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Endemic amphibians of the Cerrado and Caatinga: species richness, geographic range and conservation

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The Cerrado and the Caatinga have few formally protected areas and encompass a high diversity of amphibians, which is still relatively unknown. In this study we present the list of amphibian species endemic to the Cerrado or Caatinga and their geographic range, highlighting current conservation status. We obtained the species list from the compilation of scientific publications (up to July 2022). We obtained the occurrence records from the databases SpeciesLink, GBIF, Portal da Biodiversidade and literature. We classified the species in the categories of threat according to the Brazilian list of threatened species and the global list of threatened species. We compiled 2,659 occurrences of amphibians, 1,335 from the SpeciesLink platform, 414 from GBIF, 371 from the Biodiversity Portal and 539 obtained from the literature. We recorded 100 endemic species, 82 from the Cerrado and 18 from the Caatinga. The Cerrado has three species Vulnerable (VU) (*Boana buriti*, *Bokermannohyla napolii* and *Scinax pinimus*), one Critically Endangered (CR) (*Proceratophrys moratoi*), 14 species Data Deficient (DD), 46 in the Least Concern (LC) category and 18 Not Evaluated (NE). The Caatinga has three species CR (*Adelophryne maranguapensis*, *Proceratophrys ararype*, *Rhinella casconi*), three DD, five LC and seven NE. Threatened, DD and NE species have few records within the protected areas of Cerrado and Caatinga. We consider that the Cerrado and Caatinga present a rich diversity of endemic amphibians, which have a geographic range relatively reduced, especially the threatened ones, DD and NE. Distribution and taxonomy data are essential, because the lack can hinder the assessment of conservation status, since threatened species, DD, NE, including LC, may be undervalued and at risk.

Keywords: amphibia, distribution, endemism, species list, species protection

INTRODUCTION

Amphibians are among the most diverse vertebrate groups, with 8,483 known species (Amphibiaweb, 2022). About 1,188 occur in Brazil, making it the richest country in amphibian species (Segalla et al., 2021). However, amphibians are globally threatened with extinction. The Neotropical region concentrates the largest number of threatened amphibians (Amphibiaweb, 2022), especially because of the destruction of native habitats, pollution, introduction of exotic species (Duellman & Trueb, 1994), climate change (Ficetola & Maiorano, 2016) and diseases (Fisher & Garner, 2020).

The South American dry diagonal of structurally open vegetation includes the Cerrado, Chaco and Seasonally Dry Tropical Forests. These biomes experience strong seasonal droughts, contain a significant number of endemic species and high taxon diversity, but all are highly threatened (Werneck, 2011; Fonseca et al., 2017; Medeiros et al., 2022). The Cerrado is the largest and most threatened tropical savanna (Myers et al., 2000) and has a great diversity of amphibians with more than 209 species (Valdujo et al., 2012). Such diversity is under intense threat, mainly from agricultural activities, in addition to the intense use of toxic agrochemicals, the construction of hydroelectric dams, and from frequent fires (Ribeiro et al., 2020). The intense degradation of the Cerrado places this biome in second place in the Brazilian deforestation ranking, with around 409,000 hectares lost by 2018 (MapBiomas, 2019).

The Caatinga, considered the largest extension of the Seasonally Dry Tropical Forests in South America (Silva et al., 2017), is the fourth most deforested biome in Brazil, with about 12,200 hectares of extension lost by 2018 (MapBiomas, 2019). Moreover, Caatinga has suffered from a gradual increase in desertification, caused by human activities with the additional influence of the dry climate (Souza & Oyama, 2011). The species richness of amphibians in the Caatinga is considered high, with 98 species recorded, however this biome is still poorly studied (Garda et al., 2017).

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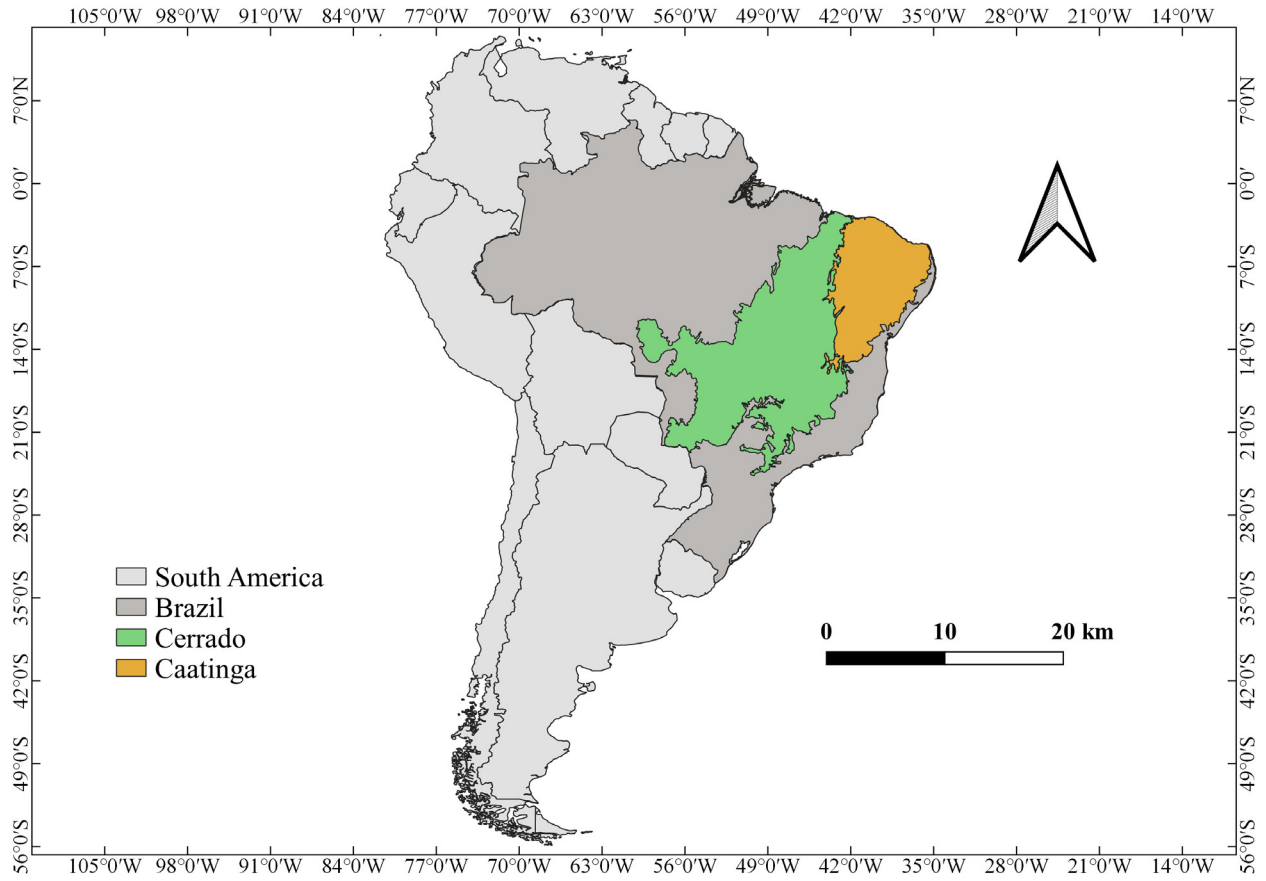

Figure 1. Location of the Cerrado and Caatinga biomes in South America. Shapefile provided by the Brazilian Institute of Geography and Statistics (IBGE, 2020).

Endemic species of each biome and those with restricted geographic distribution are among the most affected by habitat loss (Silvano et al., 2016). Habitat loss can reduce the size of the geographic range of endemic species (Mayani-Parás et al., 2019) since the low dispersal capacity and physiological restrictions (Smith & Green, 2005) may present limitations to locomotion between habitats. In this sense, endemism and the species geographic range serve as essential predictors for assessing the risks of extinction of the species (Purvis et al., 2000).

Faced with the risk of species extinctions in open vegetation biomes in South America, the allocation of areas for environmental protection becomes even more important for the conservation of biodiversity (Rodrigues et al., 2004). This is most evident when it was discovered that about 24% of amphibian species worldwide are not located within protected areas (Nori et al., 2015). In Brazil, both the Cerrado and the Caatinga have few protected areas, corresponding to 8.6% and 7.7% of their total area, respectively (Vieira et al., 2019). By 2020, the National Biodiversity Commission established that at least 17% of the total area of every biome in the world should be protected (CONABIO, 2013).

Knowledge of the geographic range of each species individually allows us to understand the organisation of these species on a regional scale (Valdujo et al., 2012) and support conservation proposals (Keil & Hawkins, 2009). Thus, here we have gathered and discussed the updated list of amphibian species endemic to the Cerrado or Caatinga, their geographic range, and their current conservation. We were guided by the following questions considering the endemism of amphibian species in the Cerrado or Caatinga biomes: 1) what is the available knowledge regarding the geographic range and conservation of the species; 2) what is the current number of known species and what are the advances and contrasts since the last compilations; 3) do endemic threatened species occur within protected areas; 4) do digital databases provide substantial information regarding the occurrence of endemic species?

MATERIALS & METHODS

Study area

The species listed in this study are endemic to the Brazilian biomes called Cerrado and Caatinga, defined and delimited by the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística - IBGE) (IBGE, 2020) (Fig. 1).

The Cerrado is considered the largest savanna area and the second-largest biome in South America, occupying an area of 1,983,017 km^2 (IBGE, 2019). The

Cerrado has boundaries with the biomes in South America Caatinga, Amazon Forest, Atlantic Forest, Pantanal and the Pampa. The prevailing climate in the Cerrado is of the Aw type, according to the Köppen classification, which is markedly seasonal, with dry winters and annual rainfall ranging from 1,300 to 2,300 mm (Alvares et al., 2013).

The Cerrado has a great diversity of endemic species, most listed as Threatened, one of the reasons why it is considered a hotspot of global biodiversity (Myers et al., 2000). This biome has been affected by intense habitat degradation caused mainly by suppressing native vegetation for use in agricultural expansion (MapBiomas, 2022; Zalles et al., 2019). Of the total area of the biome, about 44% is destined for farming activities, in which pasture is the activity that occupies most of the biome, followed by monocultures of soybean, sugarcane and rice (MapBiomas, 2022). Due to its high flammability, the Cerrado also suffers from frequent fires (Oliveira et al., 2021).

The Caatinga is an exclusively Brazilian biome, covering about 913,000 km², and is primarily located in Brazil's north-east region (Silva et al., 2017). The Caatinga has extensive flat surfaces with altitudes ranging from 300 to 500 m, relatively high temperatures ranging from 26 to 30 °C, and annual rainfall ranging from 300 to 1,200 mm (Prates & Navas, 2009; Silva et al., 2017). The vegetation is dominated by small, thorny trees with twisted trunks and by many succulent and cactus plants, which respond efficiently to the minimum levels of precipitation in this biome (Queiroz et al., 2017).

The Caatinga is recognised as one of the world's richest dry forests, with 3,150 species of vascular plants, 276 species of ants, 386 fish, 98 amphibians, 191 reptiles, 548 birds and 183 mammals (Silva et al., 2017). The Caatinga is one of the least scientifically explored Brazilian biomes, meaning thousands of new species are yet to be described (Tabarelli et al., 2018). About 35% of the Caatinga is already destined for agricultural activities, including pasture, sugarcane and soybean plantations (MapBiomas, 2022). In recent decades, the Caatinga suffered an intense process of desertification, which can have serious consequences, for example, in the hydrological cycle in the semi-arid region of north-eastern Brazil (Souza & Oyama, 2011).

Data collection and analysis

We produced a list of amphibian species endemic to the Cerrado and Caatinga biomes from the compilation of works by Valdujo et al. (2012) and Azevedo et al. (2016) for the Cerrado, and Garda et al. (2017) for the Caatinga. We also compiled records from descriptions of species published later, up to July 2022. We consider as endemic the species that occurs exclusively within the limits of the Cerrado or Caatinga biomes, including adjacent transition areas. We followed the taxonomic updates adopted by Segalla et al. (2021).

To compile the new species descriptions, considering the period from 2013 to 2022 for the Cerrado, and from 2018 to 2022 for the Caatinga, we consulted national and international scientific articles, available in the Google Scholar and Scopus databases. Internet searches were guided by the keywords 'amphibians', 'endemic amphibians', 'Cerrado and Caatinga' and by the specific name of the species.

We compiled species occurrence records by searching the SpeciesLink (SpeciesLink, 2022), Global Biodiversity Information Facility (GBIF) (GBIF, 2022), and Biodiversity Portal platforms (SISBIO, 2022). Additionally, we searched for publications with occurrence records of endemic species. For this, we consulted scientific articles, distribution notes, masters' dissertations and doctoral theses. The search included national and international documents on the geographic distribution of endemic species, available in Google Scholar and Scopus databases, and scientific journals such as Herpetological Review, Biota Neotropica, Check List, Herpetology Notes, Zootaxa and South American Journal of Herpetology.

We checked the current geographic range of the species compiled through the Biodiversity Portal of the Chico Mendes Institute for Biodiversity Conservation (Portuguese: Instituto Chico Mendes de Conservação da Biodiversidade, ICMBio) (SISBIO, 2022) (Disponívelem: https://biodiversidade.icmbio.gov.br/portal/), the International Union for Conservation of Nature (IUCN) (IUCN, 2022) and Frost (2022).

To avoid taxonomic uncertainties regarding the identification of species in the different databases and thus have reliable records, we considered those that presented the name of the collector or identifier and the available collection in which the specimen was deposited. We considered uncertain those records that did not have such information. Furthermore, we did not consider records of species with uncertain identifications, such as those listed as aff., cf., gr. or sp. We consulted expert Adrian Garda to clarify uncertainties about the taxonomy of Caatinga species.

We classified the species in the categories Least Concern (LC), Data Deficient (DD), Near Threatened (NT), Vulnerable (VU), Endangered (EN), Critically Endangered (CR) and Not Evaluated (NE) according to the Brazilian list of threatened species (MMA, 2022), the Red Book of Brazilian Fauna Threatened with Extinction (2018), and to complement, the global list of threatened species (IUCN, 2022). In order to verify the occurrence of endemic species within the Brazilian, municipal, state and federal protected areas (PAs), and of Integral Protection and Sustainable Use of the Cerrado and Caatinga, we overlapped the occurrence records of the species with the referred PAs. We extracted the file with the PAs in shapefile format, made available by the Ministry of the Environment (MMA, 2020). We used the QGIS 3.6.2 software to overlay the occurrence records with the PAs and verify if the species are within these protected areas (QGIS, 2020). We considered only the records identified within the limits of the PAs. We grouped species by conservation status to ascertain the distribution of occurrence records through a histogram, removing, in this case, duplicate records.

Table 1. List of amphibian species endemic to the Cerrado and Caatinga biomes: CE=Cerrado; CA=Caatinga; CS=Conservation status; N=Number of records with no duplicates; REF=Source; LC=Least Concern; DD=Data Deficient; CR=Critically Endangered; EN=Endangered; VU=Vulnerable; NE= Not Evaluated; 1=Garda et al. (2017); 2=Azevedo et al. (2016); 3=Valdujo et al. (2012); * Species compiled after the studies by Garda et al. (2017), Azevedo et al. (2016) and Valdujo et al. (2012), and added in this study.

AMPHIBIA	CA	CE	CS	N	REF
ANURA					
Aromobatidae					
Allobates goianus (Bokermann, 1975)		■	DD	9	3
Brachycephalidae					
Ischnocnema penaxavantinho Giaretta, Toffoli & Oliveira, 2007		■	DD	11	3
Bufonidae					
Rhinella casconi Roberto, Brito & Thomé, 2014	■		CR	1	1
Rhinella cerradensis Maciel, Brandão, Campos & Sebben, 2007		■	LC	13	3
Rhinella inopina Vaz-Silva, Valdujo & Pombal, 2012		■	LC	8	3
Rhinella veredas (Brandão, Maciel & Sebben, 2007)		■	LC	10	3
Ceratophryidae					
Ceratophrys joazeirensis Mercadal de Barrio, 1986	■		LC	6	1
Craugastoridae					
Oreobates antrum Vaz-Silva, Maciel, Andrade & Amaro, 2018		■	NE	1	*
Oreobates remotus Teixeira, Amaro, Recoder, Sena & Rodrigues, 2012		■	LC	3	3
Pristimantis dundeei (Heyer & Muñoz, 1999)		■	LC	18	3
Pristimantis relictus Roberto, Loebmann, Lyra, Haddad & Ávila, 2022	■		NE	12	*
Pristimantis rupicola Taucce, Nascimento, Trevisan, Leite, Santana, Haddad & Napoli, 2020	■		NE	13	*
Pristimantis ventrigranulosus Maciel, Vaz-Silva, Oliveira & Padial, 2012		■	LC	2	3
Dendrobatidae					
Ameerega berohoka Vaz-Silva & Maciel, 2011		■	LC	3	3
Ameerega braccata (Steindachner, 1864)		■	LC	1	3
Eleutherodactylidae					
Adelophryne baturitensis Hoogmoed, Borges & Cascon, 1994	■		LC	1	1
Adelophryne maranguapensis Hoogmoed, Borges & Cascon, 1994	■		CR	2	1
Hylidae					
Aplastodiscus heterophonicus Pinheiro, Pezzuti, Berneck, Lyra, Lima & Leite, 2021		■	NE	5	*
Aplastodiscus lutzorum Berneck, Giaretta, Brandão, Cruz & Haddad, 2017		■	NE	4	*
Boana botumirim (Caramaschi, Cruz & Nascimento, 2009)		■	LC	14	3
Boana buriti (Caramaschi & Cruz, 1999)		■	VU	2	3
Boana caiapo Pinheiro, Cintra, Valdujo, Silva, Martins, Silva & Garcia, 2018		■	NE	18	*
Boana cipoensis (B. Lutz, 1968)		■	LC	22	3
Boana ericae (Caramaschi & Cruz, 2000)		■	LC	3	3
Boana goiana (B. Lutz, 1968)		■	LC	21	3
Boana jaguariaivensis (Caramaschi, Cruz & Segalla, 2010)		■	LC	6	3
Boana paranaiba (Carvalho, Giaretta & Facure, 2010)		■	LC	18	*
Bokermannohyla alvarengai (Bokermann, 1956)		■	LC	3	3
Bokermannohyla diamantina Napoli & Juncá, 2006	■		DD	1	1
Bokermannohyla flavopicta Leite, Pezzuti & Garcia, 2012	■		NE	2	1
Bokermannohyla juiju Faivovich, Lugli, Lourenço & Haddad, 2009	■		DD	1	1
Bokermannohyla nanuzae (Bokermann & Sazima, 1973)		■	LC	26	3
Bokermannohyla napolii Carvalho, Giaretta & Magrini, 2012		■	VU	2	2
Bokermannohyla pseudopseudis (Miranda-Ribeiro, 1937)		■	LC	7	3
Bokermannohyla ravida (Caramaschi, Napoli & Bernardes, 2001)		■	DD	3	3
Bokermannohyla sapiranga Brandão, Magalhães, Garda, Campos, Sebben & Maciel, 2012		■	NE	16	3
Bokermannohyla saxicola (Bokermann, 1964)		■	LC	5	3
Bokermannohyla sazimai (Cardoso & Andrade, 1982)		■	LC	10	3
Corythomantis botoque Marques, Haddad & Garda, 2021		■	NE	8	*
Dendropsophus araguaya (Napoli & Caramaschi, 1998)		■	LC	5	3
Dendropsophus cerradensis (Napoli & Caramaschi, 1998)		■	DD	4	3
Pseudis tocantins Caramaschi & Cruz, 1998		■	LC	13	3
Scinax cabralensis Drummond, Baêta & Pires, 2007		■	DD	7	3

AMPHIBIA	CA	CE	CS	N	REF
Scinax canastrensis (Cardoso & Haddad, 1982)		■	LC	27	3
Scinax centralis Pombal & Bastos, 1996		■	LC	11	3
Scinax curicica Pugliesse, Pombal & Sazima, 2004		■	LC	56	3
Scinax goya (Andrade, Santos, Rocha, Pombal & Vaz-Silva, 2018)		■	NE	1	*
Scinax machadoi (Bokermann & Sazima, 1973)		■	LC	39	3
Scinax maracaya (Cardoso & Sazima, 1980)		■	LC	13	3
Scinax montivagus Juncá, Napoli, Nunes, Mercês & Abreu, 2015	■		NE	4	1
Scinax pinimus (Bokermann & Sazima, 1973)		■	VU	2	3
Scinax pombali Lourenço, Carvalho, Baêta, Pezzuti & Leite, 2013		■	NE	1	2
Scinax rogerioi Pugliesi, Baêta & Pombal, 2009		■	LC	4	3
Scinax rupestris Araujo-Vieira, Brandão & Faria, 2015		■	NE	1	*
Scinax skaios Pombal, Carvalho, Canelas & Bastos, 2010		■	LC	2	3
Scinax tigrinus Nunes, Carvalho & Pereira, 2010		■	LC	4	3
Trachycephalus mambaiensis Cintra, Silva, Silva, Garcia & Zaher, 2009		■	DD	9	3
Hylodidae					
Crossodactylus trachystomus (Reinhardt & Lütken, 1862)		■	LC	6	3
Hylodes otavioi Sazima & Bokermann, 1983		■	DD	5	3
Leptodactylidae					
Adenomera saci Carvalho & Giaretta, 2013		■	LC	8	2
Leptodactylus avivoca Carvalho, Seger, Magalhães, Lourenço & Haddad, 2021		■	NE	5	*
Leptodactylus camaquara Sazima & Bokermann, 1978		■	LC	31	3
Leptodactylus kilombo Alves da Silva, Magalhães, Thomassen, Leite, Garda, Brandão, Haddad, Giaretta & Carvalho, 2020		■	NE	4	*
Leptodactylus oreomantis Carvalho, Leite & Pezzuti, 2013	■		LC	9	1
Leptodactylus payaya Magalhães, Lyra, Carvalho, Baldo, Brusquetti, Burella, Colli, Gehara, Giaretta, Haddad, Langone, López, Napoli, Santana, de Sá & Garda 2020	■		NE	18	*
Leptodactylus sertanejo Giaretta & Costa, 2007		■	LC	23	3
Leptodactylus tapiti Sazima & Bokermann, 1978		■	DD	11	3
Physalaemus claptoni Leal, Leite, Costa, Nascimento, Lourenço & Garcia, 2020		■	NE	1	*
Physalaemus deimaticus Sazima & Caramaschi, 1988		■	DD	9	3
Physalaemus evangelistai Bokermann, 1967		■	LC	18	3
Pseudopaludicola coracoralinae Andrade, Haga, Lyra, Carvalho, Haddad, Giaretta & Toledo, 2020		■	NE	2	*
Pseudopaludicola jazmynmcdonaldae Andrade, Silva, Koroiva, Fadel & Santana, 2019		■	NE	2	*
Pseudopaludicola matuta Andrade, Haga, Lyra, Carvalho, Haddad, Giaretta & Toledo, 2018		■	NE	3	*
Pseudopaludicola mineira Lobo, 1994		■	LC	22	3
Pseudopaludicola murundu Toledo, Siqueira, Duarte, Veiga-Menoncello, Recco-Pimentel & Haddad, 2010		■	DD	31	3
Microhylidae					
Chiasmocleis centralis Bokermann, 1952		■	DD	5	3
Odontophrynidae					
Odontophrynus monachus Caramaschi & Napoli, 2012		■	LC	2	3
Proceratophrys ararype Mângia, Koroiva, Nunes, Roberto, Ávila, Sant'Anna, Santana & Garda, 2018	■		CR	4	*
Proceratophrys bagnoi Brandão, Caramaschi, Vaz-Silva & Campos, 2013		■	DD	2	2
Proceratophrys branti Brandão, Caramaschi, Vaz-Silva & Campos, 2013		■	LC	17	2
Proceratophrys carranca Godinho, Moura, Lacerda & Feio, 2013		■	DD	2	2
Proceratophrys cururu Eterovick & Sazima, 1998		■	LC	9	3
Proceratophrys dibernardoi Brandão, Caramaschi, Vaz-Silva & Campos, 2013		■	LC	9	2
Proceratophrys goyana (Miranda-Ribeiro, 1937)		■	LC	34	3
Proceratophrys huntingtoni Ávila, Pansonato & Strüssmann, 2012		■	NE	6	2
Proceratophrys minuta Napoli, Cruz, Abreu & Del-Grande, 2011	■		LC	3	1
Proceratophrys moratoi (Jim & Caramaschi 1980)		■	CR	19	3
Proceratophrys redacta Teixeira, Amaro, Recoder, Vechio & Rodrigues, 2012	■		LC	2	1
Proceratophrys rotundipalpebra Martins & Giaretta, 2013		■	LC	4	2
Proceratophrys salvatori (Caramaschi, 1996)		■	LC	16	3
Proceratophrys velhochico Mângia, Magalhães, Leite, Cavalheri & Garda, 2022	■		NE	2	*
Proceratophrys vielliardi Martins &Giaretta, 2011		■	LC	4	3

AMPHIBIA	CA	CE	CS	N	REF
Phyllomedusidae					
Phasmahyla jandaia (Bokermann & Sazima, 1978)		■	LC	4	3
Pithecopus araguaius Haga, Andrade, Bruschi, Recco-Pimentel & Giaretta, 2017		■	NE	5	*
Pithecopus centralis (Bokermann, 1965)		■	DD	2	3
Pithecopus gonzagai Andrade, Haga, Ferreira, Recco-Pimentel, Toledo & Bruschi, 2020	■		NE	8	*
Pithecopus megacephalus (Miranda-Ribeiro, 1926)		■	LC	4	3
Pithecopus oreades (Brandão, 2002)		■	LC	8	3
GYMNOPHIONA					
Typhlonectidae					
Chthonerpeton arii Cascon & Lima-Verde, 1994	■		DD	3	1
Chthonerpeton tremembe Maciel, Leite, Silva-Leite, Leite & Cascon, 2015		■	NE	1	*

RESULTS

We recorded 100 species of endemic amphibians: 82 from the Cerrado (81 frogs and one caecilian) and 18 from the Caatinga (17 frogs and one caecilian) (Table 1). For the Cerrado, the most represented families were Hylidae (36 species), Leptodactylidae (14) and Odontophrynidae (12). The least representative families were Aromobatidae, Brachycephalidae, Microhylidae and Typhlonectidae, with only one species each. For the Caatinga, the most representative families were Hylidae and Odontophrynidae with four species, and Craugastoridae, Eleutherodactylidae and Leptodactylidae with two species each, while the least represented were Bufonidae, Ceratophryidae, Phyllomedusidae and Typhlonectidae with one species each.

Thirty-seven species in Cerrado and two in Caatinga are no longer considered endemic, because their range is now known to occur elsewhere (Table S1). We consider *Pristimantis* sp., cited as endemic by Garda et al. (2017), because its taxonomy has recently been clarified, now known as *Pristimantis rupicola* (Taucce et al., 2020; consultation with specialist Adrian Garda). In addition, we compile 16 new species endemics to the list for the Cerrado, compiled considering the period from 2013 to 2022 (Anura: *Aplastodiscus heterophonicus*, *Aplastodiscus lutzorum*, *Boana caiapo*, *Boana paranaiba*, *Corythomantis botoque*, *Leptodactylus avivoca*, *Leptodactylus kilombo*, *Oreobates antrum*, *Physalaemus claptoni*, *Pithecopus araguaius*, *Pseudopaludicola coracoralinae*, *Pseudopaludicola jazmynmcdonaldae*, *Pseudopaludicola matuta*, *Scinax goya*, *Scinax rupestris*; Gymnophiona: *Chthonerpeton tremembe*) and six species for the Caatinga, compiled considering the period from 2018 to 2022 (Anura: *Leptodactylus payaya*, *Pithecopus gonzagai*, *Pristimantis relictus*, *Pristimantis rupicola*, *Proceratophrys ararype*, *Proceratophrys velhochico*) (Table 1). We clarify that the species added in this study were already known by science but can be considered new if compared with the records obtained in Garda et al. (2017) for the Caatinga, and Valdujo et al. (2012) and Azevedo et al. (2016) for the Cerrado.

We gathered 2,659 occurrences of amphibians, of which 2,544 were from the Cerrado and 115 from the Caatinga (1,335 from the SpeciesLink, 414 from GBIF, 371 from the Biodiversity Portal and 539 records from the literature).

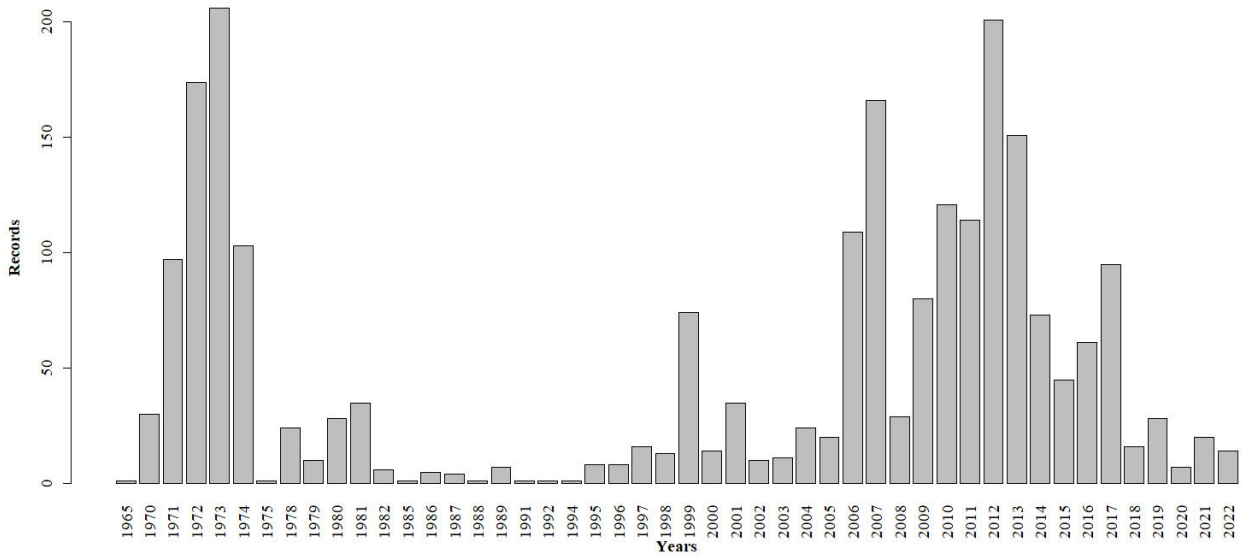

Figure 2. Number of occurrence records obtained on platforms and in the literature with the corresponding years

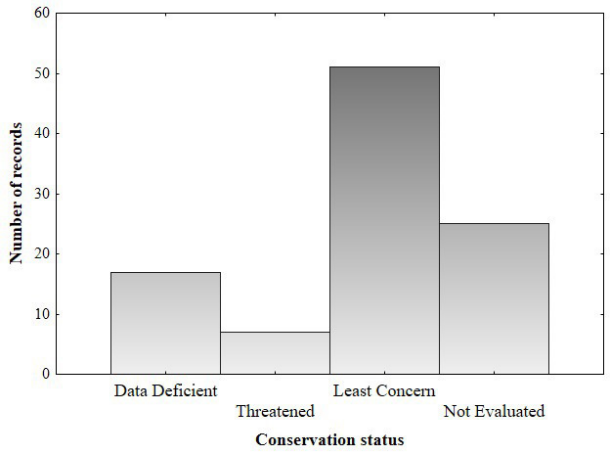

Figure 3. Distribution of the number of occurrence records for the threatened species, LC, DD and NE of Cerrado and Caatinga

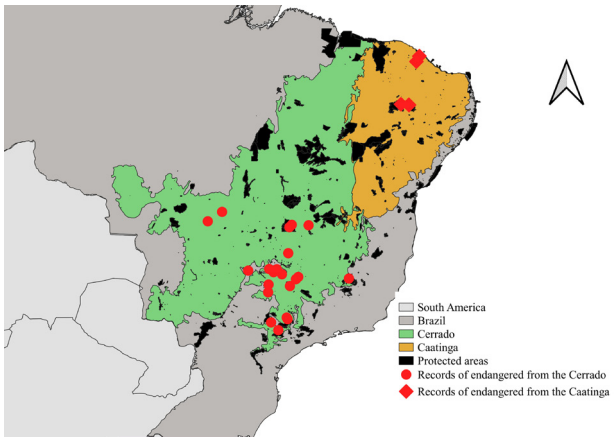

Figure 4. Overlap of the Protected Areas (PAs) with the occurrences of endangered species from the Cerrado and Caatinga

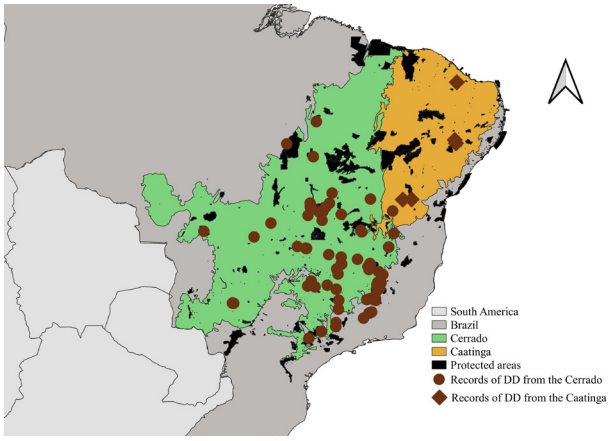

Figure 5. Overlap of the Protected Areas (PAs) with the occurrences of the DD species of the Cerrado and Caatinga

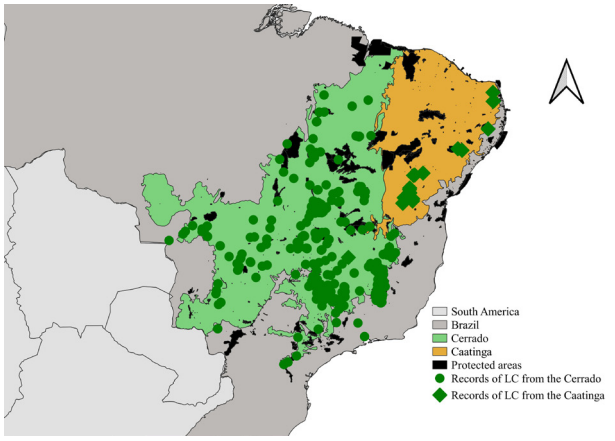

Figure 6. Overlap of the Protected Areas (PAs) with the occurrences of the LC species from Cerrado and Caatinga

However, when removing the duplicate occurrences, we obtained a total of only 897 unique occurrences: 805 for Cerrado and 92 for Caatinga (Table 1).

Considering the accuracy of the occurrence records obtained from the databases, GBIF presented 415 secure records with the presence of the name of the collector/identifier and the available collection and 937 uncertain records, due to the absence of this information; SpeciesLink presented 1,335 secure records, all with the collector/identifier name and collection, and 3,012 uncertain records; and the Biodiversity Portal had 371 secure records and 668 uncertain ones. The species with the highest number of uncertain data were *Bokermannohyla saxicola* (75), *Bokermannohyla alvarengai* (46), *Proceratophrys goyana* (38), *Proceratophrys cururu* (34), *Pseudis tocantins* (33), *Pithecopus megacephalus* (30), *Crossodactylus trachystomus* (26), *Pithecopus gonzagai* (24), *Ameerega braccata* and *Adelophryne baturitensis* (17), *Phasmahyla jandaia* (15), *Ceratophrys joazeirensis* and *Bokermannohyla pseudopseudis* (14), *Bokermannohyla sazimai* (13), *Rhinella veredas*, *Leptodactylus camaquara*, *Pithecopus centralis*, *Pithecopus oreades* and *Adelophryne maranguapensis* (9), *Ameerega berohoka* (8), *Bokermannohyla nanuzae* (7), *Leptodactylus sertanejo* and *Physalaemus evangelistai* (6), *Rhinella cerradensis*, *Bokermannohyla diamantina* and *Boana buriti* (4).

The records covered the period from 1965 to 2022, and records from previous periods were not considered due to not presenting collector or identifier data and the collection. The highest number of records are from 1972 (174), 1973 (206) and 2012 (201), while the years 1965, 1975, 1985, 1988, 1991, 1992 and 1994 had the lowest number of records (one each) (Fig. 2). A large number of records (1,577) were not considered in the analyses due to not having the year.

Regarding the conservation status, the Cerrado has three species classified nationally as VU (*Boana buriti*, *Bokermannohyla napolii* and *Scinax pinimus*) and one globally as CR (*Proceratophrys moratoi*), whereas 14 are considered DD, 46 are LC, and 18 are NE (Table 1). The Caatinga has three species classified as CR (*Adelophryne maranguapensis*, *Proceratophrys ararype*, *Rhinella casconi*), and three listed as DD status, five as LC and seven are NE (Table 1). In general, the species are not well known and have unique records of occurrences, ranging from one to 50 records, with threatened and DD species having fewer records than the others (Table 1, Fig. 3).

We recorded 72 protected areas that included species occurrence (12 for the Caatinga and 61 for the Cerrado). The protected areas of the Cerrado that had the most records of occurrence of endemic amphibians were: Morro da Pedreira Environmental Protection Area (72), João Leite Environmental Protection Area (31), Pouso Alto Environmental Protection Area (27), Environmental Protection Area Environmental Águas Vertentes (21) and Chapada dos Veadeiros National Park (15). For the Caatinga they were the Chapada Diamantina National Park (10), the Serra do Barbado Environmental Protection Area (5), and the Chapada do Araripe Environmental Protection Area (4).

Verifying the presence of endemic amphibian species within the protected areas of the Cerrado and Caatinga, we identified 81 species that occur within the protected areas (68 for the Cerrado and 13 for the Caatinga), with 19 species not being recorded in these areas (14 for the Cerrado and five for the Caatinga) (Table S2). We did not identify occurrence records of the endangered species *B. napolii*.

In general, the species had few occurrence records within the protected areas, in which the threatened species had from one to four records (Fig. 4), the DD from one to eight records (Fig. 5), the LC from one to 15 (Fig. 6) and NE species from one to three records (Fig. 7).

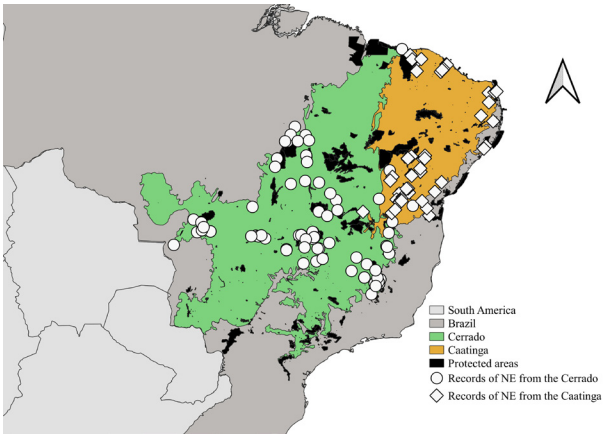

Figure 7. Overlap of the Protected Areas (PAs) with the occurrences of the NE species of Cerrado and Caatinga

DISCUSSION

The Caatinga is a unique biome that has suffered great anthropic pressure. This region is known to receive less attention in relation to research, requiring more conservation strategies directed at it and its biodiversity (Lessa et al., 2019). In addition, the Caatinga has a relatively unknown richness of endemic species (about 18 species), requiring more sampling and studies, especially in poorly accessed areas, for a complete understanding of its biodiversity (Albuquerque et al., 2012).

The Cerrado is considered the richest savanna in terms of biodiversity, which has been intensely threatened by increasing human pressures (Silva & Bates, 2002), and has an enormous richness of endemic amphibian species (about 82 species). It is essential to carry out more studies in the Cerrado, in order to better understand its biodiversity and propose conservation strategies in the face of anthropic pressures. It is known that human pressures will probably advance in future scenarios, which will eventually drastically reduce its native vegetation (Resende et al., 2019), harming the entirety of its biodiversity with the imminent loss of their natural habitats.

Geographic occurrence data allowed us to better understand the geographic area of amphibian species endemic to the Cerrado or Caatinga, and the real diversity of these species. It is important to know the size of the species geographic range and their changes over time, because besides being an ecological and evolutionary characteristic of species, it can be a predictor of extinction risk (Gaston & Fuller, 2009). Biodiversity records present in digital databases (e.g. GBIF) greatly facilitate access to information and are essential because they are based on verifiable specimens and therefore have ballast in scientific collections (Nelson & Ellis, 2018). These data can be used for purposes of basic research in ecology, applied ecology in conservation, scientific outreach, and integrated studies (Smith & Blagoderov, 2012). However, care must be taken with data quality, avoiding uncertainty and bias (Jin & Yang, 2020).

The endemic species from the Cerrado and Caatinga, especially the threatened ones, DD and NE, have few occurrence records and reduced geographical range. According to Smith & Green (2005), the geographical range of species is determined by several factors, such as geographic and ecomorphological restrictions and low dispersal capacity. In this sense, we assume that, for most species, this smaller geographical range may be related to a lower local abundance, which could explain the low number of records, in addition to the ecomorphological characteristics of the different species (Gaston, 1990).

The Cerrado and the Caatinga have few species classified as threatened (four and three, respectively), but have many species considered DD and NE. The species previously considered threatened in the Cerrado, *Allobates goianus*, *A. brunneus* and *Proceratophrys moratoi* (classified as EN, CR, and EN, respectively) were removed from the Brazilian list of threatened species updated in 2022 (MMA, 2022). However, in the IUCN global assessment *A. goianus* is classified as DD and *P. moratoi* CR. The Cerrado species *Boana buriti*, *Bokermannohyla napolii* and *Scinax pinimus* previously classified as LC, NE, and DD respectively are now considered threatened, classified as VU (MMA, 2022). The Caatinga species *Proceratophrys ararype* and *Rhinella casconi* previously classified as NE are now classified as CR along with *Adelophryne maranguapensis* (MMA, 2022). These updated results highlight the essential importance of knowing more about the species geographic ranges and the environmental quality in order to better assess the species conservation status, because species previously assessed as DD, NE, and even LC may be underestimated and at risk.

Doubtful taxonomy and poor knowledge on geographic distribution affect the assessment of the species conservation status, as in the case of *A. brunneus*, which was considered endemic and threatened from the Cerrado (Lima et al., 2009), but due to the similarity with others, such as *Allobates magnussoni*, there are many dubious records in the literature, for example, for the Brazilian Amazon, Bolivia and Colombia (Lima et al., 2014).

The DD species needs more attention for their conservation and strategies that consider their diversity, their abundance, geographic reach, and the conservation status of the environments in which they live. Studies suggest that up to 63% of DD species are at high risk of extinction and are neglected due to the lack of information about them (Howard & Bickford, 2014). Therefore, it is vital to better understand the taxonomy of species and their geographic range, whether LC, DD, threatened or NE, in order to assess their actual conservation status and propose effective conservation measures.

The protected areas of the Cerrado and Caatinga play an essential role in protecting the species. The Cerrado has about 8.6% of its extension formally protected and the Caatinga has about 7.7%, which is still low compared to other biomes like the Amazon (27.8%) and the Atlantic Forest (10.1%) (Vieira et al., 2019). Moreover, all these percentages are considerably below conservation targets proposed by the National Biodiversity Commission (CONABIO, 2013).

We emphasise the importance of amphibian occurrence records to know their biodiversity, their geographic range, their conservation status and thus propose effective measures for their protection. In this sense, we suggest that the records on endemic amphibians be increasingly included in digital databases to make them accessible. However, it is necessary that these inserted data are refined, containing all the necessary information about the record of the specimen such as the year of registration, location, collector, among others.

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DATA ACCESSIBILITY

The data supporting the supplementary material (Table S1) can be accessed at https://osf.io/4w8yx/?view_only=4bf4cbbec17c413eb961ef992f7ab76d. The data supporting the supplementary material (Table S2) can be accessed at https://osf.io/8snue/?view_only=bb69383d4260446f9d8013d7ab43526d.

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