

Herpetofauna of the Environmental Protection Area Delta do Parnaíba, Northeastern Brazil

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ABSTRACT

Recent studies on Brazilian coastal zones and restinga environments revealed a high richness of amphibian and reptile species. However, there is still a lack of information about herpetofauna diversity in coastal zones of Northeastern Brazil. This study provides a checklist of amphibians and reptiles inhabiting the Environmental Protection Area (EPA) Delta do Parnaíba, Northeastern Brazil, suggesting conservation actions. To elaborate the checklist, we searched in seven electronic databases and check the following scientific collections: Zoological collection of Universidade Federal do Piauí (UFPI) and Herpetological collection of Universidade Regional do Cariri (URCA). In addition, we sampled 16 areas along the EPA Delta do Parnaíba close to the river branches and temporary ponds that compose the Parnaíba River Delta (December 2015 to April 2017) to fill gaps of information about herpetofauna in some regions from the EPA. We recorded 86 species (34 amphibians and 52 reptiles), including four anurans, one crocodylian, 14 snakes, 12 lizards and two amphisbaenians reported for the first time for the EPA Delta do Parnaíba. In addition, we added the first record of the snake *Oxybelis fulgidus* in Piauí state. The EPA Delta do Parnaíba shows high herpetofaunal richness; thus, we suggest that conservation actions should be taken to preserve the restingas environments in the Parnaíba River Delta and its high diversity of amphibians and reptiles.

Key words: Checklist; Amphibians; Reptiles; Parnaíba River Delta.

RESUMO

As áreas costeiras e ambientes de restinga têm sido bastante estudados nos últimos anos. Estes ambientes apresentam uma elevada riqueza de anfíbios e répteis, no entanto ainda existem lacunas de informações sobre a diversidade da herpetofauna nas áreas costeiras da região Nordeste do Brasil. O presente estudo fornece uma lista dos anfíbios e répteis que ocorrem na Área de Proteção Ambiental (APA) Delta do Parnaíba, Nordeste do Brasil, e sugestões que auxiliem na conservação destas espécies na região. Para a elaboração da lista da herpetofauna do Delta do Parnaíba nós realizamos uma pesquisa bibliográfica em publicações científicas disponíveis em sete banco de dados eletrônicos, e consultamos os acervos das seguintes coleções científicas: Coleção Zoológica do Delta do Parnaíba, da Universidade Federal do Piauí (UFPI) e Coleção Herpetológica da Universidade Regional do Cariri (URCA). Adicionalmente, para preencher algumas lacunas sobre a herpetofauna da APA Delta do Parnaíba nós amostramos 16 áreas ao longo da APA próximas aos braços dos rios e lagoas temporárias que formam o Delta do Parnaíba (dezembro de 2015 e abril de 2017). Nós registramos 86 espécies (34 anfíbios e 52 répteis), sendo que quatro espécies de anfíbios anuros, um crocodilo, 14 espécies de serpentes, 12 lagartos e duas anfisbenas tiveram seus primeiros registros para a APA Delta do Parnaíba. Além disso, adicionamos o primeiro registro *Oxybelis fulgidus* para o estado do Piauí. A APA Delta do Parnaíba possui uma rica herpetofauna; portanto, sugerimos que ações de conservação sejam tomadas para preservar a restinga no delta do Rio Parnaíba e sua alta diversidade de anfíbios e répteis.

Palavras-chave: Inventário; Anfíbios; Répteis; Delta do Rio Parnaíba.

Introduction

Species inventories are crucial for decisions about natural environments management and conservation (Silveira *et al.*, 2010). Faunal conservation is essential to biological and ecological stability and maintenance of biological diversity (Almeida, 1996). However, despite being considered one of the countries with the highest biodiversity worldwide (Lewinson and Prado, 2004), there is still a lack of information about Brazilian biodiversity and extensive areas remain understudied.

There are 548 Conservation Units in Brazil, both federal and state Units (Brasil, 2020), and the establishment of these "Biodiversity Islands" has been an important tool for natural resources preservation and conservation in Brazil (Hassler, 2005). Historically, the biodiversity data generated for these conservation areas, mainly in the Caatinga domain, were based on inaccurate data (Leal *et al.*, 2005), a situation that has only improved in the last decade with an increase of studies in the region (Camardelli and Napoli, 2012; Pedrosa *et al.*, 2014; Benício *et al.*, 2015; Calixto and Morato, 2017; Marinho *et al.*, 2018; Campos *et al.*, 2019); however, since these studies do not cover all Conservation Units, it is necessary to gather more data for a consistent ecological database. Therefore, it is important to elaborate adequate management strategies and plans that aimed the conservation of these environments and the species living there.

Among the Brazilian Conservation Units, the Environmental Protected Area (EPA) Delta do Parnaíba had a considerable number of studies about local herpetofauna recently published, including amphibian checklists (Silva *et al.*, 2007; Loebmann and Mai, 2008; Andrade *et al.*, 2014; 2016), reptile distribution records (Loebmann *et al.*, 2006; Battistella *et al.*, 2008; Santana *et al.*, 2009; Silva-Leite *et al.*, 2009; 2010a; 2010b; Roberto *et al.*, 2012), and ecological relationships (Araújo *et al.*, 2018). However, there is still a lack of information about reptile species and undersampled areas in the EPA Delta do Parnaíba.

The local fauna may reflect the conservation status from a given geographic region because some species have their important functions closely linked to environmental alterations. Therefore, these species are considered bioindicators of environment quality, being important to measure the conservation status of an area (Hodkinson and Jackson, 2005). Among

the vertebrates, both amphibians and reptiles are considered important environmental bioindicators (Pianka and Vitt, 2003; Toledo, 2009). Moreover, they are highly threatened (IUCN, 2020), and climate changes, habitat loss, and fragmentation are the main causes of declines and extinctions (Rodrigues, 2005; McCallum, 2007; Alroy, 2015; Andrade, 2015). Therefore, it is important to provide herpetofaunal checklists to evaluate the conservation status from a region and plan future actions that aimed to maintain biological diversity.

In recent years, new amphibians and reptiles species were described in Brazil (*e.g.* Fernandes and Hamdan, 2014; Lourenço *et al.*, 2014; Magalhães *et al.*, 2014; Pansonato *et al.*, 2014; Colli *et al.*, 2015; Maciel *et al.*, 2015; Carvalho *et al.*, 2016; Franco *et al.*, 2017). However, without carrying out exhaustive checklists and fieldworks, many Brazilian species could become extinct before scientists even have a chance to identify them. Thus, the present study provides an amphibian and reptile checklist from the Environmental Protection Area (EPA) Delta do Parnaíba, Northeastern Brazil.

Material and methods

Study area

The Environmental Protection Area (EPA) Delta do Parnaíba was instituted from Federal Decree n° 99,274 on 06 June 1990 for preservation and conservation of natural water resources, fauna and flora from region. The EPA has approximately 3,138 km² encompassing the Brazilian municipalities of Ilha Grande, Parnaíba, Luís Correia and Cajueiro da Praia, in Piauí state; Araisos and Tutóia, in Maranhão state; Chaval and Barroquinha, in Ceará state (Brasil, 2002; Fig. 1).

The EPA Delta do Parnaíba is located within a transitional area between Caatinga and Cerrado morphoclimatic domains (Ab'Saber, 1977). Despite mangrove forests being present in the Parnaíba River Delta (Brasil, 2006), the restinga is the predominant physiognomy, located on a quaternary environment, characterized by sandy soils with high salt concentrations and covered predominantly by herbaceous and shrubby xerophytic vegetation (Xavier *et al.*, 2015). This physiognomy was labeled in three basic formations: grasses, shrub and arboreal, being the families Fabaceae, Poaceae, Cyperaceae, and Euphorbiaceae

most abundant in the Piauí state coastal vegetation (see Santos-Filho *et al.*, 2010; 2015).

Sampling

The bibliographic reference searches to elaborate the herpetofaunal checklist from the EPA Delta do Parnaíba was carried out in scientific publications available from seven electronic databases (Google, Google Scholar, PubMed, Scielo, Science Direct, Scopus and Web of Science) using 18 keywords combined amongst itself in English and Portuguese (Alligators, Amphibians, Anurans, Ceará state, Coastal zone, Crocodiles, Gymnophiona, Lizards, Maranhão state, Parnaíba River Delta, Piauí state, Reptiles, Serpents, Snakes, Snakes blind, Squamata, Testudines and Turtles). Furthermore, the following scientific collections were consulted: Zoological collection of Universidade Federal do Piauí (UFPI) and Herpetological collection of Universidade Regional do Cariri (URCA). The data compilation of the collections and literature records occurred from February 2017 to March 2020.

We also sampled 16 areas along the EPA Delta do Parnaíba located between the coordinates 2°49'15.39" S; 42°17'34.82" W (WGS84 datum and 26 m a.s.l) and 2°59'30.83" S; 41°11'34.48" W (WGS84 datum, 10 m a.s.l). Samples were carried out near river branches and temporary ponds that compose the Parnaíba River Delta (December 2015 to April 2017). The sampled areas are located in Tutóia and Araisos municipalities, Maranhão state; Ilha Grande, Parnaíba and Cajueiro da Praia, Piauí state; Chaval and Barroquinha, Ceará state (see Fig. 1). Herpetofaunal sampling occurred during the nocturnal period (06:00 p.m. to 00:00 a.m., sampling effort of approximately 1.248 hours/4 researchers) employing visual (Crump and Scott Junior, 1994) and auditory surveys (Zimmerman, 1994). The voucher specimens were deposited in the Zoological collection of Universidade Federal do Piauí (UFPI) and Herpetological collection of Universidade Regional do Cariri (URCA). The species nomenclature follows Frost (2020) and Costa and Bérnils (2018).

Statistical analyzes

Species distributions and associations with other Brazilian morphoclimatic domains (see Ab'Saber, 1977) were obtained from literature to amphibian records (see Bastazini *et al.*, 2007; Ferrão *et al.*, 2012; Valdujo *et al.*, 2012; Dal Vechio *et al.*, 2013; 2015; Roberto *et al.*, 2013; Gondim-Silva *et al.*, 2016;

Andrade *et al.*, 2017; Freitas *et al.*, 2017) and reptile records (see Bertoluci *et al.*, 2009; Condez *et al.*, 2009; Scartozzoni *et al.*, 2009; Loebmann and Hadad, 2010; Recoder *et al.*, 2011; Dal Vechio *et al.*, 2013; 2015; Guedes *et al.*, 2014; Freitas *et al.*, 2016; 2017; Costa and Bérnils, 2018; Uetz *et al.*, 2020). Species that occur in the four Brazilian morphoclimatic domains were considered of wide distribution. The herpetofaunal conservation status was obtained from IUCN (2020).

We also search for herpetofaunal scientific publications performed in the Brazilian restingas in the above-cited electronic databases. This literature was used to compare the composition and species richness of the EPA Delta do Parnaíba with other studies performed along the Brazilian coastal zone. For amphibians, we used published databases from the states of Amapá (Araújo and Costa-Campos, 2014), Ceará (Borges-Leite *et al.*, 2014; Roberto and Loebmann, 2016), Maranhão (Miranda, 2007), Bahia (Bastazini *et al.*, 2007; Rocha *et al.*, 2008; Gondim-Silva *et al.*, 2016; Dantas *et al.*, 2019), Espírito Santo (Rocha *et al.*, 2008; Oliveira *et al.*, 2020), Rio de Janeiro (Rocha *et al.*, 2008; Silva *et al.*, 2008; Telles *et al.*, 2012; Carmo *et al.*, 2019; Martins *et al.*, 2019), São Paulo (Narvaes *et al.*, 2009; Vilela *et al.*, 2011; Zina *et al.*, 2012), Santa Catarina (Pacheco, 2012; Wachlevski and Rocha, 2016; Argaez *et al.*, 2017), and Rio Grande do Sul (Colombo *et al.*, 2008; Quintela *et al.*, 2009; Oliveira *et al.*, 2013). For reptile, we used published databases from the states of Maranhão (Miranda *et al.*, 2012), Ceará (Borges-Leite *et al.*, 2014; Roberto and Loebmann, 2016), Rio Grande do Norte (Freire, 1996), Paraíba (Freire, 1996; Falcão, 2009; Sampaio *et al.*, 2018), Bahia (Couto-Ferreira *et al.*, 2011; Dias and Rocha, 2014; Travassos *et al.*, 2015; Marques *et al.*, 2016; 2017; Fazolato *et al.*, 2019a, 2019b; Marques and Tinôco, 2019; Travassos *et al.*, 2019a, 2019b), Espírito Santo (Silva-Soares *et al.*, 2011; Rocha *et al.*, 2014), Rio de Janeiro (Rocha *et al.*, 2004; Carvalho *et al.*, 2007; Lamonica, 2007; Rocha and Sluys, 2007; Martins *et al.*, 2012; 2019), São Paulo (Marques and Sazima, 2004; Hartmann, 2005; Cicchi *et al.*, 2009), Santa Catarina (Ghizoni-Junior *et al.*, 2009; Kunz *et al.*, 2011; Dacol, 2015; Argaez *et al.*, 2017), and Rio Grande do Sul (Santos *et al.*, 2012; Souza-Filho and Verrastro, 2012). Sea turtles recorded in the Parnaíba River Delta also occur along the Brazilian coast (Costa and Bérnils, 2018).

Subsequently, we created a presence and ab-

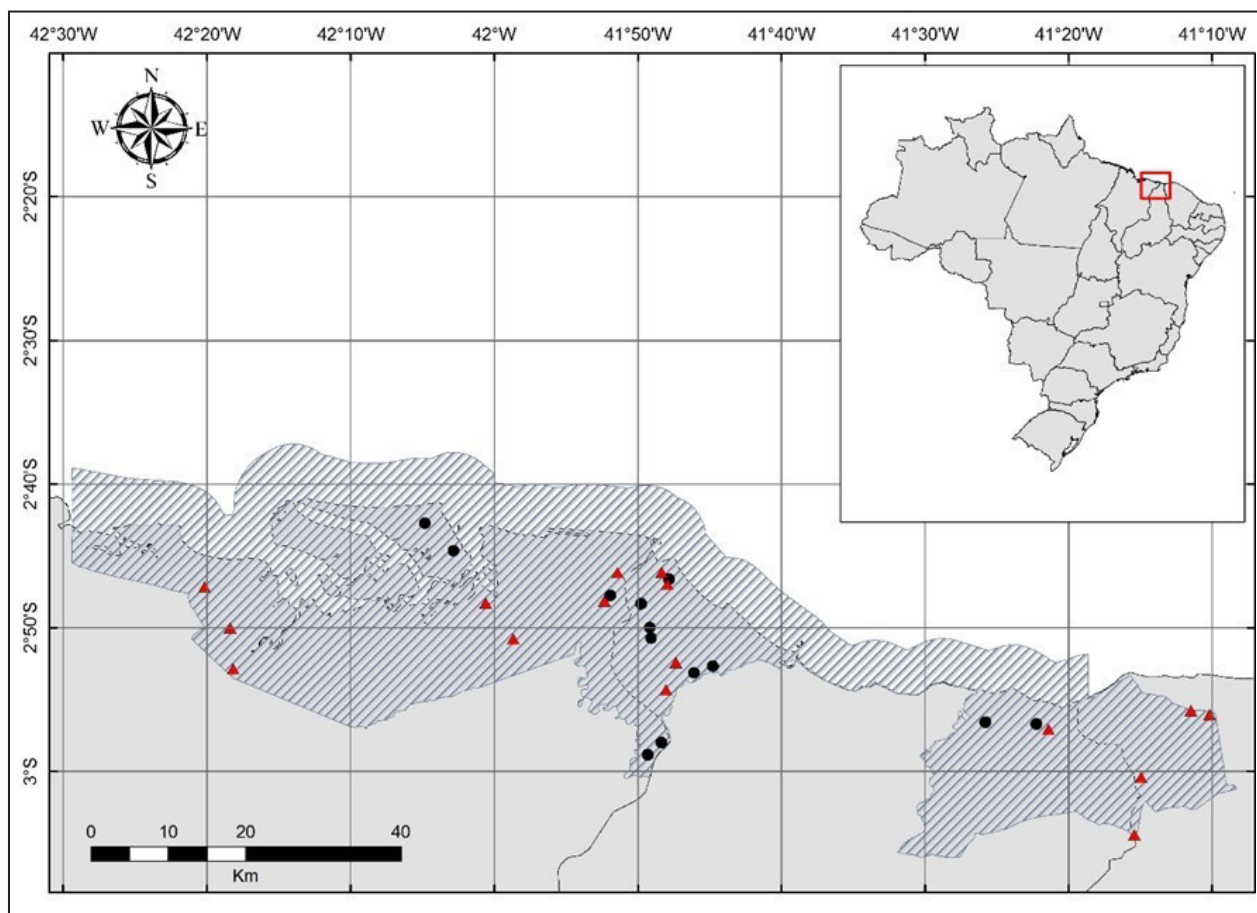


Figure 1. Schematic map of the Environmental Protection Area Delta do Parnaíba (shaded area), Northeastern Brazil. Red triangles are the sampled areas while black circles are herpetofauna literature records.

sence species matrix to compare the amphibian and reptile species composition from the Parnaíba River Delta to the studies above cited. From the matrix, we performed a Cluster Analysis using the Jaccard similarity coefficient (Magurran, 1988; Krebs, 1999). The geographic distances among the restinga areas compared were measured using ArcGIS software (Esri, 2008) and their relationship with the sampled species richness from these studies was obtained using Mantel test (Manly, 1994). Statistical analyzes were performed on R software, using Vegan package (Oksanen *et al.*, 2016).

Results

Amphibian species composition

We recorded in the EPA Delta do Parnaíba 34 amphibian species (Table 1) belonging to 14 genera and seven families: Bufonidae (3 spp.), Hylidae (14 spp.), Leptodactylidae (11 spp.), Microhylidae (2 spp.), Phyllomedusidae (2 spp.), Odontophrynidae (1 sp.) and Typhlonectidae (1 sp.).

Regarding the amphibian species composition from the restingas of the Parnaíba River Delta and other herpetofaunal scientific publications performed in the Brazilian restingas environments, the states of Ceará ($J' = 0.625$) and Maranhão ($J' = 0.501$) was more similar to the Parnaíba River Delta, presenting 25 and 17 species in common, respectively. On the other hand, the restingas areas from São Paulo ($J' = 0.015$), Rio de Janeiro ($J' = 0.034$), Santa Catarina ($J' = 0.048$), and Rio Grande do Sul states ($J' = 0.050$) were more distinct in relation to amphibian species composition (Fig. 2).

No species was common to all restingas analyzed; however, nine species were recorded only in the restingas environments from the Northeastern states: *Rhinella jimi*, *Boana raniceps*, *Scinax fuscomarginatus*, *S. x-signatus*, *Leptodactylus macrosternum*, *L. fuscus*, *L. troglodytes*, *Pleurodema diplolister* and *Pseudopaludicola mystacalis*. *Boana raniceps* and *L. macrosternum* are also common to Amapá state, in North region. Conversely, *S. alter* and *L. latrans* were common to all the restingas environments

Table 1. Amphibian species recorded in the EPA Delta do Parnaíba, with their voucher, IUCN status and the morphoclimatic domains of occurrence (MDO): Caatinga (CA), Cerrado (CE), Atlantic rain forest (AT), Amazon rain forest (AM) domains and wide distribution (WD). The localities in the Parnaíba River Delta where the species were recorded: Maranhão state (Araioses - 1, Tutoia - 2), Piauí state (Ilha Grande - 3, Parnaíba - 4, Cajueiro da Praia - 5) and Ceará state (Barroquinha - 6, Chaval - 7). The new species records to the Parnaíba River Delta (*).

Taxon	Voucher	IUCN status	MDO	Localities
Order Anura				
Bufonidae				
<i>Rhinella granulosa</i> (Spix, 1824)	CZDP (I1) 0101	LC	CA, AT	1, 3, 4, 5, 6, 7
<i>Rhinella jimi</i> (Stevaux, 2002)	CZDP (I1) 0337	LC	CA, AT	1, 2, 3, 4, 5, 6, 7
<i>Rhinella mirandaribeiroi</i> (Gallardo, 1965)	CZDP (I1) 0281	NE	CE	1, 3, 4, 5
Hylidae				
<i>Boana crepitans</i> (Wied-Neuwied, 1824)	CHDP-0585	LC	WD	4
<i>Boana punctata</i> (Schneider, 1799)	CZDP (I1) 0095	LC	WD	4, 5
<i>Boana raniceps</i> (Cope, 1862)	CZDP (I1) 0484	LC	WD	1, 2, 3, 4, 7
<i>Dendropsophus minusculus</i> (Rivero, 1971)	CZDP (I1) 0478	LC	WD	1, 2, 3, 4
<i>Dendropsophus minutus</i> (Peters, 1872)	UFPB 4519	LC	WD	4, 5
<i>Dendropsophus nanus</i> (Boulenger, 1889)	CZDP (I1) 0463	LC	WD	1, 3, 4, 5, 7
<i>Dendropsophus rubicundulus</i> * (Reinhardt & Lütken, 1862)	URCA-H12132	LC	CA, CE	5
<i>Dendropsophus soaresi</i> * (Caramaschi & Jim, 1983)	CZDP (I1) 0634	LC	CA, CE, AT	1, 5, 6, 7
<i>Scinax fuscomarginatus</i> (Lutz, 1925)	CZDP (I1) 0026	LC	WD	1, 3, 4
<i>Scinax fuscovarius</i> (Lutz, 1925)	CHDP 0456	LC	WD	1, 3, 6
<i>Scinax nebulosus</i> (Spix, 1824)	UFPB 4533	LC	WD	3, 4
<i>Scinax gr. ruber</i> (Laurenti, 1768)	CZDP (I1) 0637	NE	ID	1, 3, 4, 5, 6
<i>Scinax x-signatus</i> (Spix, 1824)	CZDP (I1) 0466	LC	WD	1, 2, 3, 4, 5, 6, 7
<i>Trachycephalus typhonius</i> (Linnaeus, 1758)	UFPB 4530	LC	WD	4, 5
Leptodactylidae				
<i>Adenomera cf. hylaedactyla</i> (Cope, 1868)	CZDP (I1) 0479	LC	AM, CE, AT	1, 2, 3, 4, 7
<i>Leptodactylus macrosternum</i> Miranda-Ribeiro, 1926	CZDP (I1) 0032	LC	WD	1, 2, 3, 4, 5, 6, 7
<i>Leptodactylus fuscus</i> (Schneider, 1799)	CZDP (I1) 0009	LC	WD	1, 2, 3, 4, 5, 6, 7
<i>Leptodactylus natalenses</i> Lutz, 1930	CZDP (I1) 0021	LC	CA, AT	1, 3, 4, 5
<i>Leptodactylus vastus</i> Lutz, 1930	CZDP (I1) 0452	LC	CA, CE, AT	1, 2, 3, 4, 5, 6, 7
<i>Leptodactylus pustulatus</i> (Peters, 1870)	CZDP (I1) 0471	LC	CE	1, 3, 4, 5
<i>Leptodactylus troglodytes</i> Lutz, 1926	CZDP (I1) 0076	LC	WD	1, 2, 3, 4, 5, 6, 7
<i>Physalaemus albifrons</i> (Spix, 1824)	CZDP (I1) 0519	LC	CA, CE, AT	1, 2, 3, 4, 5, 6, 7
<i>Physalaemus cuvieri</i> Fitzinger, 1826	CZDP (I1) 0497	LC	WD	1, 2, 3, 4, 5, 6, 7
<i>Pleurodema diplolister</i> (Peters, 1870)	CZDP (I1) 0012	LC	CA, CE, AT	1, 2, 3, 4, 5, 6, 7
<i>Pseudopaludicola mystacalis</i> (Cope, 1887)	CZDP (I1) 0474	LC	WD	1, 2, 3, 4, 5, 6, 7
Microhylidae				
<i>Dermatonotus muelleri</i> * (Boettger, 1885)	CZDP (I1) 0641	LC	WD	1, 4, 5
<i>Elachistocleis piauiensis</i> Caramaschi & Jim, 1983	CZDP (I1) 0498	LC	CA, CE	1, 3, 4, 5, 6, 7
Odontophrynidae				
<i>Proceratophrys cristiceps</i> (Müller, 1883)	CZDP (I1) 0642	LC	CA	1, 3, 4, 5, 6
Phyllomedusidae				
<i>Pithecopus azureus</i> * (Cope, 1862)	CZDP (I1) 0676	LC	CE	1, 2
<i>Pithecopus nordestinus</i> (Caramaschi, 2006)	CZDP (I1) 0477	LC	CA, CE, AT	3, 4, 5
Order Gymnophiona				

Typhlonectidae

Chthonerpeton tremembe Maciel, Leite, Silva-Leite, Leite & Cascon, 2015 MPEG 35526 NE CA 3

from the Southeastern and Southern states analyzed. Corroborating these differences, we observed that the dissimilarity in amphibian composition increases with geographic distance ($r = 0.809$, p -value < 0.005, Fig. 3A).

Reptile species composition

We recorded 52 reptile species (Table 2) belonging to three orders: Crocodylia (two species), Squamata (42 species) and Testudines (seven species). For Crocodylia order, we registered two Alligatoridae species belonging to two genera. Among Squamata, we recognize 41 species (37 genera) belonging to the following families: Amphisbaenidae (2 spp.), Boidae (4 spp.), Colubridae (8 spp.), Dipsadidae (14 spp.), Elapidae (1 sp.), Gekkonidae (2 spp.), Gymnophthalmidae (1 sp.), Iguanidae (1 sp.), Mabuyidae (1 sp.), Sphaerodactylidae (1 sp.), Teiidae (5 spp.), Tropiduridae (2 spp.), and Viperidae (1 sp.). Testudines has seven species belonging to seven genera and three families: Chelidae (1 sp.), Cheloniidae (5 spp.), and Emydidae (1 sp.).

Reptile composition from states of Maranhão ($J = 0.557$) and Ceará ($J = 0.537$) was more similar

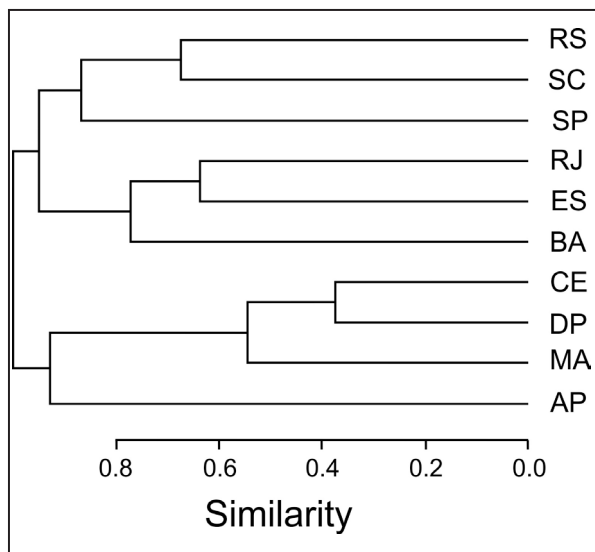


Figure 2. Amphibian composition similarity and distance found in the EPA Delta do Parnaíba (DP) and other coastal zones and restingas environments from the states of Amapá (AP), Ceará (CE), Maranhão (MA) Bahia (BA), Espírito Santo (ES), Rio de Janeiro (RJ), São Paulo (SP), Santa Catarina (SC), and Rio Grande do Sul (RS). Cophenetic correlation coefficient ($r = 0.915$).

to the Parnaíba River Delta, presenting 34 and 43 species in common, respectively. On the other hand, the restingas areas from Santa Catarina ($J = 0.103$), São Paulo ($J' = 0.106$), and Rio Grande do Sul ($J' = 0.137$) were more distinct in relation to reptile species composition, respectively (Fig. 4).

Despite the high reptile diversity along the Brazilian restinga environments, only the Cheloniidae species and the lizard *Hemidactylus mabouia* was common to all coastal environments analyzed above-cited. The lizard species *Ameivula ocellifera* and *Tropidurus hispidus* were common to Nor-

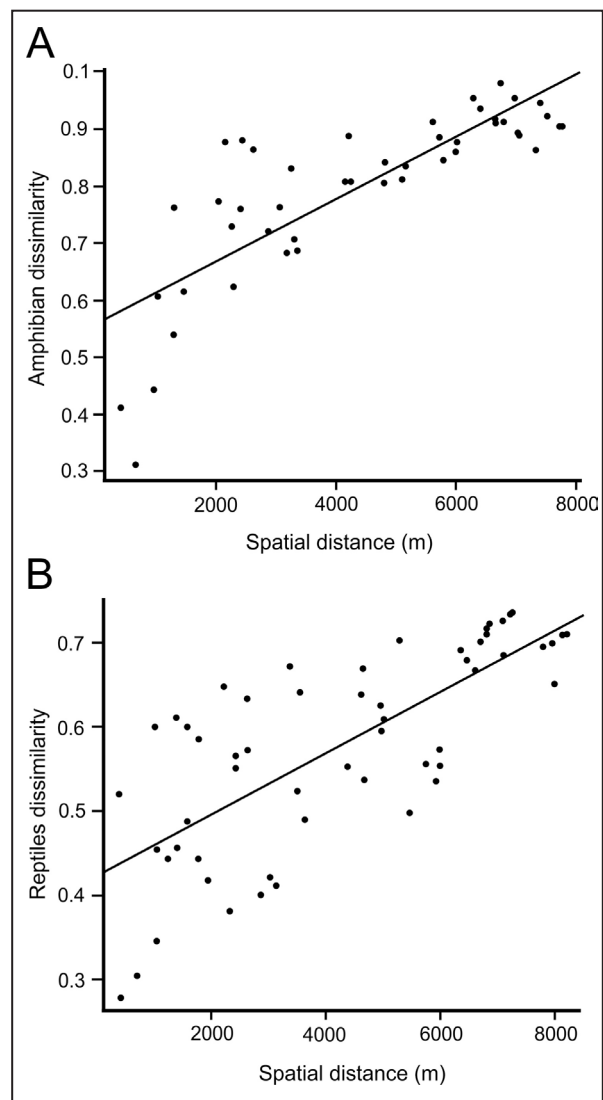


Figure 3. Mantel test between amphibians (A) and reptiles (B) richness dissimilarity and geographic distance.

Table 2. Reptiles species recorded in the EPA Delta do Parnaíba, with their voucher, IUCN status and the morphoclimatic domains of occurrence (MDO): Caatinga (CA), Cerrado (CE), Atlantic rain forest (AT), Amazon rain forest (AM) domains and wide distribution (WD). The localities in the Parnaíba River Delta where the species were recorded: Maranhão state (Araioses - 1, Tutoia - 2), Piauí state (Ilha Grande - 3, Parnaíba - 4, Cajueiro da Praia - 5) and Ceará state (Barroquinha - 6, Chaval - 7). The new species records to the Parnaíba River Delta (*).

Taxon	Voucher	IUCN status	MDO	Localities
Order Testudines				
Chelidae				
<i>Mesoclemmys tuberculata</i> (Luederwaldt, 1926)	INPA- H 16020	NE	WD	4, 5
Cheloniidae				
<i>Caretta caretta</i> (Linnaeus, 1758)	CZDP (J1) 0002	VU	WD	3, 4, 5
<i>Chelonia mydas</i> (Linnaeus, 1758)	CZDP (J1) 0005	EN	WD	3, 4, 5
<i>Dermochelys coriacea</i> (Vandelli, 1761)	CZDP (J1) 0001	VU	WD	3, 4, 5
<i>Eretmochelys imbricata</i> (Linnaeus, 1766)	CZDP (J1) 0003	CR	WD	3, 4, 5
<i>Lepidochelys olivacea</i> (Eschscholtz, 1829)	CZDP (J1) 0007	VU	WD	3, 4, 5
Emyridae				
<i>Trachemys adiutrix</i> Vanzolini, 1995	Personal observation	EN	CA	1, 3, 4, 5
Order Crocodylia				
Alligatoridae				
<i>Caiman crocodilus</i> (Linnaeus, 1758)	CZDP (J4) 0001	LC	WD	1, 3, 4
<i>Paleosuchus palpebrosus</i> * (Cuvier, 1807)	Personal observation	LC	WD	1, 3, 4
Order Squamata				
Amphisbaenidae				
<i>Amphisbaena alba</i> * Linnaeus, 1758	CZDP (J5) 0006	LC	WD	3, 4
<i>Amphisbaena vermicularis</i> * Wagler, 1824	CZDP (J5) 0005	NE	WD	3, 4
Boidae				
<i>Boa constrictor</i> Linnaeus, 1758	CZDP (J2) 0049	NE	WD	3, 4, 5
<i>Corallus hortulana</i> (Linnaeus, 1758)	CZDP (J2) 0004	LC	WD	3, 4, 5
<i>Epicrates assisi</i> Machado, 1945	CZDP (J2) 0041	NE	CA, CE	3
<i>Eunectes murinus</i> (Linnaeus, 1758)	CZDP (J2) 0115	NE	WD	3, 4, 5
Colubridae				
<i>Chironius carinatus</i> (Linnaeus, 1758)	CZDP (J2) 0072	NE	WD	1, 3, 4, 5
<i>Chironius flavolineatus</i> * Jan, 1863	CZDP (J2) 0047	NE	WD	3
<i>Drymarchon corais</i> * (Boie, 1827)	CZDP (J2) 0038	NE	WD	4
<i>Leptophis ahaetulla</i> * (Linnaeus, 1758)	CZDP (J2) 0034	NE	WD	1, 3
<i>Oxybelis aeneus</i> * (Wagler, 1824)	CZDP (J2) 0028	NE	WD	1, 3, 4
<i>Oxybelis fulgidus</i> * (Daudin, 1803)	CZDP (J2) 0078	NE	AM, CA, CE	3
<i>Spilotes pullatus</i> * (Linnaeus, 1758)	CZDP (J2) 0085	NE	WD	1, 3, 4
<i>Tantilla melanocephala</i> * (Linnaeus, 1758)	CZDP (J2) 0058	NE	WD	3
Dipsadidae				
<i>Apostolepis cearensis</i> Gomes, 1915	CZDP (J2) 0055	NE	CA, AT	3
<i>Boiruna sertaneja</i> * Zaher, 1996	CZDP (J2) 0162	NE	CA, CE	3
<i>Erythrolamprus poecilogyrus</i> (Wied-Neuwied, 1825)	CZDP (J2) 0023	NE	WD	1, 3, 4
<i>Helicops leopardinus</i> (Schlegel, 1837)	CZDP (J2) 0167	NE	WD	3, 4, 5, 6, 7
<i>Hydrodynastes gigas</i> (Duméril, Bibron & Duméril, 1854)	CZDP (J2) 0077	NE	WD	3, 4, 5
<i>Leptodeira annulata</i> * (Linnaeus, 1758)	CZDP (J2) 0123	LC	WD	3, 4
<i>Lygophis paucidens</i> * Hoge, 1953	CZDP (J2) 0075	NE	CA, CE	3

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<i>Oxyrhopus trigeminus</i> Duméril, Bibron & Duméril, 1854	CZDP (J2) 0030	NE	CA, CE, AT	3, 4
<i>Philodryas nattereri</i> * Steindachner, 1870	CZDP (J2) 0037	NE	CA, CE	1, 3, 4
<i>Philodryas olfersii</i> * (Lichtenstein, 1823)	CZDP (J2) 0039	NE	CA, CE, AT	3, 4
<i>Pseudoboa nigra</i> * (Duméril, Bibron & Duméril, 1854)	CZDP (J2) 0163	NE	CA, CE, AT	1, 3
<i>Psomophis joberti</i> * (Sauvage, 1884)	CZDP (J2) 0045	NE	WD	1, 3, 4
<i>Thamnodynastes hypoconia</i> (Cope, 1860)	CZDP (J2) 0089	NE	CA, CE, AT	3, 4, 5
<i>Xenodon merremii</i> (Wagler, 1824)	CZDP (J2) 0087	NE	WD	3, 4
Elapidae				
<i>Micrurus ibiboboca</i> (Merrem, 1820)	CZDP (J2) 0044	NE	CA, AT	3, 4
Viperidae				
<i>Bothrops</i> gr. <i>atrox</i> (Linnaeus, 1758)	CZDP (J2) 0035	NE	CA	1, 3, 4, 5
Gekkonidae				
<i>Hemidactylus agrius</i> * Vanzolini, 1978	CZDP (J3) 0033	LC	CA, CE	3, 4
<i>Hemidactylus mabouia</i> * (Moreau de Jonnés, 1818)	CZDP (J3) 0031	NE	WD	1, 2, 3, 4, 5, 6, 7
Gymnophthalmidae				
<i>Vanzosaura multiscutata</i> * (Amaral, 1933)	CZDP (J3) 0030	LC	CA	3, 4, 5
Iguanidae				
<i>Iguana iguana</i> * (Linnaeus, 1758)	CZDP (J3) 0001	LC	WD	1, 2, 3, 4, 5, 6, 7
Mabuyidae				
<i>Brasiliscincus heathi</i> * (Schmidt & Inger, 1951)	CZDP (J3) 0016	LC	CA, CE, AT	3, 4, 5
Sphaerodactylidae				
<i>Coleodactylus meridionalis</i> * (Boulenger, 1888)	CZDP (J3) 0027	LC	CA, CE, AT	3, 4
Teiidae				
<i>Ameiva ameiva</i> * (Linnaeus, 1758)	CZDP (J3) 0022	LC	WD	3, 4
<i>Ameivula ocellifera</i> * (Spix, 1825)	CZDP (J3) 0024	LC	WD	3, 4
<i>Kentropyx calcarata</i> Spix, 1825	CHUFC L4236	NE	WD	2, 3
Tropiduridae				
<i>Tropidurus hispidus</i> * (Spix, 1825)	CZDP (J3) 0028	LC	WD	1, 2, 3, 4, 5, 6, 7
<i>Tropidurus semitaeniatus</i> * (Spix, 1825)	Personal observation	LC	CA, AT	4, 5, 7
Tupinambinae				
<i>Salvator merianae</i> * Duméril & Bibron, 1839	CZDP (J3) 0023	LC	WD	3, 4
<i>Tupinambis teguixin</i> * (Linnaeus, 1758)	CZDP (J3) 0015	LC	WD	3, 4

the eastern restingas environments, while the species *Bothrops jararaca* was common to Southeastern and Southern restinga areas. In addition, 25 reptile species occurs in both restingas of the Parnaíba River Delta, Maranhão, Ceará, and Bahia, reinforcing the hypothesis that the species composition of distant regions tends to be more dissimilar ($r = 0.7389$, p -value < 0.001 , Fig. 3B).

Discussion

Amphibian species composition

The Brazilian restingas presented high amphibian diversity (Oliveira and Rocha, 2015), with about

170 species occurring in these environments and approximately 20% of them were recorded in the present study. The amphibian richness recorded in the Parnaíba River Delta was similar to other local studies undertaken in the restingas of Conde and Mata de São João municipalities, both in Bahia state (Bastazini *et al.*, 2007; Gondim-Silva *et al.*, 2016), and it was higher than other local studies realized in restingas environments from the states of Amapá and Rio de Janeiro (Telles *et al.*, 2012; Araújo and Costa-Campos, 2014). Also, the restingas areas from the states of Bahia and Rio de Janeiro present highest amphibian richness with 71 and 55 species, respectively (see Bastazini *et al.*, 2007; Rocha *et al.*,

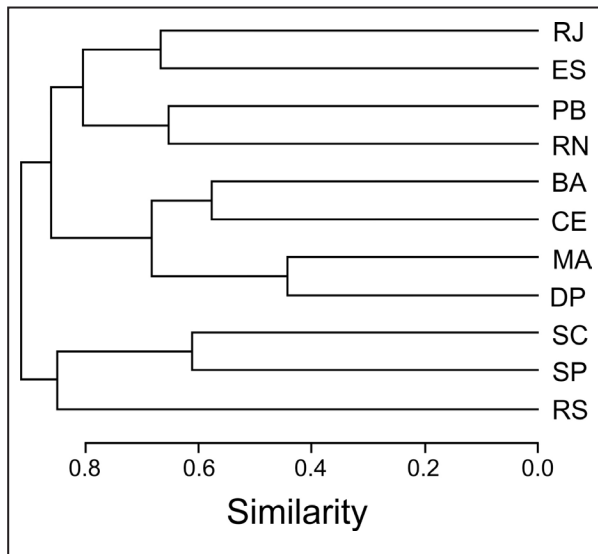


Figura 3. Reptile composition similarity and distance found in the EPA Delta do Parnaíba (DP) and other coastal zones and restingas environments from the states of Ceará (CE), Maranhão (MA), Rio Grande do Norte (RN), Paraíba (PB), Bahia (BA), Espírito Santo (ES), Rio de Janeiro (RJ), São Paulo (SP), Santa Catarina (SC), and Rio Grande do Sul (RS). Cophenetic correlation coefficient ($r = 0.914$).

2008; Silva *et al.*, 2008; Telles *et al.*, 2012; Gondim-Silva *et al.*, 2016; Carmo *et al.*, 2019; Martins *et al.*, 2019; Dantas *et al.*, 2019).

According to the Neutral Biodiversity Theory, species diversity in a given locality could be explained by the functional and competitive equivalence among species (Hubbell, 2001). In addition, this theory predicts the influence of geographic distance on the similarity patterns of species richness of assemblages (Hubbell, 2006). Thus, geographically closer areas tend to be more similar in species composition. This relationship was noted by presence of 10 amphibian species common to Northeastern states. Despite all sampling localities being in the restinga environments, amphibian composition similarity of Northeastern coastal zones may have been influenced by the presence of typical species from the Caatinga and Cerrado domains, whereas in Southeastern and Southern regions by typical species from the Atlantic rain forest.

We also registered four new anuran records for the EPA Delta do Parnaíba, confirming Loebmann and Mai (2008) affirmation that *Dendropsophus soaresi* and *Dermatonotus muelleri* could occur in the EPA Delta do Parnaíba. Both species were recorded in Cajueiro da Praia municipality, Piauí state. We present the first record of *Dendropsophus rubicundulus* to Chaval municipality, Ceará state.

This species was recorded in close localities in Ceará state (Silva *et al.*, 2011); however, it has not been previously registered in the EPA Delta do Parnaíba. We recorded the first occurrence of *Pithecopus azureus* for Tutóia municipality, Maranhão state, increasing the species geographic distribution about 900 km north from Ribeiro Gonçalves municipality, Piauí state (Roberto *et al.*, 2013) and about 600 km north from Parque Estadual do Mirador, Maranhão state (Andrade *et al.*, 2017). Furthermore, we report that *Corythomantis greeningi* is possibly absent in the Parnaíba River Delta, although has been listed in the Biodiversidade do litoral do Piauí guide (Mai and Loebmann, 2010). This species was recorded outside of the EPA Delta do Parnaíba in distinct environments from our study area.

Most species found has wide distribution along the Brazilian morphoclimatic domains (47.1%, 17 species), being *Rhinella mirandaribeiroi* and *Lepidodactylus pustulatus* endemic to Cerrado domain and transitional zones, while *Proceratophrys cristiceps* and *Chthonerpeton tremembe* are endemic to Caatinga domain and transitional zones. It is also noteworthy that *C. tremembe* is endemic to the Parnaíba River Delta (Maciel *et al.*, 2015) and the treefrog *Scinax* sp. (gr. *ruber*) could represent a new species. Overall, the majority of species are classified as Least Concern by IUCN (2020). Species described recently do not contain sufficient data to evaluate their conservation status (Table 1).

Reptile species composition

Brazil has the third richest reptile fauna in the world, with 795 species (Costa and Bérnils, 2018), and about 218 species occur in restingas environments, being about 24% of these registered in the Parnaíba River Delta. The reptile richness recorded in the Parnaíba River Delta was similar to other studies in Brazilian restingas, except those from Bahia (Couto-Ferreira *et al.*, 2011; Dias and Rocha, 2014; Travassos *et al.*, 2015; Marques *et al.*, 2016; 2017; Fazolato *et al.*, 2019a, 2019b; Marques and Tinôco, 2019; Travassos *et al.*, 2019a, 2019b) and Ceará states (Borges-Leite *et al.*, 2014; Roberto and Loebmann, 2016), which present 115 and 71 species, respectively.

Likewise, we observed nine reptile species common to Northeastern restingas environments. Considering the Northeastern restingas which are not influenced by typical species from the Atlantic Rain Forest, we observed 27 reptile species common to restingas from the states of Maranhão, Piauí, and

Ceará, being 15 snakes, five lizards, five sea turtles, one crocodile, and one amphisbaenian. Therefore, the reptile composition similarity may be due to presence of typical species from the Caatinga and Cerrado domains, whereas in Southeastern and Southern regions by typical species from the Atlantic Rain Forest.

Until now, the knowledge about the Parnaíba River Delta reptiles was based on a succinct field guide (Mai and Loebmann, 2010) and scattered notes on geographic distribution and ecological aspects (*e.g.* Santana *et al.*, 2009, Silva and Henderson, 2010; Silva-Leite *et al.*, 2009; 2010a; 2010b, Roberto *et al.*, 2012; Silva *et al.*, 2012). Therefore, our list adds 14 snakes, 12 lizards, two amphisbaenians and one crocodylian to the EPA Delta do Parnaíba (see Table 2). Furthermore, we report the first record of *Oxybelis fulgidus* to Piauí state. This species has a wide distribution along the Amazon Forest and Cerrado domains. We increased this species geographic distribution about 170 km eastern of closest locality in the Maranhão state (Scartozzoni *et al.*, 2009; Costa and Bérnils, 2018). We also present the second record of *Tupinambis teguixin* for Piauí state, extending its distribution in approximately 190 km north from the nearest previously known record in the municipality of Barras, Piauí (Benício and Fonseca, 2014).

Considering the reptile distribution most of them also have wide distribution along the Brazilian morphoclimatic domains (65.3%, 34 species), being *Bothrops gr. atrox*, *Vanzosaura multiscutata*, and *Trachemys adiutrix* endemic to Caatinga domain and transitional zones, the last one restricted to states of Maranhão and Piauí (Ernst *et al.*, 2010). Other eight species were endemic to at least two morphoclimatic domain and transitional zones.

Except for *Mesoclemmys tuberculata*, all Testudines registered in the present study are considered endangered species, being three Cheloniidae species classified as vulnerable to extinction (*Caretta caretta*, *Dermochelys coriacea*, and *Lepidochelys olivacea*), two as endangered (*Chelonia mydas* and *Trachemys adiutrix*), and one as critically endangered (*Eretmochelys imbricata*). Conversely, the Squamata species are classified as least concern or do not contain sufficient data to evaluate their conservation status (IUCN, 2020; Table 2). Therefore, herpetofaunal inventories might improve the species distribution knowledge and, consequently help to create preservation measures for these species.

The importance of restinga fragments conservation

The intrinsic characteristics of the restingas fragments as temperature, humid, salinity, and vegetation makes these environments isolated microecosystems with a particular biodiversity driven by invasion, extinction, and competition process; thus, more studies are necessary for better comprehension of its dynamics (Rocha and Van Sluys, 2007).

These microecosystems harbors high herpetofaunal diversity along the Brazilian restinga environments (Rocha and Bergallo, 1997; Rocha and Van Sluys, 2007; Bastazini *et al.*, 2007; Araújo *et al.*, 2018), including some anuran endemism as *Leptodactylus marambaiae* and *Xenohyla truncata* restricted to the restingas of Rio de Janeiro state (Carvalho-e-Silva *et al.*, 2000; Frost, 2020), and also reptiles endemism as *Amphisbaena nigricauda* and *Liolaemus occipitalis* endemics to Southern and Southeastern Brazilian restingas, respectively (Rocha and Van Sluys, 2007). Regarding the Northeastern Brazilian restingas, the lizards *Glaucomastix itabaianensis* and *G. abaetensis*, the turtle *Trachemys adiutrix*, and the amphibian *Chthonerpeton tremembe* are relevant endemism cases in these environments (Rocha and Van Sluys, 2007; Ernst *et al.*, 2010; Maciel *et al.*, 2015; Rosário *et al.*, 2019). Therefore, the restinga fragments may be considered endemism areas or even so hotspots of herpetofaunal diversity (Silva *et al.*, 2018).

Overall, it is important to preserve the restinga fragments due to their high habitat diversity and the biological factors that make these ecosystems so complex (Araujo and Lacerda, 1987). Furthermore, these environments also are susceptible to degradation, given the high human occupation in coastal plains (Marques *et al.*, 2015); thus, biodiversity studies might help the preservation and conservation of these coastal zones.

Concluding remarks

The Parnaíba River Delta has a mosaic of distinct physiognomies (Santos-Filho *et al.*, 2010), and restinga environments harbors high richness of herpetofauna and great environmental heterogeneity (Araújo *et al.*, 2018). However, these restingas areas have been deforested by intensive anthropic actions, such as, fires, agriculture, housing activities and windfarms. Thus, we suggest that conservation actions should be taken to preserve the restingas environments of the Parnaíba River Delta and its high diversity of amphibians and reptiles.

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