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Anuran species in Brazil's protected areas network

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Amphibians are one of the most threatened among the vertebrates species and urgently require conservation protection and planning. The establishment of protected areas (PAs) is one of the most important strategies in protecting biodiversity, as they offer a partial solution to habitat modification. Our main objective was to analyse the temporal and spatial trends in the anuran species inventories of PAs in Brazil, therefore providing an extensive list of anuran species in the Brazilian PAs network for the first time. We considered a combination of keywords while using the data on "Scopus", "Scielo", and "Web of Science". We found 115 papers that published anuran species lists for 101 Brazilian protected areas. Overall, we registered 605 species distributed in 20 families. Only seven out of the 605 anuran species registered in the present study are threatened by extinction and 40 are listed as Data Deficient. The number of anuran species inventories in Brazilian protected areas has increased over time ($r = 0.17$; $r^2 = 0.267$; $p<0.01$), with its peak in 2011 (n = 15 inventories). The majority of the species inventories were conducted in protected areas located in the Atlantic Forest (55.45 %). The number of anuran species per protected area varied from seven to 80; however, we did not find any relationship between the species richness and size of the protected areas ($r^2 = 0.027$; $r = 0.165$; $p = 0.092$). Our results can be useful to fill the gaps and integrate knowledge; and this reinforces the importance of the present study in contributing to the knowledge and conservation of anuran species in Brazil.

Keywords: Brazilian biomes, species list, inventory, temporal and spatial trends

INTRODUCTION

Financial resources and time are running out in the race to protect biodiversity around the world (Brooks et al., 2006). Effective conservation actions need to be quickly implemented in order to avoid the loss of species. In this context, the establishment of protected areas (PAs) is one of the most important local, regional, and global strategies to protect all biodiversity components (Rodrigues et al., 2004; Nori et al., 2015). PAs have been created and utilised since the nineteenth-century (Watson et al., 2014). Currently, the IUCN (Dudley & Stolton, 2008) defines PAs as "a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values". Since 2010, the Convention on Biological Diversity (CBD, 2010) recommends that 17 % of the territory of all countries should be legally protected through of PAs. As a consequence, the coverage of these areas has considerably expanded in the last decade (e.g., Jenkins & Joppa, 2009; Juffe-Bignoli et al., 2014; WDPA, 2016). However, the nature protection in situ is still far from ideal and only 13 % of terrestrial land is protected (Bertzky et al., 2012).

Amphibians comprise over 8,000 species of frogs, salamanders, newts, and caecilians (Frost, 2019). Roughly 31.4 % (~2,100 spp.) of the amphibian species evaluated by the IUCN are classified within one of the threat categories, while another 22.3 % (~1490 spp.) are classified as Data Deficient (IUCN, 2019). Even though it is the most threatened group among the vertebrates (Stuart et al., 2004; IUCN 2019), amphibians are still underrepresented in the global network of PAs (Jenkins et al., 2013; Nori et al., 2015). Several factors have negatively affected the amphibians; however, the habitat loss and fragmentation have been considered the main threats to these animals, since their effects have caused population declines in different amphibian species around in the world (Stuart et al., 2004; Becker et al., 2010). Amphibian species should be a conservation priority (Stuart et al., 2004), since sufficient evidence points towards the danger of them disappearing (Pyron, 2018), without proper protection (Nori et al., 2015).

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Recently, Brazil has previously been recognised as a global leader in the creation of protected areas (Jenkins & Joppa, 2009; Loyola, 2014), a key conservation strategy considering in protecting the large number of amphibians species (~1,140 amphibian species; Segalla et al., 2019). In Brazil, the first protected area was established in 1937 (Cabral & Brito, 2013) and ever since the United Nations Conference on Environment and Development in 1992 (the Rio "Earth Summit") more than two thousand have been created (Vieira et al., 2019). The late expansion of the Brazilian protected areas network can be explained by the National System of Conservation Units – NSCU (Brazilian Law nº 9,985/2000 - Sistema Nacional de Unidades de Conservação - SNUC) which established criterion to create and manage the PAs (Brasil, 2000; Silva, 2005). According to the NSCU, the Brazilian PAs are categorised into two major groups: (1) strictly protected areas (National Parks, Biological Reserves, Ecological Stations, Natural Monuments, and Wildlife Refuges) of which only one indirect use of nature resource is allowed; and (2) sustainable use reserves (Extractive Reserves, Sustainable Development Reserves, Wildlife Reserves, National Forests, Environmental Protection Areas, and Areas of Relevant Ecological Interest) that aims to harmonise the nature conservancy and a sustainable use of natural resources including different forms of management.

By recognising the importance of the PAs network, the present study provided a list of anuran species occurring in the Brazilian PAs network based on an intensive search in the literature. Herein, our main objective was to analyse the temporal and spatial trends in the anuran species inventories in Brazilian PAs. Specifically, we addressed the following questions: (1) How many and which anuran species effectively occur in Brazilian protected areas? (2) How did the number of anuran species inventories in PAs increase over time? (3) Does the number of species inventories differ among the Brazilian biomes? (4) How does the size of the protected areas influence the anuran species richness?

METHODS

We chose to focus on anurans for this study, as 96 % of amphibians in Brazil are anuran species (Segalla et al., 2019); of which 41 species are currently threatened by extinction and 167 species are Data Deficient (according to the Brazilian Red List; MMA, 2018). We searched for studies that provided list of anuran species in Brazilian protected areas. Firstly, we accessed the sources of the data on "Scopus", "Scielo", and "Web of Science" and used the combination of the following keywords: anuran*, species list, AND inventory AND Brazil* AND protected area* OR Conservation Unit OR Park OR Biological Reserve OR Ecological Station OR Extractive Reserve OR Sustainable Development Reserve OR Wildlife Reserve OR Natural monument OR Forest OR Environmental Protection Area OR Area of Relevant Ecological Interest and Private Reserve of Natural Heritage. We did not consider grey literature (i.e. conference proceedings, dissertation, theses and technical reports). All possible redundant studies were removed and articles published after June 2019 were not included in our sample.

For each study, we obtained the following variables: (i) year of publication; (ii) title; (iii) number of anurans species; (iv) species list (species composition); (v) PAs name; (vi) PAs size (in hectare); (vii) geographic coordinates; (viii) biome, as cited in the study; and (ix) federal state name. Undetermined species such as "sp.", "cf.", "gr." and "aff" were not included in our analysis. The taxonomy and nomenclature used follow Frost (2019). To verify whether the number of lists of anuran species in protected areas from Brazil increased throughout the years, we used a simple linear regression analysis. Furthermore, we used a simple linear regression to test the influence of the size of the Brazilian PAs had on anuran species richness in each anuran species inventory. This statistical procedure describes a linear relationship between one response variable (e.g. number of anuran species inventory or anuran species richness) and another independent variables (e.g. years or size of the protected areas). For this, we tested the assumptions (e.g. homogeneity of variance and normal distribution) of the test prior to analysis and considered our significance level to be 5 %.

RESULTS

Our database includes 115 papers of which each one contain, at least, an anuran species list for 101 PA in Brazil (Fig. 1; Supplementary Materials Table 1). In general, these studies include inventories from a singular PA, but three studies simultaneously considered more than one protected area. Fourteen protected areas were systematically studied more than once, because they were considered in more than one study. All 115 studies considered, we identified 605 species distributed in 20 families (Fig. 2; Supplementary Materials Table 2). According to the Brazilian Red List of Threatened Species categories (MMA 2014), there are one Critically Endangered species, one Endangered, and five Vulnerable (Table 1), while nine species are classified as Near Threatened, 40 Data Deficient, and 549 Least Concern species found in Brazilian PAs.

Some families are represented in more PAs than others. In total, about 37.2 % of species belong to the family Hylidae, while the families Allophrynidae and Alsodidae were represented by one species of each family. In the present study, *Boana albomarginata*, *B. albopunctata*, *B. faber*, *Dendropsophus elegans*, *D. minutus*, *D. nanus*, *Elachistocleis cesarii*, *Haddadus binotatus*, *Leptodactylus fuscus*, *L. labyrinthicus*, *L. latrans*, *L. mystaceus*, *L. mystacinus*, *Physalaemus cuvieri*, *Rhinella diptycha*, *R. icterica*, *R. ornata*, *Scinax fuscomarginatus*, and *S. fuscovarius* were the species more representative within protected areas, since they have been identified in more than 20 PAs (Supplementary Materials Table 2). Approximately 33 % of species were identified in only one PA.

The anuran species list from Estação Ecológica do Taim was the first inventory of a Brazilian PA made in 1988 (Supplementary Material Table 1). Hereafter, the number of anuran species inventories in Brazilian protected areas has increased over time ($r = 0.517$; $r^2 = 0.267$; $p < 0.01$;

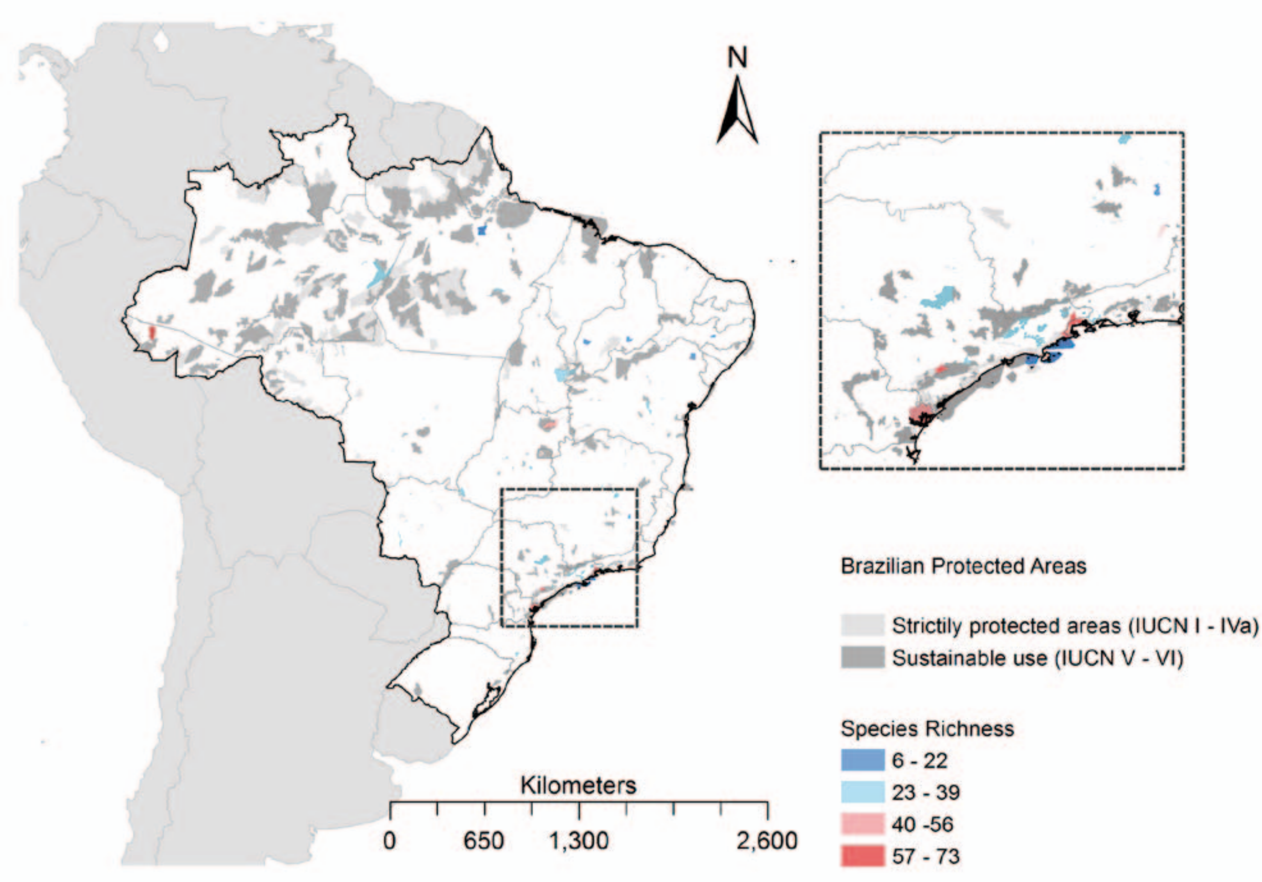

Figure 1. Brazilian PAs with anuran species inventories. Zoom illustrates PAs of the Atlantic Forest

Table 1. Threatened anuran species found in the inventories conducted in Brazilian protected areas network.

Species	Brazilian red list category (MMA 2014)	Protected area where the species occurs	Reference
Allobates goianus	Endangered	Floresta Nacional de Silvânia / Parque Nacional da Chapada dos Veadeiros	Morais et al. (2012) / Santoro & Brandão (2014)
Allobates olfersiodes	Vulnerable	Área de Proteção Ambiental de Lagoa Encantada e Rio Almada / Reserva Sapiranga / Reserva Ecológica da Michelin / Reserva Particular do Patrimônio Natural Serra Bonita	Dias et al. (2014a) / Bastazini et al. (2007) / Camurugi et al. (2010) / Dias et al. (2014b)
Boana cymbalum	Critically Endangered	Parque Natural Municipal Nascentes de Paranapi-acaba	Trevine et al. (2014)
Boana curupi	Vulnerable	Parque Estadual do Turvo / Parque Estadual Frtiz Plaumann / Parque Nacional das Araucárias / Parque Natural Municipal de Sertão	Iop et al. (2011) / De Bastiani & Lucas (2013) / Lucas & Marocco (2011) / Zanella et al. (2014)
Melanophryniscus dorsalis	Vulnerable	Parque Estadual de Itapeva	Colombo et al. (2008)
Physalaemus maximus	Vulnerable	Parque Estadual da Serra do Brigadeiro	Moura et al. (2012)
Scinax duartei	Vulnerable	Reserva Particular do Patrimônio Santuário do Caraça	Canelas & Bertoluci (2007)

Fig. 3), peaking in 2011 (n = 15 inventories). The number of species inventories and the anuran species richness per protected area in each Brazilian biome are described in Table 3. The majority of the species inventories were conducted in PAs located in the Atlantic Forest (n = 56 PAs; 55.45 %), followed by the Cerrado (n = 18 PAs studies; 17.82 %), Amazon (n = 13 PAs; 12.87 %), and the Caatinga (n = 7 PAs; 6.93 %) (Table 2). Although some PAs in ecotone regions were also studied (5 %, Table 3). There are not available any anuran species inventory of PAs in the Pantanal biome. In general, more studies were realised in strictly PAs (n = 76) than sustainable use protected areas (n = 25) (Table 2).

The Brazilian PAs of which contains an anuran species inventory cover an area greater than 8 million of hectares. The RPPN Campo Escoteiro Geraldo Hugo Nunes (Atlantic Forest biome), with 45.2 hectares, is the smallest protected area with a list of anuran species, while the Reserva de Desenvolvimento Sustentável Piagaçu-Purus (Amazon biome), with 834,245 hectares, is the largest one (Supplementary Material Table 1). The number of anuran species per protected area range from seven to 80 (33.7±16.27 species; n = 101 protected areas). Two PAs contain the greatest anuran species richness

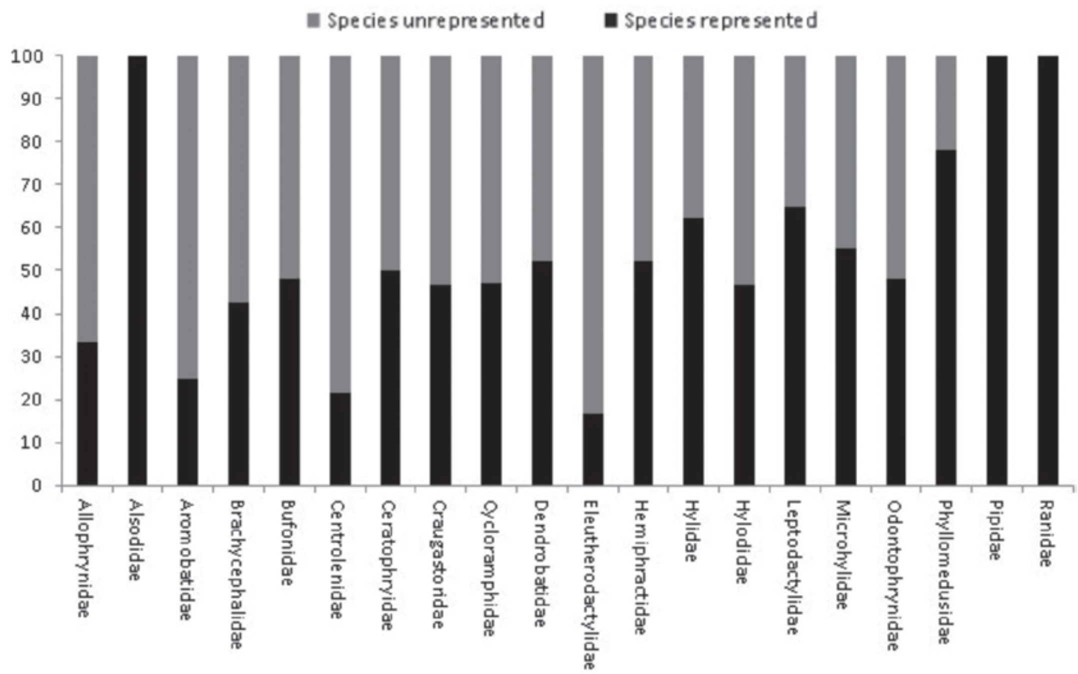

Figure 2. Representativeness of families of anuran species within Brazilian protected areas network

Table 2. Number of protected areas and anuran species richness per protected area for each Brazilian biome

Biome	Number of protected areas: Strictly protected areas	Number of protected areas: Sustainable use protected areas	Species richness: Strictly protected areas	Species richness: Sustainable use protected areas
Atlantic Forest	46	10	34.26±17.84 (7-80)	39.5±17.61 (19 – 79)
Cerrado	14	4	32.14±8.69 (19 – 54)	28±11.74 (16 – 42)
Amazon	5	8	35.4±14.92 (13 – 49)	43.62±21.25 (21 – 80)
Caatinga	7	--	19±7.18 (7 – 31)	--
Atlantic Forest-Cerrado ecotone	2	2	35±15.55 (24 – 46)	37±1.41 (36 – 38)
Caatinga-Cerrado ecotone	1	--	18	--
Coastal Marine	1	--	32	--
Pampa	--	1	--	18
Total	76	25	32.13±15.76 (7 – 80)	38.48±17.17 (16 – 80)

(n = 80) namely Parque Natural Municipal Nascentes de Paranapiacaba (Atlantic Forest biome) and Reserva Extrativista Riozinho da Liberdade (Amazon biome). Surprisingly, there is not a relationship between the species richness and size of the PAs ($r^2 = 0.027$; $r = 0.165$; $p = 0.092$).

DISCUSSION

PAs are a key strategy for protecting biological resources (Oliveira et al., 2019) presupposing the species extinctions prevention in situ. PAs inventories are important to know which species are currently protected (Bruner et al., 2001); therefore, they are a first step for conservation management options and strategy analysis in order to increase PA effectiveness (Bruner et al., 2001). In Brazil, there is a knowledge gap in PAs inventories, since less than 5 % of all Brazilian PAs (see Vieira et al., 2019) have a list of anuran species available in literature. The lack of financial resources or qualified personnel (e.g., Taxonomists) can explain such knowledge gap; however, we suggest that the logistical difficulties of accessing many Brazilian protected areas as well as the bureaucracy to obtain collection permits within PAs (especially at state and municipal levels) also contribute to this gap.

Approximately half of all anuran species inhabiting in Brazil (Segalla et al., 2019) were included into these inventory studies, and those one occur in at least one of the 101 protected areas. Recently, Nori et al. (2015) illustrated that only 63 % of all currently extant amphibian species (~8,050 spp.) are estimated to occur in the worlds' global protected area network. Previous studies have

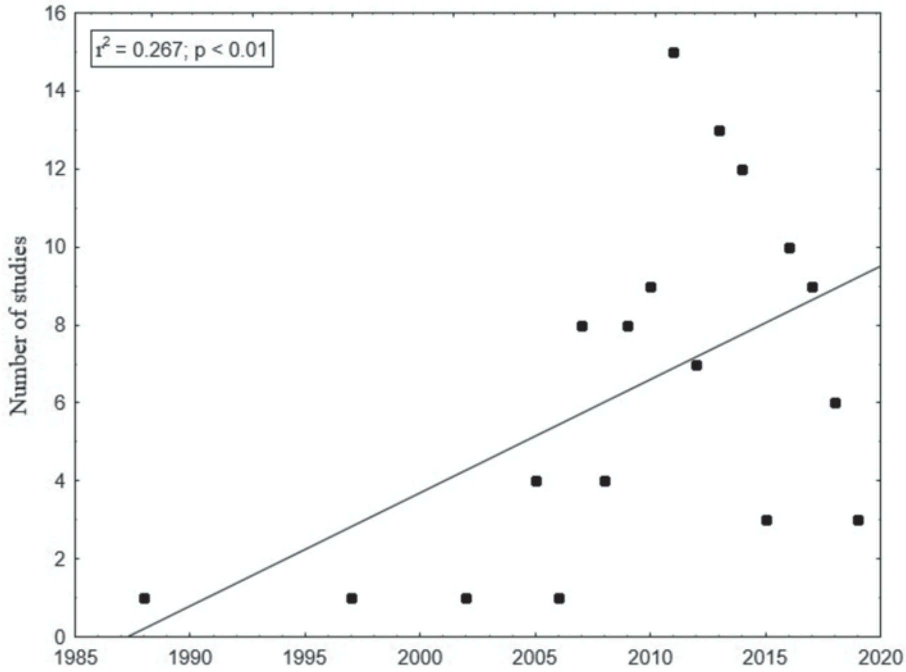

Figure 3. Temporal variation in the number of inventories of anuran species in Brazil's protected areas network

demonstrated a positive relationship between amphibian species diversity and species knowledge (Bini et al., 2006; Diniz-Filho et al., 2009) where sampling efforts are not affected by accessibility difficulties (i.e., Oliveira et al., 2016). Here, we emphasised that the Atlantic Forest is the most inventoried biome (Fig. 1; Table 3). Recently, this region has been identified as a global priority area for anuran research, mainly due to the highest anuran extant diversity, but also due to ongoing human pressure (Nori et al., 2018). However, the current state of anuran diversity in the Atlantic Forest may be an outcome of increased species knowledge due to the presence of major universities, dense populations and improved infrastructure in the region.

When implementing conservation strategies, the first step should be to verify the species representativeness and the site's irreplaceability degree (Le Saout et al., 2013). Such management efforts are advisable even where there are currently establishments PAs. Beyond this, the inclusion of Endangered and Data Deficient species (Polak et al., 2016) can be an important tool for management the conservation options (Nori & Loyola, 2015). According to some global analyses, both Endangered and Data Deficient anuran species have typically been poorly represented in PAs (Nori et al., 2015; Nori & Loyola, 2015) even when distribution maps (minimum convex polygon; IUCN 2019) were used. Gap analyses are meaningful for conservation actions (Rodrigues et al., 2004; Venter et al., 2014; Watson et al., 2014; Nori et al., 2015), but they may include some commission errors which can occur when falsely assuming species presence in PAs; therefore, this reinforce the importance of the present study to subsidy the management and conservation actions for amphibians species.

In general, the anurans inventories might be used as a guide for the conservation management of PAs since they offer a detailed species list from exhaustive hours of fieldworks. Here, we gathered and reported all literature pertinent to the anuran inventory of Brazil. The first Brazilian anuran species inventory in a PA was conducted in 1988 (Estação Ecológica do Taim); and since 2005, the number of inventories has considerably increased. Many other anuran inventories were performed according as the expansion of the Brazilian PA network increased, mainly in the Atlantic Forest biome. Considering that most conservation actions can occur at regional and local levels (Possingham et al., 2002) it has become urgent to focus in research efforts regarding those poorly sampled areas (Nori et al., 2018). For example, many environmental agencies, NGOs, and research fund may act at regional and local levels, and this can be useful to reduce the knowledge gap between Brazilian biomes. Additionally, we have observed an increase in research regarding the Caatinga biome (e.g., Garda et al., 2013; Cavalcanti et al., 2014; Pedrosa et al., 2014; Magalhães et al., 2015; Caldas et al., 2016; Costa et al., 2018) which may have filled the knowledge gap about anuran species in previously data deficient Brazilian PAs.

We provided an extensive list of anuran species present in the Brazilian PAs network. Initiatives that objective to collect and compile data on biodiversity allowing to fill gaps and also the integration of knowledge must be supported (Jenkins et al., 2015). Then, our study is important to include into conservation management options for all biomes, including those less represented in our anuran inventories dataset. In this sense, we suggest that inventories must be conducted in more areas, especially those in which there are rapid destruction of habitats and sampling gaps (e.g., Amazon and Cerrado Biomes). For this, we suggest that it would be ideal to create an integrated network of researchers focused on conducting anuran species inventories in protected areas across Brazil.

Finally, for a long time now, Brazilian researchers have been subject to insufficient funding (or simply no funding) and discouraged by actual and recent past governments which hinders necessary herpetological expeditions far from large urban centres. Also, there is a movement to discredit and impede current environmental research and conservation management of biological resources in Brazil which diverge from economic plans for the development of natural resources (e.g., Ferrante & Fearnside, 2019). We really hope that science in Brazil can continue to progress hand in hand with development in order to be intelligent drive conservation plans decided upon by Brazilian decision-makers.

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