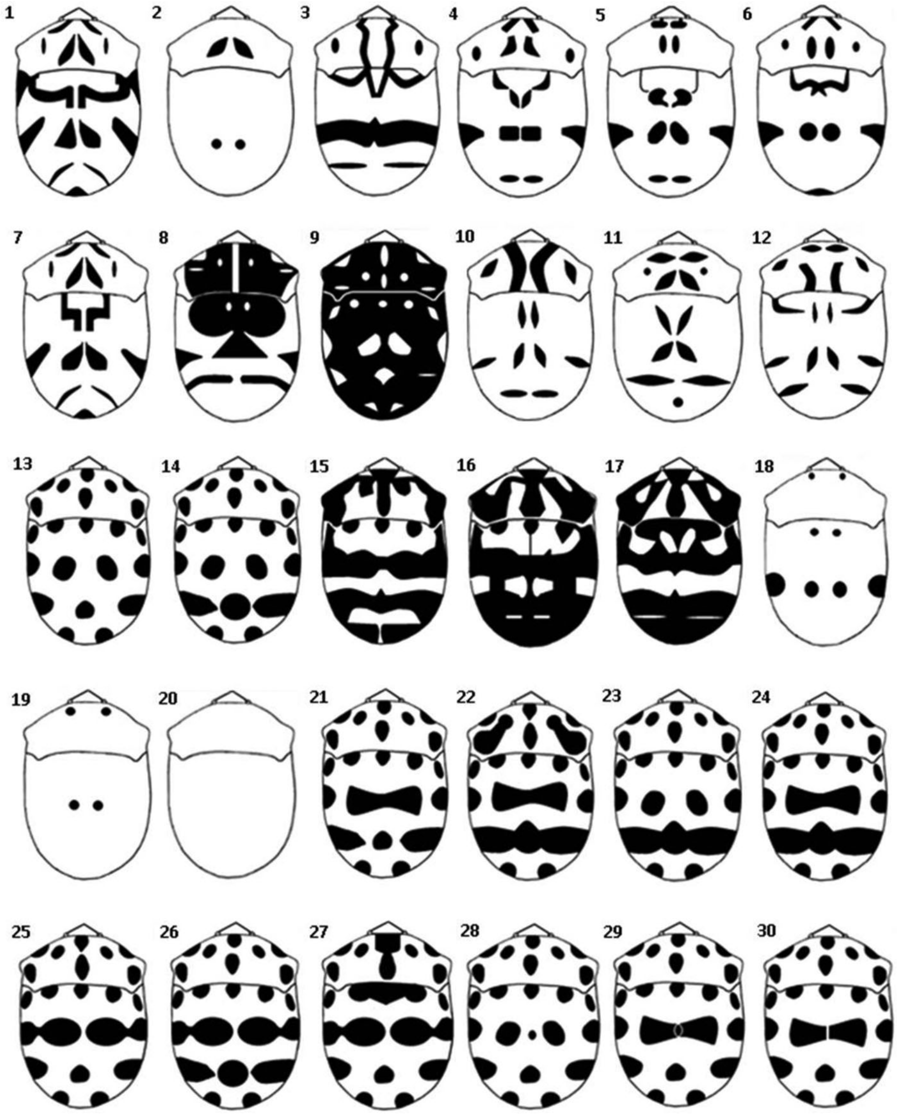

Figure 3. Schemes of 30 chromatic patterns of *P. torridus*. In black the spots.

Pattern 10. Features 12 spots. Pronotum with four, being two in the middle, and two on the sides, and scutellum with eight, arranged in three rows with 2, 4 and 2 spots each (Monte 1937).

Pattern 11. Features 13 spots. Pronotum with six, being two near the base, two near the apex and two on the sides, and scutellum with seven, arranged in four rows with 2, 2, 2 and 1 spots respectively from base to apex (Monte 1937).

Pattern 12. Features 16 spots. Pronotum with six, being two near the base, two near the apex and 2 on the sides, and scutellum with ten, arranged in three rows of 4, 4 and 2 spots, respectively, from the base to the apex (Monte 1937).

Pattern 13. Features 22 spots. Pronotum with eight spots, and scutellum with fourteen, neatly arranged in four rows, respectively of 5, 4, 3 and 2 spots from base to apex (Monte 1937).

Pattern 14. Features 22 spots. Pronotum with eight spots, and scutellum with fourteen, with the spots 10, 11 and 12 higher than the basic pattern (Figure 1) and very close together (Sanchez-Soto et al. 2004).

Pattern 15. Features 6 spots. Pronotum with a single spot, the eight spots of the basic pattern (Figure 1) joined from lateral and anterior margins, and scutellum with five spots, the spots 1, 6, 7, 8, 9 and 5, joined and formed a continuous strip, and spots 10, 11, 12, 13 and 14 joined leaving a small space near the apex (Sanchez-Soto et al. 2004).

Pattern 16. Features 3 spots. Pronotum with one spot, formed by the union of the eight spots of the basic pattern (Figure 1), and scutellum with two spots, one is the spot 2 of the basic pattern (Figure 1), and the other formed by the union of spots 1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 and 14 (Sanchez-Soto et al. 2004).

Pattern 17. Features 3 spots. Pronotum with one spot, formed by the union of the 8 spots of the basic pattern (Figure 1), and scutellum with two spots formed by the union of spots 1, 2, 3, 4, 5, 6, 7, 8 and 9, near the base, and spots 10, 11, 12, 13 and 14 near the apex (Sanchez-Soto et al. 2004).

Pattern 18. Features 8 spots. Pronotum with two near the head, and scutellum with six, being two near the base, two on median region, and two on the sides (Santos et al. 2005).

Pattern 19. Features 4 spots. Pronotum with two near the head, and scutellum with two on the medium region (Santos et al., 2005).

Pattern 20. Without spots (Santos et al., 2005).

Pattern 21. Features 21 spots. Pronotum with eight spots, and scutellum thirteen, with the spots 7 and 8 of the basic pattern joined (Figure 1) and the spots 10 and 12 larger than the basic pattern (Pikart et al. 2011).

Pattern 22. Features 17 spots. Pronotum with six, being spots 1 and 8 of the basic pattern (Figure 1) joined, respectively, with the spots 3 and 7, and scutellum with eleven, presented the spots 7 and 8 united, and spots 10, 11 and 12 joined forming a continuous strip (Souza et al. 2012).

Pattern 23. Features 20 spots. Pronotum with eight, and scutellum with twelve, the spots 10, 11 and 12 of the basic pattern (Figure 1) joined forming a continuous strip (Souza et al. 2012).

Pattern 24. Features 19 spots. Pronotum with eight spots, and scutellum with eleven, the spots 7 and 8 of the basic pattern joined (Figure 1) and spots 10, 11 and 12 grouped forming a continuous strip (Souza et al. 2012).

Pattern 25. Features 20 spots. Pronotum with eight spots, being the spots 4 and 5 very close together, and scutellum with 12, being the spots 6 and 9 joined, respectively, with spots 7 and 8 (Souza et al. 2012).

Pattern 26. Features 20 spots. Pronotum with eight spots, and scutellum with twelve, the spots 6 and 7 joined, as well as the spots 8 and 9, and the spots 10, 11 and 12 are larger and closer together (Souza et al. 2012).

Pattern 27. Features 17 spots. Pronotum with seven, the spots 4 and 5of basic pattern joined (Figure 1), and scutellum with ten, the spots 2, 3 and 4 grouped near the base forming a continuous strip and spots 6 and 9 joined, respectively, with spots 7 and 8 (Souza et al. 2012).

Pattern 28. Features 23 spots. Pronotum with eight spots, and scutellum fifteen, with one additional spot between the spots 7 and 8 of the basic pattern (Figure 1). (This paper) (Figure 2a).

Pattern 29. Features 21 spots. Pronotum with eight spots, and scutellum with thirteen, the spots 7 and 8 of the basic pattern joined (Figure 1) (This paper) (Figure 2b).

Pattern 30. Features 22 spots. Pronotum with eight spots, and scutellum with fourteen, the spots 7 and 8 are larger and closer together, that the basic pattern (Figure 1) (This paper) (Figure 2c).

Discussion

The stink bug *P. torridus* shows different phenotypes with several variations in the pattern of spots and colors of your body, however, all their phenotypic diversity had not been described. Monte (1937) iniciated the disciption of this species and recorded 13 different patterns in 13 of 16 specimens collected on an unidentified plant. He depicted the basic chromatic patterns of this stink bug as being one that presents 22 spots, being eight in the pronotum and 14 in the scutellum, neatly arranged in the scutellum where present in four rows respectively of 5, 4, 3 and 2 spots, starting from the base to the apex. The color of the spots is diversified, varying of red to yellow (Monte, 1937). Years later, Sanchez-Soto et al. (2004) recorded in *Schinus terebinthifolius* Raddi (1820) more four patterns; Santos et al. (2005) more three in *Cnidoscolus pubescens* Pohl (1827); Pikart et al. (2011) described a new pattern in *Coffea arabica* Linnaeus (1737) and, Souza et al. (2012) described six patterns with specimens collected in *Jatropha curcas* Linnaeus (1753). In this article we performed a checklist of the 27 color patterns described and we describe three new patterns, completing a list of 30 color patterns described for *P. torridus.*

The high polymorphism of *P. torridus* already led to great taxonomic mistakes, with this species described eight time as new (Costa Lima 1940). According to Monte (1937), the color variations of *P. torridus* are not hereditary and the factors that may contribute to the differentiation of a color are diverse and complex, however the factors involved in the polychromatism of *P. torridus* have not yet been identified.

Grazia & Schwertner (2011) in a checklist about biodiversity of the State of Sao Paulo, Brazil, emphasized that the Scutelleridae family needs of taxonomic revision and highlighted the importance of the developing of tools to identification and dissemination of the knowledge of the group. Souza et al. (2012) also emphasize that the high chromatic variation of *P. torridus* makes necessary to describe new phenotypes to assure its correct taxonomic identification. Souza-Firmino et al. (2014) described the presence of *P. torridus* in 15 Brazilian states and emphasized their infestations in the culture of physic nut and they highlight the characteristic of polyphagous of *P. torridus*, which allows this insect can colonize and mainly become an agricultural pest to other crops of economic importance.

Thus, because of this great importance as agricultural pest, this great phenotypic variability and due the scarcity of information about this insect, the checklist and description of three new chromatic patterns of *P. Torridus*, is a new tool for taxonomy of this stink bug, synthesizing all the chromatic patterns described for the specie.

Conclusion

This article makes, for the first time, one checklist of all the chromatic patterns described for the specie *P. torridus* and fundament the patterns already described in descriptions initial contained in scientific articles. Thus, this study enabled us to identified the high chromatic polymorphism of this stink bug.

Acknowledgments

This research was supported by Fundação de Apoio à Pesquisa e Extensão de São José do Rio Preto (FAPERP) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

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Received 5/01/2015
Revised 30/01/2016
Accepted 11/02/2016