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RAFAELA CÂNDIDO DE FRANÇA

ESTADO DE CONSERVAÇÃO DAS SERPENTES DO CENTRO DE ENDEMISMO PERNAMBUCO

ILHÉUS - BAHIA

2020

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Tese apresentada à Universidade Estadual de Santa Cruz, como parte das exigências para obtenção do título de Doutor em Ecologia e Conservação da Biodiversidade.

Área de concentração: Ecologia e Conservação da Biodiversidade

Orientador: Dr. Mirco Solé
Co-orientador: Dr. Frederico Gustavo Rodrigues França

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Ilhéus, 31 de Março de 2020.

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Aos meus pais, Joenir e Assis, por
todo amor, carinho e cuidado

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ESTADO DE CONSERVAÇÃO DAS SERPENTES DO CENTRO DE ENDEMISMO PERNAMBUCO

RESUMO

A biodiversidade global, assim como as funções ecológicas, vem sofrendo ameaças sem precedentes, devido a acelerada perda de espécies decorrentes das inúmeras transformações dos sistemas naturais. Dada a atual crise da biodiversidade e a falta de recursos, espécies ameaçadas devem ser diferenciadas das outras, de modo que as espécies que apresentam maior prioridade de conservação possam ser atendidas primeiro. A Floresta Atlântica é uma das maiores e mais ricas florestas tropicais do planeta, sendo uma das 25 prioridades mundiais para conservação. Localizado no Nordeste Brasileiro, o Centro de Endemismo de Pernambuco (CEP), é o setor mais degradado, menos conhecido e menos protegido de toda a Floresta Atlântica, sendo uma das regiões do planeta onde os esforços de conservação são mais urgentes. Com base em registros de cinco coleções científicas e informações adicionais da literatura, nós descrevemos a composição de serpentes do CEP, fornecendo informações sobre a diversidade, história natural e distribuição geográfica das espécies. Nós também avaliamos a vulnerabilidade à extinção das 78 espécies de serpentes que ocorrem no CEP e analisamos os principais fatores que podem ameaçar a viabilidade das populações. Os nossos resultados indicam que 46% da fauna de serpentes desta região pode estar ameaçada de extinção. As espécies *Helicops angulatus* e *Oxyrhopus trigeminus* foram as serpentes que apresentaram os menores riscos de extinção, enquanto *Caaeteboia* sp. e *Bothrops muriciensis*, duas espécies endêmicas do CEP, são as mais ameaçadas. Nós também analisamos a distribuição potencial das espécies de serpentes consideradas ameaçadas na região e observamos que a distribuição dessas espécies estão próximas de Áreas Protegidas, no entanto algumas dessas áreas são pequenas para uma proteção eficaz. Além disso, outros pontos de distribuição destas espécies não foram contemplados por nenhuma dessas áreas. Esse trabalho apresenta o primeiro panorama sobre o status de conservação das espécies de serpentes do CEP, e contribui para uma melhor avaliação de um planejamento de conservação desse grupo, na região.

Palavras-chave: biodiversidade, répteis, história natural, riqueza, Floresta Atlântica, Nordeste do Brasil.

CONSERVATION STATUS OF SNAKES OF THE PERNAMBUCO ENDEMISM CENTER

ABSTRACT

Global biodiversity, as well as ecological functions, are suffering unprecedented threats due to the accelerated loss of species resulting from the many transformations of natural systems. Due to the current biodiversity crisis and lack of resources, threatened species must be differentiated from others, so that species with the highest conservation priority can be considered first. The Atlantic Forest is one of the largest and richest tropical forests on the planet, being one of the 25 world conservation priorities. Located in the Northeast of Brazil, the Pernambuco Endemism Center (PEC) is the most degraded, least known and least protected sector of the entire Atlantic Forest, being one of the regions on the planet where conservation efforts are most urgent. Based on records from five scientific collections and additional information from the literature, we describe the composition of snakes from the PEC, providing information on the diversity, natural history and geographical distribution of species. We also assessed the vulnerability to extinction of the 78 snake species that occur in the PEC and analyzed the main factors that may threaten the viability of populations. Our results indicate that 46% of the snake fauna in this region may be threatened with extinction. The species *Helicops angulatus* and *Oxyrhopus trigeminus* were the snakes that presented the lowest risk of extinction, while *Caaeteboia* sp. and *Bothrops muriciensis*, two endemic species of the PEC, presented the highest risk of extinction. We also analyzed the potential distribution of snake species considered threatened in the region and observed that the distributions of these species are near Protected Areas, however some of these areas are small for effective protection. Furthermore, other points of distribution of these species have not been contemplated by any of these areas. This work presents the first overview of the conservation status of snake species in the PEC, and contributes to a better assessment of a conservation plan for this group in the region.

Keywords: biodiversity, reptilia, natural history, richness, Atlantic Forest, Northeast of Brazil

Sumário

INTRODUÇÃO GERAL

A biodiversidade global, assim como as funções ecológicas, vem sofrendo ameaças sem precedentes, devido a acelerada perda de espécies decorrentes das inúmeras transformações dos sistemas naturais. Estas estão diretamente relacionadas com atividades antrópicas, voltadas à produção de energia e alimentos, assim como à exploração dos recursos naturais (PIRATELLI; FRANCISCO, 2013; PRIMACK; RODRIGUES, 2001). Esse problema vem se agravando na medida que há uma intensificação do desmatamento nos ecossistemas tropicais, que é onde se concentram a maior parte da biodiversidade (GANEM, 2011).

A Floresta Atlântica é considerada uma das 25 áreas prioritárias para conservação em todo o mundo (MYERS et al., 2000). Esse bioma foi uma das maiores florestas tropicais das Américas, cobrindo originalmente 150 milhões de hectares ao longo da costa brasileira e partes do Paraguai e Argentina (SILVA; CASTELETI, 2003). Hoje, a Floresta Atlântica foi reduzida para menos de 12% de sua cobertura original (RIBEIRO et al., 2009). Mesmo tendo sofrido uma extensa fragmentação desde longa data, a Floresta Atlântica ainda apresenta uma grande biodiversidade, abrigando uma das maiores porcentagens de espécies endêmicas do mundo (MORELLATO; HADDAD, 2000).

Embora praticamente toda a costa brasileira tenha sido ocupada pela colonização européia, foi no nordeste que a Floresta Atlântica se degradou mais rapidamente, devido ao ciclo econômico do pau-brasil e da cana-de-açúcar (COIMBRA-FILHO; CÂMARA, 1996). Essa degradação é ainda mais evidente na porção da Floresta Atlântica localizada ao norte do rio São Francisco, onde um importante centro de endemismo está localizado na América do Sul - O Centro de Endemismo de Pernambuco (CEP) (PRANCE, 1982; SILVA; CASTELETI, 2003). Nesta região, a cana-de-açúcar é a principal cultura agrícola e outras ações antrópicas, como o extrativismo animal e vegetal, contribuíram para a redução da biodiversidade na região (COIMBRA-FILHO; CÂMARA, 1996; TABARELLI; MARINS; SILVA, 2002; TABARELLI; MELO; LIRA, 2006). Em meio a esse cenário, o CEP é considerado o setor mais devastado, menos conhecido e menos protegido da Floresta Atlântica, sendo uma das regiões do planeta onde os esforços de conservação são mais urgentes (COIMBRA-FILHO; CÂMARA, 1996; TABARELLI; MARINS; SILVA, 2002; TABARELLI; RODA, 2005).

Entre os répteis, as serpentes são o grupo que atualmente apresenta os riscos mais subestimados de extinção, devido à escassez de informações sobre a história natural da maioria das espécies, principalmente por terem longos períodos de inatividade, serem difíceis de observar e viverem em baixas densidades populacionais (SEIGEL, 1993). Embora alguns estudos realizados em remanescentes de Floresta Atlântica do Centro de Endemismo de Pernambuco tenham fornecido informações importantes sobre as serpentes dessa região (FRANÇA; GERMANO; FRANÇA, 2012; FREITAS et al., 2019; MESQUITA et al., 2018; MOURA et al., 2011; PEREIRA-FILHO et al., 2017; PEREIRA FILHO; MONTINGELLI, 2011; ROBERTO et al., 2012; ROBERTO; ÁVILA; MELGAREJO, 2015; RODRIGUES et al., 2015; SAMPAIO et al., 2018), o conhecimento sobre a diversidade, distribuição e história natural das espécies de serpentes do CEP permanece escasso e fragmentado. Além disso, devido a extensa degradação do bioma, principalmente nessa região, é de grande importância o conhecimento do status de conservação dessas espécies, já que grande parte dessa fauna pode e deve estar ameaçada de extinção.

Diante disso, no capítulo 1 buscamos descrever o estado atual de conhecimento das serpentes do Centro de Endemismo Pernambuco e fornecer informações sobre a diversidade, história natural e distribuição geográfica das espécies, com base em registros de coleções científicas e informações adicionais da literatura. No capítulo 2, realizamos uma revisão sobre os principais fatores intrínsecos e extrínsecos de ameaça associados à maior vulnerabilidade à extinção dos répteis ao redor do mundo. O conhecimento desses fatores, associados à vulnerabilidade à extinção das serpentes foi importante para a construção do capítulo 3. Nesse capítulo (3) avaliamos a vulnerabilidade à extinção das serpentes do CEP e analisamos os principais fatores que podem ameaçar a viabilidade das populações. Já no capítulo 4, buscamos criar um modelo de distribuição potencial das espécies de serpentes consideradas ameaçadas do CEP (conhecimento gerado no capítulo 3), analisar a distribuição dessas espécies nessa região, sobrepor esses dados com as áreas protegidas e indicar áreas adequadas para estudos voltados à conservação dessas espécies.

O capítulo 5 da tese é um manuscrito adicional gerado a partir dos estudos realizados no período do doutorado Sanduíche na Alemanha, no qual foi possível examinar uma coleção histórica de serpentes brasileiras coletadas por Paul Müller, um zoólogo alemão que coletou serpentes em diferentes regiões do Brasil entre os anos de 1964 e 1976, as quais foram depositadas no Zoological Research Museum Alexander Koenig, localizado em Bonn, Alemanha.

CAPÍTULO 1

SNAKES OF THE PERNAMBUCO ENDEMISM CENTER, BRAZIL: DIVERSITY, NATURAL HISTORY AND CONSERVATION

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Snakes of the Pernambuco Endemism Center, Brazil: Diversity, natural history and conservation

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Abstract:

The Atlantic Forest is one of the largest and richest tropical rainforests on the planet, being one of the 25 world priorities for conservation. The Atlantic Forest portion located north of the São Francisco River corresponds to the Pernambuco Endemism Center (PEC). We describe the snake composition of the PEC, providing information about the diversity, natural history and geographical distribution of the species, based on records from five scientific collections and additional information from the literature. A total of 78 species of snakes distributed in eight families was registered in the Pernambuco Endemism Center. The Caatinga is the Brazilian biome that most shares species with the PEC, followed by Cerrado. On the other hand, seven species are considered endemic of this region. Most of the snake species in the PEC have been registered in forest (94.8%), followed by “Brejos Nordestinos” (46.1%), Tabuleiros

(43.5%), Restingas (14.1%) and Mangroves (5.1%). The PEC snake fauna includes mainly terrestrial species (60.2%) and cryptozoic and/or fossorial species (21.7%), but also presents a high richness of semi-arboreal and arboreal species (29.5%). Vertebrates are the main food item consumed by the species (78% of species), among the main prey are mammals, lizards, and amphibians. Most species show a strictly nocturnal activity period (50%), followed by strictly diurnal (38%). The PEC is the most degraded and least known region of the Atlantic Forest, yet it has revealed a high richness of snake species, including seven endemic species. It is emphasized that regional conservation efforts need to be intensified, because few forests in the region are formally protected, and the majority consist of small and poorly protected fragments, which means that many species in the region may be in risk of extinction.

Keyword: biodiversity, geographic distribution, inventory, natural history, Serpentes, richness.

Introduction

The Atlantic Forest is considered one of the 25 priority areas for conservation worldwide (Myers et al. 2000). This biome was one of the largest tropical forests in the Americas, originally covering 150 million hectares along the Brazilian coast and parts of Paraguay and Argentina (Silva and Casteleti 2003). Today, the Atlantic Forest has been reduced to less than 12% of its original coverage (Ribeiro et al. 2009). Even having suffered an extensive fragmentation since long time ago, the Atlantic Forest still presents a great biodiversity, housing one of the highest percentages of endemic species in the world (Morellato and Haddad 2000).

Although practically the entire Brazilian coast was occupied by European colonization, it was in the northeast that the Atlantic Forest was more rapidly degraded, due to the economic cycle of brazilwood and sugar cane (Coimbra-Filho and Câmara 1996). This degradation is even more evident in the portion of the Atlantic Forest located north of the São Francisco River, where an important center of endemism is located in South America – The Pernambuco Endemism Center (hereafter PEC) (Prance 1982, Silva and Casteleti 2003). In this region, sugar cane is the main agricultural crop and other anthropic actions, such as animal and plant extractivism, have contributed to the reduction of biodiversity in the PEC (Coimbra-Filho and Câmara 1996, Tabarelli et al. 2002, 2006a). In the midst of this scenario, the PEC is considered the most devastated, least known and least protected sector of the Atlantic Forest, being one of the regions on the planet where conservation efforts are most urgent (Coimbra-Filho and Câmara 1996, Tabarelli et al. 2002, 2005).

Among reptiles, snakes are the group that currently presents the most underestimated risks of extinction, due to the scarcity of information on the natural history of most species, mainly because they have long periods of inactivity, are difficult to observe and live in low population densities (Seigel 1993). Although some studies carried out on Atlantic forest remnants of the PEC have provided important information about snakes in this region (e.g. Moura et al. 2011, Pereira Filho and Montingelli 2011, França et al. 2012, Roberto et al. 2012, 2015, Rodrigues et al. 2015, Pereira Filho et al. 2017, Mesquita et al. 2018, Sampaio et al. 2018, Freitas et al. 2019a), the knowledge about the diversity, distribution and natural history of PEC snake species remains scarce and fragmented. In this direction, scientific collections perform a fundamental role in obtaining information that is the basis for the description of new species, biodiversity inventories and identification of endemism areas (Rocha et al. 2014).

Herein, we describe the snake composition at the Pernambuco Endemism Center, providing information about the diversity, natural history and geographical distribution of the species, based on records from scientific collections and additional information from the literature.

Materials and methods

Study area

The study area comprises the Atlantic Forest located north of the São Francisco River, which corresponds to the Pernambuco Endemism Center (PEC) (Figure 1) (Prance 1982, Silva and Casteleti 2003), located between the states of Alagoas and Rio Grande do Norte. This region has a humid tropical climate (Köppen's As'), with autumn-winter rains and rainfall ranging from 750 to 1500 mm per year (Tabarelli et al. 2006a).

The PEC region is composed by different native forest formations and ecosystems associated with the Atlantic Forest domain. A mosaic of ombrophilous and semi-deciduous forests is present in this region (Tabarelli et al. 2006a). Also, PEC comprises the "Brejos de Altitude" or "Brejos Nordestinos", which are "islands" of humid forests established in the semi-arid region, surrounded by Caatinga vegetation (Andrade-Lima 1982). Although the vegetation of the PEC is composed mainly of humid tropical forests, we can also find open physiognomies along the coast, which are called “Restingas”, and in the interior, which are called “Tabuleiros”. The restingas are formed by strips of beaches and dunes covered by herbaceous and shrubby vegetation (Araujo 1992). The Tabuleiros are considered natural enclaves of savannah, characterized by herbaceous vegetation, with scattered trees and shrubs or grouped in patches that are structurally similar to the coastal restingas, but without the marine influence (Andrade-Lima 1982). On the coast along the PEC, we can also find areas of mangroves, with a diversified aggregation of trees and shrubs that form the dominant plant communities in saline solution of the tides (Tabarelli et al. 2006b).

According to Uchoa Neto and Tabarelli (2002), the PEC presents the largest amount of remaining area of Atlantic Forest in the state of Pernambuco (1,363.23 km²), followed by the states of Alagoas (807.95 km²), Rio Grande do Norte (567.67 km²) and Paraíba (566.09 km²).

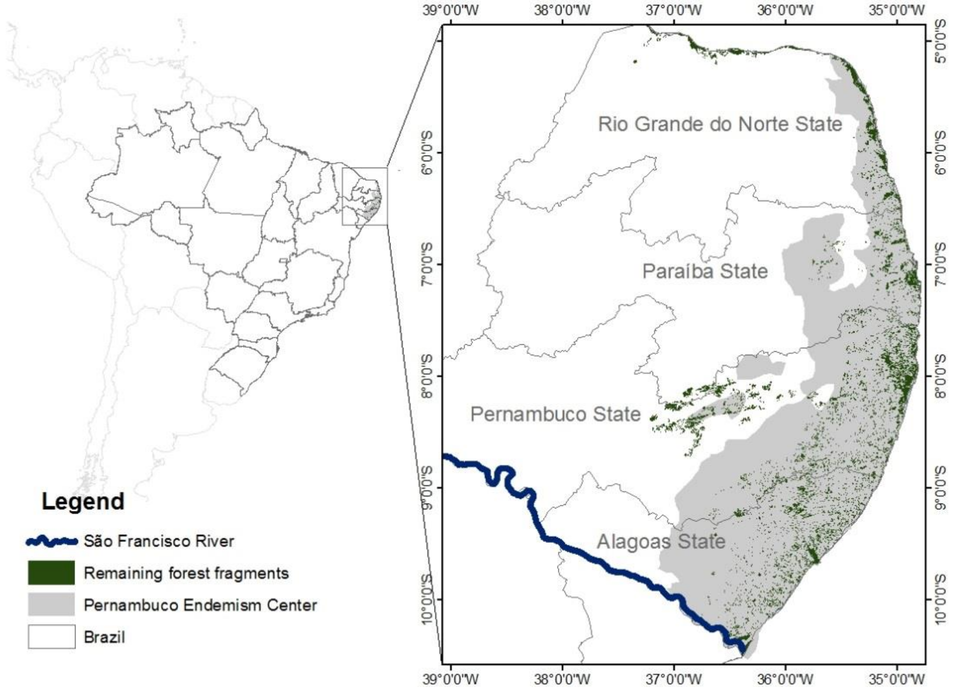

Figure 1. Map of the location of the Pernambuco Endemism Center, with the original coverage of Atlantic Forest (gray), and the actual remnants (green).

Data collection

The data presented here is the result of verification of 3,118 snake specimens deposited in five scientific collections (Coleção Herpetológica da Universidade Federal da Paraíba - UFPB; Coleção do Laboratório de Anfíbios e Répteis da Universidade Federal do Rio Grande do Norte - CLAR; Coleção Herpetológica do Museu de História Natural da Universidade Federal de Alagoas – MUFAL; Coleção Herpetológica da Universidade Federal Rural de Pernambuco – CHUFRPE; Coleção Herpetológica da Universidade Federal de Pernambuco - CHUFPE) and literature data.

The information on the distribution and occurrence of species in each environment were obtained through the records of the scientific collections and literature data, and was subsequently georeferenced. We include records of occurrence of species in the literature only when we were able to confirm the record by direct observation, photo or through museum records or documented vouchers. Information on diet, habitat use, and litter size of the species was obtained from personal data, records of scientific collections and literature data. We categorized the snake size considering the mean body size of each species based on published data as small (< 500mm), moderate (501–1000mm) and large (> 1001mm).

In this work, we have differentiated the habitats of the species into five vegetation physiognomies found in this region: Forests (when the species were found in areas with a typical forest physiognomy, with a large vegetation cover, reaching 35 meters high in the canopy, presenting epiphytes, lianas and bromeliads); Coastal Restingas; Mangroves; Tabuleiros; Brejos Nordestinos (remnants of humid forests scattered in the Caatinga) (Figure 2); and urban areas. In addition, we compared the snake fauna found in the PEC with those of five other natural ecoregions in Brazil (Amazon, Caatinga, Cerrado, Pampas, and Pantanal). These regions are divided on the basis of geomorphology, climate, and vegetation (IBGE 2004).

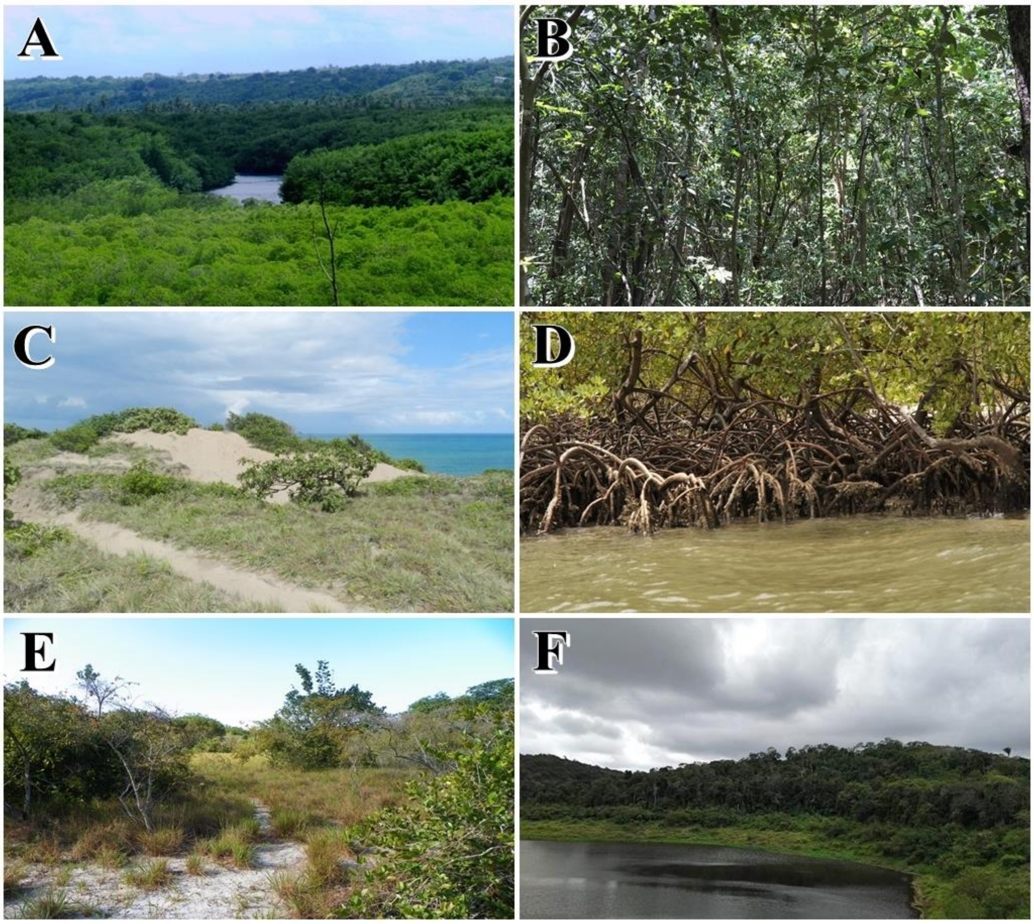

Figure 2. Vegetation physiognomies found in the Pernambuco Endemism Center. **A**. forests, **B**. forest interior, **C**. Coastal Restingas, **D**. Mangroves, **E**. Tabuleiros and **F**. brejos nordestinos. Photograph credits: Ivan L. Sampaio, in the Barra de Gramame (**A**), Frederico França, in the APA da Barra do Rio Mamanguape (**B**, **C**), Marcelo Melo, in the APA da Barra do Rio Mamanguape (**D**), Frederico França, in the Reserva Biológica Guaribas (**E**) and Adonias Teixeira, in the Parque Estadual Mata do Pau-Ferro (**F**).

Taxonomic considerations

The species *Caaeteboia* sp. found in the PEC, differs from *Caaeteboia amarali* (at present the only representative of the genus) mainly because it presents 15 rows of dorsal scales without reduction, while *C. amarali* presents 17 rows of dorsal scales without reduction. In addition, there is a strong variation between the number of ventral and subcaudal scales between the two species (Pereira Filho et al. 2017).

We decided to use the name *Micrurus ibiboboca* according to Silva Jr (2016). Although Silva Jr (2016) affirms that *M. ibiboboca* may be a species complex throughout the distribution of the species, the author still maintains the proper name. Thus, the species designated here as *M. ibiboboca* is the same mentioned in previous works as *Micrurus aff. ibiboboca* (e.g. França et al. 2012, Rodrigues et al. 2015, França and França 2019).

Results

We registered a total of 78 species of snakes of eight families, distributed in the PEC (Table 1, Figures 3, 4, 5, 6, 7). The most species rich family was Dipsadidae (47 species, 60% of total), followed by Colubridae (12 species, 15.4%), Viperidae (6 species, 7.7%), Boidae and Typhlopidae, both with four species (5.1%), Elapidae (3 species, 3.8 %) and Anomalepididae and Leptotyphlopidae, both with a single species (1.3%).

Many species of snakes that are found in PEC are also found in other Brazilian biomes. The Caatinga (58 species, 74.3% found in PEC) is the Brazilian biome that shares most species with the PEC, followed by Cerrado (44 species, 56.4%), Amazon Forest (35 species, 44.9%), Pantanal (35 species, 44.9%) and Pampas (13 species, 16.6%). On the other hand, some species (*Atractus caete*, *Atractus maculatus*, *Bothrops muriciensis*, *Caaeteboia* sp., *Dendrophidion atlantica*, *Echinanthera cephalomaculata* and *Micrurus potyguara*) are found only in the PEC and are considered endemic of this region.

Most of the snake species in the PEC have been registered in Forest areas (74 species, 94.8%), followed by Brejos Nordestinos (36 species, 46.1%), Tabuleiros (34 species, 43.5%), Restingas (11 species, 14.1%) and Mangroves (4 species, 5.1%). Six species were found in four different habitats and 31 species were found only in one habitat type (Table 1). Of these, 26 species were collected only in forested areas, three species only in the Brejos Nordestinos and one species was found only in restingas (Table 1).

The majority of snake species found in the PEC use the soil as substrate, of which 47 species (60.2%) are terrestrial and 17 (21.7%) are cryptozoic and/or fossorial. In addition, 23 species are arboreal or semi-arboreal (29.5%) and 16 (20.5%) are aquatic or semi-aquatic. The diet of PEC snakes consists mainly of vertebrates (61 species, 78.2%), of which 23 species are considered generalists, feeding on three or more types of prey, 21 species feed on two types of prey, 23 species are specialists in amphibians, two species are specialists in snakes and two species are specialists in mammals. Only 14 species feed on invertebrates, of which six species feed on arthropods, three species feed on annelids and five species feed on mollusks (Table 1). As for the period of activity, 39 (50 %) species are nocturnal, 30 (38.4%) species are diurnal and nine (11.5%) species are diurnal and nocturnal (Table 1).

Table 1. Summary of the Information of Natural History of the Snakes in the Pernambuco Endemism Center. Abbreviations are: Habitats (BN = Brejos Nordestinos, F = forest, Tb = Tabuleiro, Rt = Restinga, Mg = Mangrove); Diet (abn = amphisbaenian, amp = amphibian, ann = annelids, art = arthropods, bi = birds, cro = crocodylians, fi = fish, mo = mollusks, li = lizard, mam = mammals, sn=snake; Activity period (D=Diurnal, N=Nocturnal); Habits (AB = arboreal, SAB = arboreal, AQ = aquatic, SAQ = semi-aquatic, CR = cryptozoic, FS=Fossorial, TE = terrestrial, SAB= semi-arboreal). * Endemic species of the Pernambuco Endemism Center.

Family/*Species*	**Habitats**	**Diet**	**Habits**	**Diel Activity**
Anomalepididae				
Liotyphlops trefauti	F	art	FS	N
Boidae				
Boa constrictor	BN, F, Tb, Rt	mam, li, bi	SAB, TE	D, N
Corallus hortulanus	F	mam, bi, li, amp	AB	N
Epicrates assisi	BN, F, Tb	mam, li, bi	TE	N
Epicrates cenchria	F	mam, bi, li, amp	TE, SAB	N
Colubridae				
Chironius carinatus	F	amp, bi, li, mam	TE, AB	D
Chironius exoletus	BN, F, Tb	amp, li	AR, TE	D
Chironius flavolineatus	BN, F, Tb	amp	SAB	D
Dendrophidion atlantica *	F	-	TE	D

Drymarchon corais	F, Tb	amp, abn li, sn, bi, mam	TE	D
Drymoluber dichrous	BN, F, Tb	li, amp	TE	D
Leptophis ahaetulla	BN, F	amp, li	AB,TE	D
Oxybelis aeneus	BN, F, Tb	li, amp, fi	AB	D
Palusophis bifossatus	F, BN	amp, mam, li	TE	D
Spilotes pullatus	BN, F, Tb	mam, bi	SAB	D
Spilotes sulphureus	F	mam, bi	SAB	D
Tantilla melanocephala	BN, F, Tb, Rt	art	FS	D, N
Dipsadidae				
Apostolepis cearensis	F, Tb	sn, abn	FS	D
Apostolepis longicaudata	F	sn	FS	D
Atractus caete *	F	ann	FS	N
Atractus maculatus	F	ann	FS	N
Atractus potschi	F	ann	FS	N
Boiruna sertaneja	Tb, F	sn, li, mam	TE	N
Caaeteboia sp. *	F	-	TE	D
Dipsas mikanii	BN, F, Tb	mo	TE	N
Dipsas neuwiedi	F, BN	mo	TE	N
Dipsas sazimai	F	mo	AB, TE	N
Dipsas variegata	F	mo	AB, TE	N
Echinanthera cephalomaculata *	F	amp	TE	D
Echinanthera cephalostriata	F	amp	TE	D
Erythrolamprus aesculapii	F	sn, li	TE	D
Erythrolamprus almadensis	F	amp	SAQ	D
Erythrolamprus miliaris	F, BN	amp, fi	SAQ	D, N
Erythrolamprus poecilogyrus	BN, F, Tb, Mg	amp, li	TE	D, N
Erythrolamprus reginae	F	amp, li, fi	SAQ	D

Erythrolamprus taeniogaster	F, Tb, Rt	amp, fi	SAQ	D
Erythrolamprus viridis	BN, F	amp, li	TE	D
Helicops angulatus	F, Mg, Rt	fi, amp	AQ	N
Helicops leopardinus	Rt, F	fi, amp	AQ	N
Hydrodynastes gigas	F, Rt	amp, fi, sn, mam	AQ, TE	D
Imantodes cenchoa	F, Tb	li, amp	AB	N
Leptodeira annulata	F, Rt, BN	amp, li	AB, TE	N
Lygophis dilepis	BN, F	amp	TE	D
Oxyrhopus guibei	BN, F, Tb	mam, li	TE	D, N
Oxyrhopus petolarius	BN, F, Tb	li, mam, bi, amp	TE	N
Oxyrhopus trigeminus	BN, F, Tb, Rt,	li, mam, bi	TE	D, N
Philodryas nattereri	BN, F, Tb	li, mam, amp, sn, bi	TE, SAB	D
Philodryas olfersii	BN, F, Tb, Mg	amp, li, bi, mam	TE, SAB	D
Philodryas patagoniensis	F, Tb, Rt	amp, li, mam, bi, sn	TE	D
Phimophis guerini	F, Tb	li, mam	TE	N
Pseudoboa nigra	BN, F, Tb	li, mam, sn	TE	N
Psomophis joberti	F	amp, li	TE	D
Sibon nebulatus	F, Tb	mo	AB	N
Siphlophis compressus	F, Tb	li, sn	AB, TE	N
Taeniophallus affinis	BN, F, Tb	li, amp, abn, mam	CR	N
Taeniophallus occipitalis	BN, F, Tb	li, amp, abn	CR	N
Thamnodynastes almae	BN	amp, li	AB, TE	N
Thamnodynastes hypoconia	BN	amp, li	TE, AB	N
Thamnodynastes pallidus	F, Tb	amp	TE, AB	N
Thamnodynastes phoenix	BN	amp	TE, AB	N
Xenodon merremii	BN, F, Tb	amp	TE	D

Xenodon rabdocephalus	F	amp	TE	D
Xenopholis scalaris	F	amp	TE	N
Xenopholis undulatus	BN, F	amp	TE	N
Elapidae				
Micrurus corallinus	F	abn, li, sn, amp	CR	D
Micrurus ibiboboca	BN, F, Tb	abn, sn, li	CR	D, N
Micrurus potyguara *	F, Tb	sn	CR	D, N
Leptotyphlopidae				
Epictia borapeliotes	F, BN, Rt	art	FS	D, N
Typhlopidae				
Amerotyphlops amoipira	Rt	art	FS	N
Amerotyphlops arenensis	BN, F	art	FS	N
Amerotyphlops brongersmianus	F, Tb	art	FS	N
Amerotyphlops paucisquamus	F, Tb	art	FS	N
Viperidae				
Bothrops bilineatus	F	mam, amp, bi, sn, li	AB	N
Bothrops erythromelas	F	li, mam	TE	N
Bothrops leucurus	F, BN, Tb, Mg	amp, li, sn, bi, mam	TE	N
Bothrops muriciensis *	F	amp, mam	TE	N
Crotalus durissus	BN, F, Rt	mam	TE	N
Lachesis muta	F	mam	TE	N

We present below a commented list of species of snakes that occur in PEC, with notes on natural history and distribution. The “N” corresponds to the number of individuals analyzed in the scientific collections. The species *L. trefauti*, *A. caete*, *A. potschi*, *E. cephalomaculata*, *E. cephalostriata*, *T. almae*, *T. hypoconia*, and *T. phoenix* were recorded only by literature data.

Commented List

Family Anomalepididae Taylor, 1939

Liotyphlops trefauti Freire, Caramaschi, Suzart & Argolo, 2007 - A small-sized fossorial species (total length = 366-389 mm; N = 3), with nocturnal activity (Freire et al. 2007). It has a restricted distribution, occurring in the Atlantic Forest and Caatinga (Abegg et al. 2017b). In the PEC it occurs in the states of Alagoas and Pernambuco (Figure 8A), being found in Forest areas (Freire et al. 2007, Abegg et al. 2017b). *Liotyphlops trefauti*, as observed in other congeneric species, feeds eggs and larvae of on arthropods (Marques et al. 2019).

Family Boidae Gray, 1825

Boa constrictor Linnaeus, 1758 - A large semiarboreal species (average SVL = 1023 mm; N = 42), with nocturnal activity (Marques et al. 2001). It has a wide distribution, occurring in the Atlantic Forest, Amazon Forest, Caatinga, Cerrado and Pantanal (Cunha and Nascimento 1993, Marques et al. 2005, 2015, 2019, Guedes et al. 2014). In the PEC it occurs in all states (Figure 8B), being found in Forest, Brejos Nordestinos, Tabuleiros and Restinga Areas (Pereira Filho and Montingelli 2011, Rodrigues et al. 2015, Pereira Filho et al. 2017, Sampaio et al. 2018). This species can also occur in urban areas (França and França 2019). *Boa constrictor* feeds on mammals, birds and lizards (Pizzatto et al. 2010). Its litter can range from 18 to 60 hatchlings (Vitt and Vangilder 1983, Pizzatto and Marques 2007, Fraga et al. 2013).

Corallus hortulanus (Linnaeus, 1758) - A moderate-sized arboreal snake (SVL = 745 mm; N = 11), with nocturnal activity (Marques et al. 2019). It has a wide distribution, occurring in the Atlantic Forest, Amazon Forest, Caatinga, Cerrado and Pantanal (Marques et al. 2005, 2015, 2019, Fraga et al. 2013, Guedes et al. 2014). In the PEC it occurs in all states (Figure 8B), being found in Forest. *Corallus hortulanus* feeds on mammals, birds, lizards and amphibians (Pizzatto et al. 2010). Its litter can range from 3 to 24 hatchlings (Pizzatto and Marques 2007, Fraga et al. 2013).

Epicrates assisi Machado, 1945 – A moderate-sized terrestrial species (average SVL = 691 mm; N = 135), with nocturnal activity (Marques et al. 2019). This species occurs in the Cerrado, Caatinga and Atlantic Forest (Guedes et al. 2014, Marques et al. 2015, 2019). In the PEC it occurs in all states (Figure 8C), being found in Forest, Brejos

Nordestinos, Tabuleiros, Restingas and urban areas (França et al. 2012, Rodrigues et al. 2015, Pereira Filho et al. 2017, Sampaio et al. 2018). *Epicrates assisi* feeds on mammals, birds, and lizards. Its litter can range from 7 to 14 hatchlings (Pizzatto and Marques 2007).

Epicrates cenchria (Linnaeus, 1758) – A large semi-arboreal or terrestrial species (average SVL = 1105 mm; N = 6), with nocturnal activity (Marques et al. 2019). It has a wide distribution, occurring in the Atlantic Forest, Amazon Forest, Cerrado and Pantanal (Marques et al. 2005, 2015, 2019, Passos and Fernandes 2008). In the PEC it occurs in the states of Alagoas and Pernambuco (Figure 8C), being found in Forest areas, but also in urban areas. *Epicrates cenchria* feeds on mammals, birds, lizards and amphibians (Martins and Oliveira 1998, Pizzatto et al. 2010). Its litter can range from 8 to 25 hatchlings (Pizzatto and Marques 2007).

Family Colubridae Oppel, 1811

Chironius carinatus (Linnaeus, 1758) – A large terrestrial and arboreal species (average SVL = 1001 mm; *N* = 15), with diurnal activity (Marques et al. 2019). It has a disjunct distribution, occurring in the Amazon Forest and Atlantic Forest (Araújo et al. 2019). In the PEC it occurs in the states of Alagoas, Pernambuco and Paraíba (Figure 8D), being found in Forest and urban areas when these are close to forests (Araújo et al. 2019). *Chironius carinatus* feeds on amphibians, birds, lizards and mammals (Dixon et al. 1993, Silva et al. 2010, Rodrigues et al. 2016). Its litter can have 5 to 12 eggs (Dixon et al. 1993, Goldberg 2007).

Chironius exoletus (Linnaeus, 1758) – A moderate-sized arboreal and terrestrial species (average SVL = 614 mm; *N* = 16), with diurnal activity (Marques et al. 2019). It has a wide distribution, occurring in the Atlantic Forest, Caatinga, Cerrado, Pantanal and Amazon Forest (Cunha and Nascimento 1993, Marques et al. 2005, 2015, 2019, Guedes et al. 2014). In the PEC it occurs in the states of Alagoas, Pernambuco and Paraíba (Figure 8D), being found in Forest, Brejos Nordestinos and Tabuleiro (Pereira Filho and Montingelli 2011, Rodrigues et al. 2015). *Chironius exoletus* feeds mainly on amphibians, but occasionally on lizards (Marques and Sazima 2004, Rodrigues et al. 2016). Its litter can range from 4 to 12 eggs (Dixon et al. 1993, Goldberg 2007).

Chironius flavolineatus (Linnaeus, 1758) – A moderate-sized semi-arboreal species (average SVL = 592 mm; *N* = 60), with diurnal activity (Marques et al. 2019). It presents a wide distribution, occurring in the Atlantic Forest, Cerrado, Caatinga, Pantanal and Amazon Forest (Cunha and Nascimento 1993, Dixon et al. 1993, Marques et al. 2005, 2015, Guedes et al. 2014). In the PEC it occurs in all states (Figure 8E), being found in Forest, Brejos Nordestinos, Tabuleiros, and urban areas (França et al. 2012, Rodrigues et al. 2015, Sampaio et al. 2018). *Chironius flavolineatus* feeds on amphibians (Pinto et al. 2008, Rodrigues et al. 2016). Its litter can range from 3 to 8 eggs (Dixon et al. 1993, Hamdan and Fernandes 2015).

Dendrophidion atlantica Freire, Caramaschi & Gonçalves, 2010 – A small-sized terrestrial species (average SVL = 366 mm; *N* = 24), with diurnal activity (Marques et al. 2019). *Dendrophidion atlantica* is endemic to the PEC and occurs in the states of Alagoas, Pernambuco and Paraíba (Figure 8E), being found in Forest (Freire et al. 2010, Pereira Filho et al. 2017, Barbosa et al. 2019). *Dendrophidion atlantica* feeds on amphibians (Marques et al. 2019). Its litter can have 3 eggs (Lima et al. 2019).

Drymarchon corais (Boie, 1827) – A large terrestrial species (average SVL = 1288 mm; *N* = 7), with diurnal activity (Marques et al. 2019). It presents a wide distribution, being registered in the Amazon Forest, Cerrado, Caatinga and Pantanal (Cunha and Nascimento 1993, Strussmann and Sazima 1993, Guedes et al. 2014, Marques et al. 2015, 2019). In the PEC it occurs in all states (Figure 8F), being found in Forest, Tabuleiros and urban areas (Rodrigues et al. 2015, Mesquita et al. 2018). *Drymarchon corais* feeds on amphibians, amphisbaenians, lizards, snakes, birds and mammals (Prudente et al. 2014). Its litter can range from 3 to 15 eggs (Prudente et al. 2014).

Drymoluber dichrous (Peters, 1863) – A small-sized terrestrial species (average SVL = 348 mm; *N* = 15), with diurnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Amazon Forest, and Caatinga (Cunha and Nascimento 1993, Guedes et al. 2014, Marques et al. 2019). In the PEC it occurs in the states of Alagoas and Paraíba (Figure 8F), being found in Forest, Brejos Nordestinos, Tabuleiros and urban areas (Rodrigues et al. 2015, Pereira Filho et al. 2017, Mesquita et al. 2018, França and França 2019). *Drymoluber dichrous* feeds on lizards and amphibians (Martins and Oliveira 1998, Borges-Nojosa and Lima 2001). Its litter can range from 2 to 6 eggs (Martins and Oliveira 1998, Fraga et al. 2013).

Leptophis ahaetulla (Linnaeus, 1758) – An arboreal and terrestrial, moderate-sized species (average SVL = 582 mm; *N* = 42), with diurnal activity (Marques et al. 2019). This species occurs in Atlantic Forest, Amazon Forest, Caatinga, Cerrado, Pantanal, and Pampas (Strussmann and Sazima 1993, Bérnils et al. 2007, Guedes et al. 2014, Marques et al. 2015, 2019). In the PEC it can be found in all states (Figure 8G) in Forest, Brejos Nordestinos and urban areas (Pereira Filho and Montingelli 2011, França and França 2019). *Leptophis ahaetulla* feeds on amphibians and lizards (Albuquerque et al. 2007). Its litter can range from 3 to 12 eggs (Vitt and Vangilder 1983, Mesquita et al. 2009).

Oxybelis aeneus (Wagler, 1824) – An arboreal, moderate-sized species (average SVL = 780 mm; *N* =46), with diurnal activity (Marques et al. 2019). It presents a wide distribution, being found in the Atlantic Forest, Amazon Forest, Caatinga, Cerrado, and Pantanal (Cunha and Nascimento 1993, Marques et al. 2005, 2015, 2019, Guedes et al. 2014). In the PEC it occurs in all states (Figure 8H), being found in Forest, Brejos Nordestinos, Tabuleiros, and urban areas (Pereira Filho and Montingelli 2011, Rodrigues et al. 2015, França and França 2019). *Oxybelis aeneus* feeds on lizards, amphibians, and occasionally fishes (Henderson 1982, Hetherington 2006, Grant and Lewis 2010, Mesquita et al. 2013, Franzini et al. 2018). Its litter can range from 4 to 9 eggs (Vitt and Vangilder 1983, Mesquita et al. 2009, Fraga et al. 2013).

Palusophis bifossatus (Raddi, 1820) – A moderate-sized terrestrial species (average SVL = 801 mm; *N* = 5), with diurnal activity (Marques et al. 2019). It presents a wide distribution, occurring in the Atlantic Forest, Amazon Forest, Caatinga, Cerrado, Pampas, and Pantanal (Cunha and Nascimento 1993, Strussmann and Sazima 1993, Lema 2003, Bérnils et al. 2007, Guedes et al. 2014, Marques et al. 2019). In the PEC it occurs in all states (Figure 8G), being found in Forest and Brejos Nordestinos (Pereira Filho and Montingelli 2011, Pereira Filho et al. 2017). *Palusophis bifossatus* feeds on amphibians, mammals, and lizards (Leite et al. 2007). Its litter can range from 4 to 24 eggs (Costa et al. 2010).

Spilotes pullatus (Linnaeus, 1758) – A large, semi-arboreal species (average SVL = 1442 mm; *N* = 21), with diurnal activity (Marques et al. 2019). It presents a wide distribution, being found in the Atlantic Forest, Amazon Forest, Caatinga, Cerrado, and Pantanal (Cunha and Nascimento 1993, Marques et al. 2005, 2015, 2019, Guedes et al. 2014). In the PEC, it occurs in the states of Alagoas, Pernambuco and Paraíba (Figure

8I), being found in Forest, Brejos Nordestinos, Tabuleiros, and urban areas (Pereira Filho et al. 2017, Mesquita et al. 2018, França and França 2019). *Spilotes pullatus* feeds on mammals and birds (Silva et al. 2010, Marques et al. 2014). Its litter can range from 2 to 5 eggs (Hauzman et al. 2005, Fraga et al. 2013).

Spilotes sulphureus (Wagler, 1824) – A moderate-sized semi-arboreal species (average SVL = 911 mm; *N* =20), with diurnal activity (Marques et al. 2019). It presents a wide distribution, being found in the Atlantic Forest, Amazon Forest, Caatinga and Cerrado (Cunha and Nascimento 1993, Guedes et al. 2014, Marques et al. 2015, 2019). In the PEC, it occurs in the states of Alagoas and Paraíba (Figure 8I), being found in Forest and urban areas (Morais et al. 2018). *Spilotes sulphureus* feeds on mammals and birds (Beebe 1946, Cunha and Nascimento 1993, Rufino and Bernardi 1999). Its litter can range from 7 to 15 eggs (Good 1989, Fraga et al. 2013, Morais et al. 2018).

Tantilla melanocephala (Linnaeus, 1758) – A small-sized fossorial species (average SVL = 233 mm; *N* = 172), with diurnal and nocturnal activity (Marques et al. 2019). It presents a wide distribution, occurring in the Atlantic Forest, Amazon Forest, Caatinga, Cerrado, Pampas, and Pantanal (Cunha and Nascimento 1993, Marques et al. 2005, 2015, 2019, Bérnils et al. 2007, Guedes et al. 2014). In the PEC it occurs in all states (Figure 8H), being found in Forest, Brejos Nordestinos, Tabuleiros, and restingas (Pereira Filho and Montingelli 2011, Mesquita et al. 2018, Sampaio et al. 2018). *Tantilla melanocephala* feeds on arthropods. Its litter can range from 1 to 3 eggs (Mesquita et al. 2009, Fraga et al. 2013).

Dipsadidae Bonaparte, 1838

Apostolepis cearensis Gomes, 1915 – A small-sized fossorial species (average SVL = 329 mm; *N* = 44), with diurnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Caatinga and Cerrado (Guedes et al. 2014, Marques et al. 2015, Mesquita et al. 2018). In the PEC it occurs in the states of Rio Grande do Norte, Paraíba and Pernambuco (Figure 9A), being found in Forest, Tabuleiros, and urban areas (Mesquita et al. 2018, França and França 2019). *Apostolepis cearensis* feeds small elongated reptiles (Mesquita et al. 2009, Amorim et al. 2015, Marques et al. 2019).

Apostolepis longicaudata Gomes, 1921 – A small-sized fossorial species (average SVL = 235 mm; *N* = 8), with diurnal activity (Marques et al. 2019). This species occurs in the Cerrado, Caatinga and Floresta Atlântica (Curcio et al. 2011, França et al. 2012). In the PEC it occurs only in a conservation unit (Reserva Biológica Guaribas) located in the state of Paraíba (Figure 9. A), being found in Forest. *Apostolepis longicaudata* feeds on small elongated reptiles (Marques et al. 2019). We found two eggs in a female.

Atractus caete Passos, Fernandes, Bérnils & Moura-Leite, 2010 – A small-sized fossorial and cryptozoic species (average SVL = 376 mm, *N* = 1), with nocturnal activity (Passos et al. 2010, Marques et al. 2019). This species is endemic to the PEC and occurs only in the state of Alagoas (Figure 9B), being found in Forest areas. *Atractus caete* feeds mostly on earthworms (Passos et al. 2010).

Atractus maculatus (Günther, 1858) – A small-sized fossorial and cryptozoic species (average SVL = 326 mm; *N* = 5), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest and Caatinga (Passos et al. 2010, Abegg et al. 2017a). In the PEC it occurs in the states of Alagoas and Pernambuco (Figure 9B), being found in Forest and urban areas, when close to forests. *Atractus maculatus* feeds mostly on earthworms (Passos et al. 2010).

Atractus potschi Fernandes, 1995 – A small-sized fossorial and cryptozoic species (average SVL = 312 mm, *N* = 1), with nocturnal activity (Passos et al. 2010, Marques et al. 2019). This species occurs in the Atlantic Forest and Caatinga (Guedes et al. 2014). In the PEC it occurs in the state of Alagoas (Figure 9B), being found in Forest (Passos et al. 2010). *Atractus potschi* feeds mostly on earthworms (Passos et al. 2010).

Boiruna sertaneja Zaher, 1996 – A large terrestrial species (average SVL = 1358 mm; *N* = 2), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest and Caatinga (Guedes et al. 2014, Pereira Filho et al. 2017). In the PEC it can be found in the states of Pernambuco and Alagoas (Figure 9C), in Tabuleiros and Forest (Rodrigues et al. 2015, Pereira Filho et al. 2017). *Boiruna sertaneja* eats snakes, lizards and mammals (Vitt and Vangilder 1983, Gaiarsa et al. 2013). Its litter can range from 4 to 14 eggs (Vitt and Vangilder 1983, Gaiarsa et al. 2013).

Caaeteboia sp. – A small to moderate-sized terrestrial species (average SVL = 411 mm; *N* = 2), with diurnal activity (personal observation). This species is endemic to the PEC and occurs only in the states of Pernambuco and Paraíba (Figure 9C), being found in Forest.

Dipsas mikanii Schlegel, 1837 – A small-sized terrestrial species (average SVL = 302 mm; *N* = 72), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Cerrado, Caatinga and Pantanal (Marques et al. 2005, 2015, 2019, Guedes et al. 2014). In the PEC it occurs in all states (Figure 9D), being found in Forest, Brejos Nordestinos, Tabuleiros and urban areas (França et al. 2012, Pereira Filho et al. 2017, Sampaio et al. 2018). *Dipsas mikanii* feeds on mollusks (Laporta-Ferreira et al. 1986). Its litter can range from 3 to 10 eggs (Pizzatto et al. 2008).

Dipsas neuwiedi (Ihering, 1911) – A small-sized terrestrial species (average SVL = 369 mm; *N* = 17), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest and Caatinga (Guedes et al. 2014, Marques et al. 2019). In the PEC it occurs in the states of Alagoas, Pernambuco and Paraíba (Figure 9D), being found in Forest, Brejos Nordestinos and urban areas (Pereira Filho et al. 2017). *Dipsas neuwiedi* feeds on mollusks (Laporta-Ferreira et al. 1986). Its litter can range from 4 to 12 eggs (Pizzatto et al. 2008).

Dipsas sazimai Fernandes, Marques & Argôlo, 2010 – A small-sized arboreal and terrestrial species (average SVL = 299 mm; *N* = 1), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest and Caatinga (Fernandes et al. 2010, Guedes et al. 2014). In the PEC it occurs in the states of Alagoas and Pernambuco (Figure 9E), being found in Forest. *Dipsas sazimai* feeds on mollusks (Fernandes et al. 2010).

Dipsas variegata (Duméril, Bibron & Duméril, 1854) – A small to moderate size arboreal and terrestrial species (average SVL = 464 mm; *N* = 4), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest and Amazon Forest (Cunha and Nascimento 1993, Marques et al. 2019). In the PEC it occurs only in the state of Alagoas (Figure 9E), being found in Forest. *Dipsas variegata* feeds on mollusks (Marques et al. 2019).

Echinanthera cephalomaculata Di Bernardo, 1994 – A small to moderate size terrestrial species (average SVL = 297 mm, *N* = 2), with diurnal activity (Di-Bernardo 1994, Marques et al. 2019). This species is endemic to the PEC and occurs only in the states of Alagoas and Pernambuco (Figure 9F), being found in Forest (Roberto et al. 2015, Freitas et al. 2019b). *Echinanthera cephalomaculata* feeds on amphibians (Marques et al. 2019).

Echinanthera cephalostriata Di Bernardo, 1996 – A moderate-sized terrestrial species, with diurnal activity (Di-Bernardo 1996, Marques et al. 2019). This species only occurs in the Atlantic Forest (Marques et al. 2019). In the PEC it occurs in the state of Alagoas (Figure 9F), being found only in the Reserva Biológica de Pedra Talhada (Roberto et al. 2015). In the report of this species for the PEC Roberto et al. (2015) provide a photo and a voucher (URCA-H 4103). *Echinanthera cephalostriata* feeds on amphibians (Marques et al. 2009).

Erythrolamprus aesculapii (Linnaeus, 1758) – A moderate-sized terrestrial species (average SVL = 562 mm; *N* = 7), with diurnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Amazon forest, Caatinga, Cerrado and Pantanal (Cunha and Nascimento 1993, Marques et al. 2005, 2015, 2017a, 2019). In the PEC it occurs in the states of Alagoas and Pernambuco (Figure 9G), being found in Forest and urban areas. *Erythrolamprus aesculapii* feeds on snakes and lizards (Marques and Puorto 1992). Its litter can range from 1 to 8 eggs (Marques 1996a).

Erythrolamprus almadensis (Wagler, 1824) – A small-sized semi-aquatic species (average SVL = 298 mm; *N* = 4), with diurnal activity (Marques et al. 2019). This species has a wide distribution, occurring in the Atlantic Forest, Amazon forest, Caatinga, Cerrado, Pantanal and Pampas (Dixon 1989, França et al. 2006, Bérnils et al. 2007, Guedes et al. 2014). In the PEC it occurs in the states of Paraíba and Rio Grande do Norte (Figure 9. G), being found in Forest (Pereira Filho et al. 2017, França and França 2019). *Erythrolamprus almadensis* feeds on amphibians (Bernarde and Abe 2010, Rodrigues et al. 2016). Its litter can have five eggs.

Erythrolamprus miliaris (Linnaeus, 1758) – A small-sized semi-aquatic species (average SVL = 382 mm; *N* = 7), with diurnal and nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Amazon forest, Caatinga and Cerrado (Cunha and Nascimento 1993, Nogueira et al. 2010, Marques et al. 2017a, 2019). In the PEC it occurs in the states of Alagoas, Pernambuco and Paraíba (Figure 9G), being found in Forest and Brejos Nordestinos. *Erythrolamprus miliaris* feeds on amphibians and fish (Marques et al. 2019). Its litter can range from 1 to 30 eggs (Pizzatto and Marques 2006).

Erythrolamprus poecilogyrus (Wied-Neuwied, 1825*)* – A small-sized terrestrial species (average SVL = 313 mm; *N* = 35), with diurnal and nocturnal activity (Marques et al.

2019). This species occurs in the Atlantic Forest, Caatinga, Cerrado, Pantanal and Pampas (Marques et al. 2005, 2015, 2019, Bérnils et al. 2007, Guedes et al. 2014). In the PEC it occurs in all states (Figure 9H), being found in Forest, Brejos Nordestinos, Mangroves, Tabuleiros and urban areas (França et al. 2012, Pereira Filho et al. 2017, Mesquita et al. 2018). *Erythrolamprus poecilogyrus* feeds on amphibians and lizards (Prieto et al. 2012). Its litter can range from 3 to 17 eggs (Vitt and Vangilder 1983, Mesquita et al. 2009). In Figure 4N we show a juvenile that is in the process of changing its coloration to the adult stage. This species has a different color pattern in the region (Pereira Filho et al. 2017) if compared to other populations located more southwards.

Erythrolamprus reginae (Linnaeus, 1758) – A small-sized semi-aquatic species (average SVL = 355 mm; *N* = 4), with diurnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Amazon forest, Caatinga, Cerrado and Pantanal (Cunha and Nascimento 1993, Marques et al. 2005, 2015, 2019, Guedes et al. 2014). In the PEC it occurs in the states of Alagoas and Pernambuco (Figure 9H), being found in Forest. *Erythrolamprus reginae* feeds on amphibians, lizards, and fish (Martins and Oliveira 1998, Albarelli and Santos-Costa 2010, Silva et al. 2010, Rodrigues et al. 2016). Its litter can range from 1 to 4 eggs (Arzamendia 2016, Marques et al. 2016)

Erythrolamprus taeniogaster (Jan, 1863) – A small-sized semi-aquatic species (average SVL = 364 mm; *N* = 45), with diurnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Amazon forest, Caatinga, Cerrado and Pantanal (Cunha and Nascimento 1993, Marques et al. 2005, 2015, 2019, Guedes et al. 2014). In the PEC it occurs in the states of Alagoas, Pernambuco and Paraíba (Figure 9G), being found in Forest, Tabuleiros, Restingas and urban areas (Rodrigues et al. 2015, Pereira Filho et al. 2017, Mesquita et al. 2018, Sampaio et al. 2018). *Erythrolamprus taeniogaster* feeds on amphibians and fish (Cunha and Nascimento 1993, Rodrigues et al. 2016). Its litter can range from 7 to 10 eggs (Cunha and Nascimento 1993).

Erythrolamprus viridis (Günther, 1862) – A small-sized terrestrial species (average SVL = 243 mm; *N* = 21), with diurnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest and Caatinga (Guedes et al. 2014, Marques et al. 2019). In the PEC it occurs in all states (Figure 9H), being found in Forest, Brejos Nordestinos and urban areas (Pereira Filho and Montingelli 2011, Pereira Filho et al. 2017).

Erythrolamprus viridis feeds on amphibians and lizards (Vitt and Vangilder 1983, Mesquita et al. 2009). Its litter can range from 2 to 7 eggs (Vitt and Vangilder 1983, Mesquita et al. 2009).

Helicops angulatus (Linnaeus, 1758) – A small to moderate sized aquatic species (average SVL = 413 mm; *N* = 236), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Amazon Forest, Caatinga, Cerrado and Pantanal (Cunha and Nascimento 1993, Marques et al. 2005, 2015, 2019, Guedes et al. 2014). In the PEC it occurs in all states (Figure 9I), being found in Forest, Mangroves, Restingas and urban areas (França et al. 2012, Pereira Filho et al. 2017, Sampaio et al. 2018). *Helicops angulatus* feeds on fish and amphibians. Its litter can range from 1 to 21 eggs (Braz et al. 2016).

Helicops leopardinus (Schlegel, 1837) – A small-sized aquatic species (average SVL = 324 mm; *N* = 9), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Amazon Forest, Caatinga, Cerrado, Pantanal and Pampas (Strussmann and Sazima 1993, Marques et al. 2005, 2015, 2019, Bérnils et al. 2007, Guedes et al. 2014, Rodrigues et al. 2016). In the PEC it occurs in the states of Alagoas and Pernambuco (Figure 9I), being found in Forest, Restingas and urban areas. *Helicops leopardinus* feeds on fish and amphibians (Ávila et al. 2006). Its litter can range from 3 to 31 eggs (Scartozzoni and Almeida-Santos 2006, Braz et al. 2016).

Hydrodynastes gigas (Duméril, Bibron & Duméril, 1854) – A large aquatic and terrestrial species (average SVL = 1296 mm; *N* =10), with diurnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Amazon Forest, Cerrado, Pantanal and Pampas (Lema 2003, Marques et al. 2005, 2015, 2019, Rodrigues et al. 2016). In the PEC it occurs in the states of Paraíba and Rio Grande do Norte (Figure 10A), being found in Forest and Restingas (Pereira Filho et al. 2017, Sampaio et al. 2018). *Hydrodynastes gigas* feeds on fish, amphibians, mammals and snakes (López and Giraudo 2004). Its litter can range from 14 to 42 eggs (Vogel 1958, Fraga et al. 2013).

Imantodes cenchoa (Linnaeus, 1758) – An arboreal, moderate-sized species (average SVL = 633 mm; *N* = 23), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Amazon Forest, Caatinga, Cerrado and Pantanal (Cunha and Nascimento 1993, Marques et al. 2005, 2015, 2019, Guedes et al. 2014). In the PEC it occurs in all states (Figure 10B), being found in Forest and Tabuleiros (Rodrigues et al. 2015, Mesquita et al. 2018). *Imantodes cenchoa* feeds on amphibians and lizards (Martins and Oliveira 1998, Sousa et al. 2014). Its litter can range from 1 to 7 eggs (Martins and Oliveira 1998, Pizzatto et al. 2008, Fraga et al. 2013, Sousa et al. 2014).

Leptodeira annulata (Linnaeus, 1758) – A moderate-sized arboreal and terrestrial species (average SVL = 576 mm; *N* = 6), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Amazon Forest, Caatinga, Cerrado and Pantanal (Ávila and Morais 2007, Guedes et al. 2014, Marques et al. 2015, 2019). In the PEC it occurs in the states of Alagoas and Pernambuco (Figure 10B), being found in Forest, Brejos Nordestinos, and Restingas (Pereira Filho and Montingelli 2011, Roberto et al. 2015). *Leptodeira annulata* feeds on amphibians and lizards (Moura 1999, Mesquita et al. 2013, Santos-Silva et al. 2014). Its litter can range from 3 to 13 eggs (Petzold 1969, Pizzatto et al. 2008).

Lygophis dilepis Cope, 1862 – A small-sized terrestrial species (average SVL = 356 mm; *N* = 9), with diurnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Caatinga and Cerrado (Guedes et al. 2014, Marques et al. 2015, Mesquita et al. 2018). In the PEC it occurs in the states of Pernambuco, Paraíba and Rio Grande do Norte (Figure 10A), being found in Forest, Brejos Nordestinos, and urban areas (Pereira Filho and Montingelli 2011, França et al. 2012, Mesquita et al. 2018). *Lygophis dilepis* feeds on amphibians (Mesquita et al. 2009). Its litter can range from 4 to 6 eggs (Mesquita et al. 2009).

Oxyrhopus guibei Hoge & Romano, 1977 – A small sized terrestrial species (average SVL = 442 mm; *N* = 10), with diurnal and nocturnal activity (Marques et al. 2017). This species occurs in the Atlantic Forest, Caatinga, Cerrado and Pantanal (Marques et al. 2005, 2015, 2019, Guedes et al. 2014). In the PEC it occurs in all states (Figure 10C), being found in Forest, Brejos Nordestinos, and Tabuleiros (Pereira Filho and Montingelli 2011, Mesquita et al. 2018). *Oxyrhopus guibei* feeds on mammals and lizards (Andrade and Silvano 1996, Barbo et al. 2011). Its litter can range from 3 to 20 eggs (Pizzatto and Marques 2002).

Oxyrhopus petolarius (Linnaeus, 1758) – A small size terrestrial specie (average SVL = 423 mm; *N* = 36), with nocturnal activity (Marques et al. 2017). This species occurs in the Atlantic Forest, Amazon Forest, Caatinga, Cerrado and Pantanal (Marques et al. 2005, 2015, 2019, Guedes et al. 2014). In the PEC it occurs in all states (Figure 10C), being found in Forest, Brejos Nordestinos, Tabuleiros, and urban areas (Pereira Filho et al. 2017, Mesquita et al. 2018, Sampaio et al. 2018, França and França 2019). *Oxyrhopus petolarius* feeds on lizards, mammals, birds and amphibians (Alencar et al. 2013). Its litter can range from 2 to 12 eggs (Lynch 2009, Gaiarsa et al. 2013).

Oxyrhopus trigeminus Duméril, Bibron & Duméril, 1854 – A small-sized terrestrial species (average SVL = 360 mm; *N* = 237), with nocturnal activity (Marques et al. 2017). This species occurs in the Atlantic Forest, Caatinga, Cerrado and Pantanal (Marques et al. 2005, 2015, 2019, Guedes et al. 2014). In the PEC it occurs in all states (Figure 10D), being found in Forest, Brejos Nordestinos, Restingas, Tabuleiros, and urban areas (Pereira Filho and Montingelli 2011, Sampaio et al. 2018, França and França 2019). *Oxyrhopus trigeminus* feeds on lizards, mammals, and birds (Vitt and Vangilder 1983, Mesquita et al. 2009, Alencar et al. 2012). Its litter can range from 6 to 9 eggs (Vitt and Vangilder 1983, Mesquita et al. 2009).

Philodryas nattereri Steindachner, 1870 – A moderate-sized terrestrial or semi-arboreal species (average SVL = 712 mm; *N* = 76), with diurnal activity (Marques et al. 2017). This species occurs in the Atlantic Forest, Caatinga, Cerrado, Pantanal (Marques et al. 2005, 2015, Guedes et al. 2014, Mesquita et al. 2018). In the PEC it occurs in all states (Figure 10E), being found in Forest, Brejos Nordestinos, Tabuleiros, and urban areas (França et al. 2012, Pereira Filho et al. 2017, Sampaio et al. 2018). *Philodryas nattereri* feeds on lizards, mammals, amphibians, snakes, and birds (Mesquita et al. 2011b). Its litter can range from 4 to 13 eggs (Vitt and Vangilder 1983, Mesquita et al. 2009).

Philodryas olfersii (Lichtenstein, 1823) – A moderate-sized terrestrial or semi-arboreal species (average SVL = 562 mm; *N* = 123), with diurnal activity (Marques et al. 2017). This species occurs in the Atlantic Forest, Caatinga, Cerrado, Pantanal and Pampas (Marques et al. 2005, 2015, 2019, Bérnils et al. 2007, Guedes et al. 2014). In the PEC it occurs in all states (Figure 10E), being found in Forest, Brejos Nordestinos, Tabuleiros, Mangroves and urban areas (Pereira Filho and Montingelli 2011, França et al. 2012, Pereira Filho et al. 2017, Sampaio et al. 2018). *Philodryas olfersii* feeds on amphibians, lizards, birds and mammals (Hartmann and Marques 2005). Its litter can range from 1 to 16 eggs (Vitt and Vangilder 1983, Fowler et al. 1998, Mesquita et al. 2009).

Philodryas patagoniensis (Girard, 1858) – A small to moderate sized terrestrial species (average (average SVL = 436 mm; *N* = 68), with diurnal activity (Marques et al. 2019).

This species occurs in the Atlantic Forest, Caatinga, Cerrado, Pantanal and Pampas (Marques et al. 2005, 2015, 2019, Bérnils et al. 2007, Guedes et al. 2014). In the PEC it occurs in the states of Pernambuco, Paraíba, and Rio Grande do Norte (Figure 10E), being found in Forest, Tabuleiros, Restingas, and urban areas (França et al. 2012, Pereira Filho et al. 2017, Sampaio et al. 2018). *Philodryas patagoniensis* feeds on amphibians, lizards, mammals, birds, and snakes (Hartmann and Marques 2005). Its litter can range from 3 to 19 eggs (Fowler et al. 1998).

Phimophis guerini (Duméril, Bibron & Duméril, 1854) – A small to moderate sized terrestrial species (average SVL = 497 mm; *N* = 15), with nocturnal activity (Marques et al. 2017). This species occurs in the Atlantic Forest, Caatinga, Cerrado, Pampas and Pantanal (Lema 2003, Marques et al. 2005, 2015, Guedes et al. 2014, Mesquita et al. 2018). In the PEC it occurs in the states of Alagoas and Paraíba (Figure 10F), being found in Forest and Tabuleiros (Rodrigues et al. 2015, Pereira Filho et al. 2017). *Phimophis guerini* feeds on lizards and mammals (Alencar et al. 2013). Its litter can range from 3 to 7 eggs (Gaiarsa et al. 2013).

Pseudoboa nigra (Duméril, Bibron & Duméril, 1854) – A moderate-sized terrestrial species (average SVL = 543 mm; *N* = 64), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Caatinga, Cerrado and Pantanal (Marques et al. 2005, 2015, 2019, Guedes et al. 2014). In the PEC it occurs in all states (Figure 10F), being found in Forest, Brejos Nordestinos, Tabuleiros, and urban areas (Pereira Filho and Montingelli 2011, França et al. 2012, Pereira Filho et al. 2017, Mesquita et al. 2018). *Pseudoboa nigra* feeds on lizards, mammals, and snakes (Alencar et al. 2012). Its litter can range from 3 to 24 eggs (Orofino et al. 2010, Gaiarsa et al. 2013).

Psomophis joberti (Sauvage, 1884) – A small-sized terrestrial species (average SVL = 285 mm; *N* = 11), with diurnal activity (Marques et al. 2017). This species occurs in the Atlantic Forest, Amazon Forest, Caatinga and Cerrado (Guedes et al. 2014, Marques et al. 2015, Rodrigues et al. 2016, Mesquita et al. 2018). In the PEC it occurs only in the state of Paraíba (Figure 10. G), being found in Forest and urban areas (França et al. 2012, Pereira Filho et al. 2017). *Psomophis joberti* feeds on amphibians and lizards (Strussmann and Sazima 1993, Rodrigues et al. 2016). Its litter can have 7 eggs (Mesquita et al. 2009, 2011a).

Sibon nebulatus (Linnaeus, 1758) – A small-sized arboreal species (average SVL = 377 mm; *N* = 21), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Amazon Forest and can also be found on relict moist forests in Caatinga (Cunha and Nascimento 1993, Guedes et al. 2014, Marques et al. 2019). In the PEC it occurs in all states (Figure 10G), being found in Forest, Tabuleiros, and urban areas (França et al. 2012, Rodrigues et al. 2015). *Sibon nebulatus* feeds on mollusks (Duellman 2005). Its litter can have 5 eggs (Boos 2001).

Siphlophis compressus (Daudin, 1803) – A moderate-sized arboreal and terrestrial species (average SVL = 527 mm; *N* = 13), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest and Amazon Forest (Cunha and Nascimento 1993, Marques et al. 2019). In the PEC it occurs in the states of Alagoas, Pernambuco, and Paraíba (Figure 10G), being found in Forest and Tabuleiros (Roberto et al. 2015, Rodrigues et al. 2015, Pereira Filho et al. 2017). *Siphlophis compressus* feeds mainly on lizards, but may also feed on snakes (Martins and Oliveira 1998, Alencar et al. 2013). Its litter can range from 3 to 12 eggs (Martins and Oliveira 1998, Fraga et al. 2013, Gaiarsa et al. 2013).

Taeniophallus affinis (Günther, 1858) – A small-sized cryptozoic species (average SVL = 172 mm; *N* = 9), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest and Caatinga (Guedes et al. 2014, Marques et al. 2019). In the PEC it occurs in the states of Alagoas, Pernambuco, and Paraíba (Figure 10H), being found in Forest, Brejos Nordestinos, and Tabuleiros (Rodrigues et al. 2015, Pereira Filho et al. 2017). *Taeniophallus affinis* feeds on lizards, amphibians, amphisbaenians, and mammals (Sousa and Cruz 2000, Barbo and Marques 2003, Zacariotti and Gomes 2010, Gomes 2012). Its litter can range from 5 to 7 eggs (Amaral 1978).

Taeniophallus occipitalis (Jan, 1863) – A small-sized cryptozoic species (average SVL = 272 mm; *N* = 63), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Caatinga, Cerrado and Pampas (Bérnils et al. 2007, Guedes et al. 2014, Marques et al. 2015, 2019). In the PEC it occurs in all states (Figure 10H), being found in Forest, Brejos Nordestinos, Tabuleiros, and urban areas (Pereira Filho and Montingelli 2011, Rodrigues et al. 2015, Pereira Filho et al. 2017, França and França 2019). *Taeniophallus occipitalis* feeds on lizards, amphibians, and snakes (Balestrin and Di-Bernardo 2005, Gomes 2012). Its litter can have two eggs.

Thamnodynastes almae Franco & Ferreira, 2003 – A moderate-sized arboreal and terrestrial, with nocturnal activity (Franco and Ferreira 2002, Marques et al. 2019). This species occurs in the Atlantic Forest and Caatinga (Guedes et al. 2014, Marques et al. 2019). In the PEC it occurs only in Brejos Nordestinos in the state of Pernambuco (Figure 10I) (Freitas et al. 2019a). *Thamnodynastes almae* feeds on amphibians and lizards (Marques et al. 2017a).

Thamnodynastes hypoconia (Cope, 1860) – A moderate-sized arboreal and terrestrial, with nocturnal activity (Marques et al. 2017a). This species occurs in the Atlantic Forest, Caatinga, Cerrado and Pampas (Bérnils et al. 2007, Guedes et al. 2014, Marques et al. 2015, 2019). In PEC it occurs only in the Parque Estadual Mata do Pau-Ferro, state of Paraíba, a Brejo Nordestino (Figure 10I) (Pereira Filho et al. 2017). *Thamnodynastes hypoconia* feeds on amphibians and lizards (Bellini et al. 2013). Its litter can range from 4 to 13 hatchlings (Bellini et al. 2013).

Thamnodynastes pallidus (Linnaeus, 1758) – A small-sized arboreal and terrestrial (average SVL = 325 mm; *N* = 92), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Amazon Forest and Caatinga (Bailey et al. 2005, Guedes et al. 2014, Marques et al. 2019). In the PEC it occurs in the states of Alagoas, Pernambuco and Paraíba (Figure 10I), being found in Forest and Tabuleiros (Rodrigues et al. 2015, Pereira Filho et al. 2017). *Thamnodynastes pallidus* feeds on amphibians (Guedes et al. 2014, Protázio et al. 2017). Its litter can range from 3 to 6 hatchlings (Cunha and Nascimento 1981, Araújo et al. 2018).

Thamnodynastes phoenix Franco, Trevine, Montingelli & Zaher, 2017 – A small to moderate size arboreal and terrestrial, with nocturnal activity (Franco et al. 2017, Marques et al. 2017a). This species occurs in the Atlantic Forest, Caatinga and Cerrado (Guedes et al. 2014, Franco et al. 2017, Freitas et al. 2019a). In the PEC it occurs only in Brejos Nordestinos of the state of Pernambuco (Figure 10I) (Freitas et al. 2019a). *Thamnodynastes phoenix* feeds on amphibians (Pergentino and Ribeiro 2017).

Xenodon merremii (Wagler, 1824) – A small to moderate size species (average SVL = 446 mm; *N* = 97), with diurnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Caatinga, Cerrado, Pampas Pantanal (Marques et al. 2005, 2015, 2019, Bérnils et al. 2007, Guedes et al. 2014). In the PEC it occurs in all states (Figure 11A), being found in Forest, Brejos Nordestinos, Tabuleiros, and urban areas (Pereira Filho and Montingelli 2011, França et al. 2012, Rodrigues et al. 2015). *Xenodon merremii* feeds on amphibians (Vitt and Vangilder 1983, Mesquita et al. 2009). Its litter can range from 4 to 30 eggs (Gaiarsa et al. 2013).

Xenodon rabdocephalus (Wied-Neuwied, 1824) – A moderate-sized terrestrial species (average SVL = 630 mm; *N* = 2), with diurnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Amazon Forest and Cerrado (Cunha and Nascimento 1993, Marques et al. 2015, 2019). In the PEC it occurs in the states of Alagoas and Pernambuco (Figure 11A), being found in Forest. *Xenodon rabdocephalus* feeds on amphibians (Martins and Oliveira 1998). Its litter can range from 6 to 8 eggs (Martins and Oliveira 1998).

Xenopholis scalaris (Wucherer, 1861) – A small-sized terrestrial species (average SVL = 167 mm; *N* = 10), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest and Amazon Forest (Marques et al. 2015, 2019, França et al. 2019). In the PEC it occurs in the states of Alagoas and Pernambuco (Figure 11B), being found in Forest. *Xenopholis scalaris* feeds on amphibians (Martins and Oliveira 1998, Bernarde and Abe 2010). Its litter can range from 2 to 3 eggs (Martins and Oliveira 1998).

Xenopholis undulatus (Jensen, 1900) – A small-sized terrestrial species (average SVL = 268 mm; *N* = 2), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Caatinga and Cerrado (Guedes et al. 2014, Marques et al. 2015, 2019). In the PEC it occurs in the states of Alagoas, Pernambuco, and Paraíba (Figure 11B), being found in Forest and Brejos Nordestinos (Pereira Filho et al. 2017). *Xenopholis undulatus* feeds on amphibians (Cunha and Nascimento 1993, Kokobum and Maciel 2010). Its litter can have 3 eggs (Costa et al. 2013).

Elapidae Boie, 1827

Micrurus corallinus (Merrem, 1820) – A small to moderate size cryptozoic species (average SVL = 465 mm; *N* =1), with diurnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest (Marques et al. 2019). In the PEC it occurs only in the state of Rio Grande do Norte (Figure 11C), being found in Forest. *Micrurus corallinus* feeds on amphisbaenians, lizards, snakes, and caecilians (Marques and Sazima 1997). Its litter can range from 2 to 12 eggs (Azevedo 1961, Marques 1996b).

Micrurus ibiboboca (Merrem, 1820) – A moderate-sized cryptozoic species (average SVL = 533 mm; *N* =391), with diurnal and nocturnal activity (Marques et al. 2017). This species occurs in the Atlantic Forest and Caatinga (Marques et al. 2017a, 2019). In the PEC it occurs in all states (Figure 11C), being found in Forest, Brejos Nordestinos, Tabuleiros, and urban areas (Pereira Filho and Montingelli 2011, França et al. 2012, Rodrigues et al. 2015, Pereira Filho et al. 2017). *Micrurus ibiboboca* feeds on amphisbaenians, snakes, and lizards (Vitt and Vangilder 1983, Mesquita et al. 2009). We found 9 to 14 vitellogenic follicles in females.

Micrurus potyguara Pires, Da Silva Jr, Feitosa, Prudente, Preira-Filho & Zaher, 2014 – A moderate-sized cryptozoic species (average SVL = 523 mm; *N* = 14), with diurnal and nocturnal activity (Marques et al. 2019). *Micrurus potyguara* is endemic to the PEC, occurring in the states of Pernambuco, Paraíba, and Rio Grande do Norte (Figure 11C), being found in Forest, Tabuleiros, and urban areas (Pires et al. 2014, Rodrigues et al. 2015, França and França 2019).

Leptotyphlopidae Stejneger, 1891

Epictia borapeliotes (Vanzolini, 1996) – A small-sized fossorial species (average SVL = 111 mm; *N* = 34), with diurnal and nocturnal activity (Guedes et al. 2014). This species occurs in the Atlantic Forest and Caatinga (Guedes et al. 2014, Marques et al. 2019). In the PEC it occurs in the states of Pernambuco, Paraíba, and Rio Grande do Norte (Figure 11D), being found in Forest, Brejos Nordestinos, and in Restingas (Pereira Filho et al. 2017, Sampaio et al. 2018, Freitas et al. 2019a). *Epictia borapeliotes* feeds on arthropods (Marques et al. 2019).

Typhlopidae Merrem, 1890

Amerotyphlops amoipira (Rodrigues & Juncá, 2002) – A small-sized fossorial species (average SVL = 146 mm; *N* = 3), with nocturnal activity (Marques et al. 2017). This species occurs in the Caatinga and Atlantic Forest (Brito and Freire 2012). In the PEC it occurs in the states of Alagoas and Rio Grande do Norte (Figure 11E), being found in Restinga (Brito and Freire 2012). *Amerotyphlops amoipira* feeds on arthropods (Marques et al. 2017a).

Amerotyphlops arenensis Graboski, Pereira Filho, Silva, Costa Prudente & Zaher, 2015 – A small-sized fossorial species (average SVL = 148 mm; *N* = 13). This species occurs in the Atlantic Forest and Caatinga (Graboski et al. 2015, 2019). In the PEC it occurs in the states of Alagoas, Pernambuco and Paraíba (Figure 11E), being found in Forest and Brejos Nordestinos (Roberto et al. 2012, Graboski et al. 2015). We found 7 to 8 vitellogenic follicles in females.

Amerotyphlops brongersmianus (Vanzolini, 1976) – A small-sized fossorial species (average SVL = 212 mm; *N* = 120), with nocturnal activity (Marques et al. 2019). This species occurs in all Brazilian biomes (Graboski et al. 2019). In the PEC it occurs in the states of Alagoas, Pernambuco and Paraíba (Figure 11F), being found in Forest and Tabuleiros (Pereira Filho et al. 2017, Sampaio et al. 2018). This species occurs in the Atlantic Forest (Marques et al. 2019). *Amerotyphlops brongersmianus* feeds on ant larvae (Avila et al. 2006). Its litter can range from 4 to 5 eggs (Avila et al. 2006).

Amerotyphlops paucisquamus (Dixon, 1979) – A small-sized fossorial species (average SVL = 133 mm; *N* =153), with nocturnal activity (Marques et al. 2019). This species is endemic to the PEC, occurring in all states (Figure 11F), being found in Forest and Tabuleiros (Rodrigues et al. 2015, Pereira Filho et al. 2017). We found four eggs in one female and another individual laid three eggs after being collected.

Viperidae Laurenti, 1768

Bothrops bilineatus (Wied-Neuwied, 1821) – A small to moderate sized arboreal species (average SVL = 495 mm; *N* = 5), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest and Amazon Forest (Bernarde et al. 2011, Marques et al. 2019). In PEC occurs only in Alagoas state (Figure 11G), being found in Forest. *Bothrops bilineatus* feeds on mammals, amphibians, birds, snakes, and lizards (Cunha and Nascimento 1993, Martins et al. 2002, Turci et al. 2009). Its litter can range from 4 to 16 hatchlings (Dixon and Soini 1986, Campbell and Lamar 2004, Grego et al. 2012, Almeida et al. 2019).

Bothrops erythromelas Amaral, 1923 – A small to moderate size terrestrial species (average SVL = 445 mm; *N* = 3), with nocturnal activity (Marques et al. 2017). This species occurs in the Caatinga, but can also be found in transitional areas with the Atlantic Forest (Guedes et al. 2014). In the PEC it occurs in the states of Pernambuco and Rio Grande do Norte (Figure 11G), being found in Forest. *Bothrops erythromelas* feeds on arthropods when juveniles, and frogs, lizards, and mammals when adults

(Martins et al. 2002). Its litter can range from 2 to 21 hatchlings (Barros et al. 2014, Reis et al. 2015).

Bothrops leucurus Wagler, 1824 – A moderate-sized terrestrial species (average SVL = 589 mm; *N* =207), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest (Marques et al. 2019). In the PEC it occurs in the states of Alagoas, Pernambuco and Paraíba (Figure 11H), being found in Forest, Brejos Nordestinos, Tabuleiros, mangroves, and urban areas when near forest areas (Pereira Filho and Montingelli 2011, Rodrigues et al. 2015, Pereira Filho et al. 2017, França and França 2019). *Bothrops leucurus* feeds on amphibians, lizards, snakes, birds, and mammals. Its litter can range from 5 to 7 hatchlings (Lira-da-Silva et al. 1994).

Bothrops muriciensis Ferrarezzi & Freire, 2001 – A moderate-sized terrestrial species (average SVL = 512 mm; *N* =6), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest (Marques et al. 2019). This species is endemic to the PEC, occurring only in the Estação Ecológica de Murici (Figure 11H), located in the state of Alagoas, being found in Forest. See Freitas et al. (2012) for additional information on this species. As observed in other congenerics, it probably feeds on anurans and small mammals.

Crotalus durissus Linnaeus, 1758 – A moderate-sized terrestrial species (average SVL = 790 mm; *N* = 13), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest, Caatinga, Cerrado, Pampas, and Pantanal (Marques et al. 2005, 2015, 2019, Bérnils et al. 2007, Guedes et al. 2014). In the PEC it occurs in the states of Alagoas, Pernambuco, and Paraíba (Figure 11I), being found in Forest, Brejos Nordestinos, and Restingas (Lira-da-silva et al. 2009, Pereira Filho and Montingelli 2011). *Crotalus durissus* feeds on mammals (Vitt and Vangilder 1983, Strussmann and Sazima 1993, Rodrigues et al. 2016). Its litter can range from 21 to 31 hatchlings (Vitt and Vangilder 1983).

Lachesis muta (Linnaeus, 1766) – A large size terrestrial species (average SVL = 1217 mm; *N* = 4), with nocturnal activity (Marques et al. 2019). This species occurs in the Atlantic Forest and Amazon Forest (Cunha and Nascimento 1993, Marques et al. 2019). In the PEC it occurs in the states of Alagoas, Pernambuco and Paraíba (Figure 11I), being found in Forest (Pereira Filho et al. 2017). *Lachesis muta* feeds on mammals

(Cunha and Nascimento 1993, Martins and Oliveira 1998). Its litter can range from 1 to 18 eggs (Martins and Oliveira 1998, Souza 2007, Alves et al. 2014).

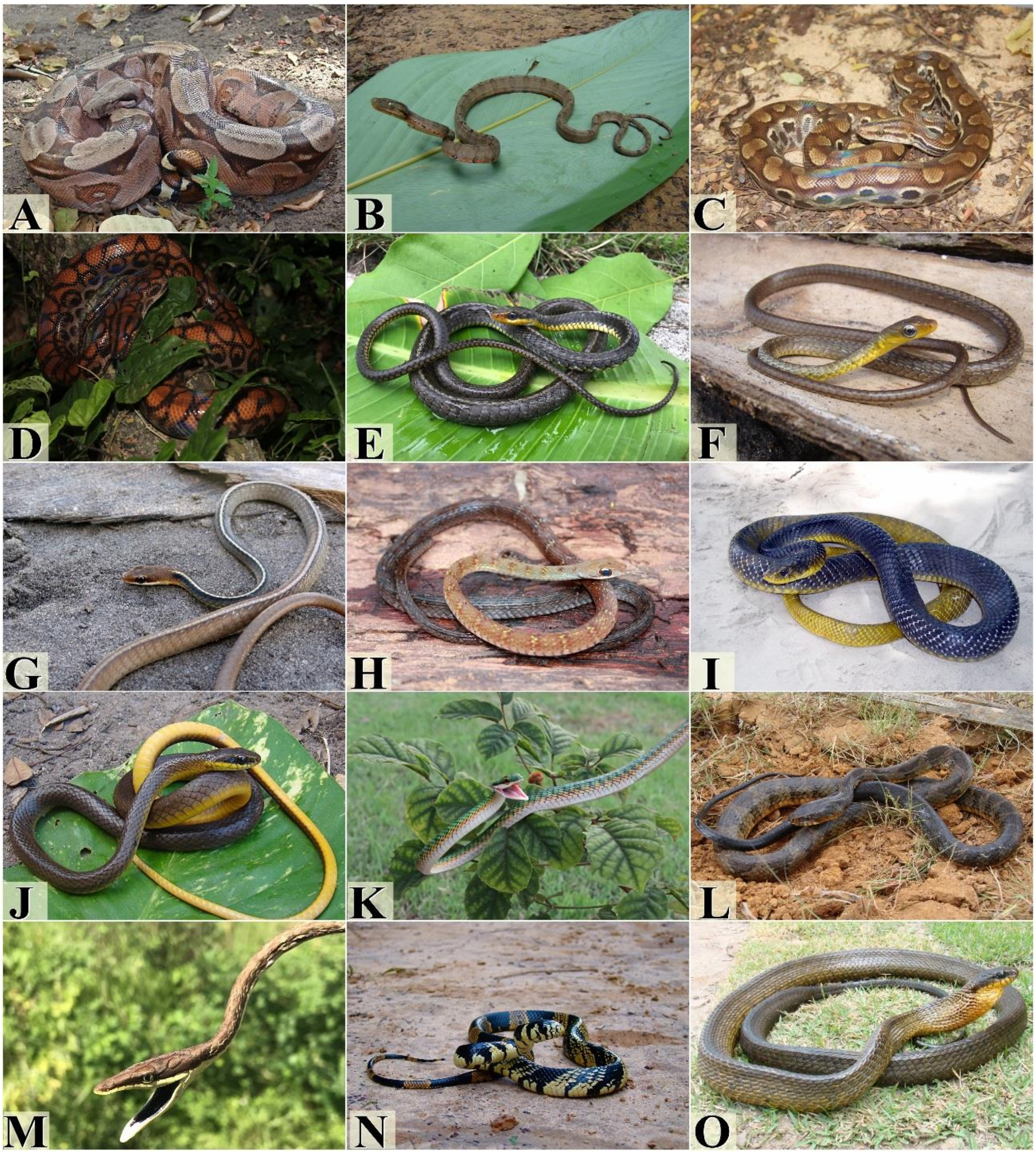

Figure 3. Snake species from the Pernambuco Endemism Center. **A** *Boa constrictor*, **B** *Corallus hortulanus*, **C** *Epicrates assisi*, **D** *Epicrates cenchria*, **E** *Chironius carinatus*, **F** *Chironius exoletus*, **G** *Chironius flavolineatus*, **H** *Dendrophidion atlantica*, **I** *Drymarchon corais*, **J** *Drymoluber dichrous*, **K** *Leptophis ahaetulla*, **L** *Palusophis bifossatus*, **M** *Oxybelis aeneus*, **N** *Spilotes pullatus*, **O** *Spilotes sulphureus*. Photograph credits: Frederico França (**A**, **B**, **C**, **E**, **F**, **G**, **J**, **L**, **M**, **O**), Vanessa Nascimento (**D**), Davi Pantoja (**H**, **I**, **N**), Rafaela França (**K**).

Figure 4. Snake species from the Pernambuco Endemism Center. **A** *Tantilla melanocephala*, **B** *Apostolepis cearensis*, **C** *Apostolepis longicaudata*, **D** *Atractus maculatus*, **E** *Atractus potschi*, **F** *Boiruna sertaneja*, **G** *Caaeteboia* sp., **H** *Dipsas mikanii*, **I** *Dipsas neuwiedi*, **J** *Dipsas sazimai*, **K** *Dipsas variegata*, **L** *Erythrolamprus aesculapii*, **M** *Erythrolamprus almadensis*, **N** *Erythrolamprus poecilogyrus*, **O** *Erythrolamprus reginae*. Photograph credits: Frederico França (**A**, **B**, **G**, **H**, **I**), Anderson A. Santos (**C**, **N**), Rafaela França (**D**, **E, J, K, L, M, O**), Paulo R. S. Freitas (**F**).

Figure 5. Snake species from the Pernambuco Endemism Center. **A** *Erythrolamprus taeniogaster*, **B** *Erythrolamprus viridis*, **C** *Helicops angulatus*, **D** *Helicops leopardinus*, **E** *Hydrodynastes gigas*, **F** *Imantodes cenchoa***, G** *Leptodeira annulata*, **H** *Lygophis dilepis***, I** *Oxyrhopus guibei*, **J** *Oxyrhopus petolarius*, **K** *Oxyrhopus trigeminus*, **L** *Philodryas nattereri***, M** *Philodryas olfersii*, **N** *Philodryas patagoniensis*, **O** *Phimophis guerini*. Photograph credits: Frederico França (**A**, **C**, **F**, **H**, **I**, **M**, **N**, **O**), Vanessa Nascimento (**B**, **D**), Ivan L. Sampaio (**E**), Willianilson Pessoa (**G**), Rafaela França (**J**, **L**), Anderson A. Santos (**K**).

Figure 6. Snake species from the Pernambuco Endemism Center. **A** *Pseudoboa nigra*, **B** *Psomophis joberti*, **C** *Sibon nebulatus*, **D** *Siphlophis compressus*, **E** *Taeniophallus affinis*, **F** *Taeniophallus occipitalis***,** **G** *Thamnodynastes almae*, **H** *Thamnodynastes hypoconia***,** **I** *Thamnodynastes pallidus*, **J** *Thamnodynastes phoenix*, **K** *Xenodon merremii*, **L** *Xenodon rabdocephalus***,** **M** *Xenopholis scalaris*, **N** *Xenopholis undulatus*, **O** *Micrurus corallinus*. Photograph credits: Frederico França (**A**, **B**, **C**, **D**, **F**, **H**, **K, N**), Vanessa Nascimento (**L**), Samuel Cardoso (**G**), Davi Pantoja (**M**), Rafaela França **(I**), Anderson A. Santos (**E**), Paulo R. S. Freitas (**J**), Adrian Garda (**O**).

Figure 7. Snake species from the Pernambuco Endemism Center. **A** *Micrurus ibiboboca*, **B** *Micrurus potyguara*, **C** *Epictia borapeliotes*, **D** *Amerotyphlops arenensis*, **E** *Amerotyphlops brongersmianus*, **F** *Amerotyphlops paucisquamus***, G** *Bothrops bilineatus*, **H** *Bothrops erythromelas***, I** *Bothrops leucurus*, **J** *Bothrops muriciensis*, **K** *Crotalus durissus*, **L** *Lachesis muta*. Photograph credits: Frederico França (**A**, **B**, **E**, **F**, **H**, **I**, **K, L**), Ivan L. Sampaio (**C**), Gentil A. Pereira Filho (**D**), Willianilson Pessoa (**J**), Rafaela França (**G**).

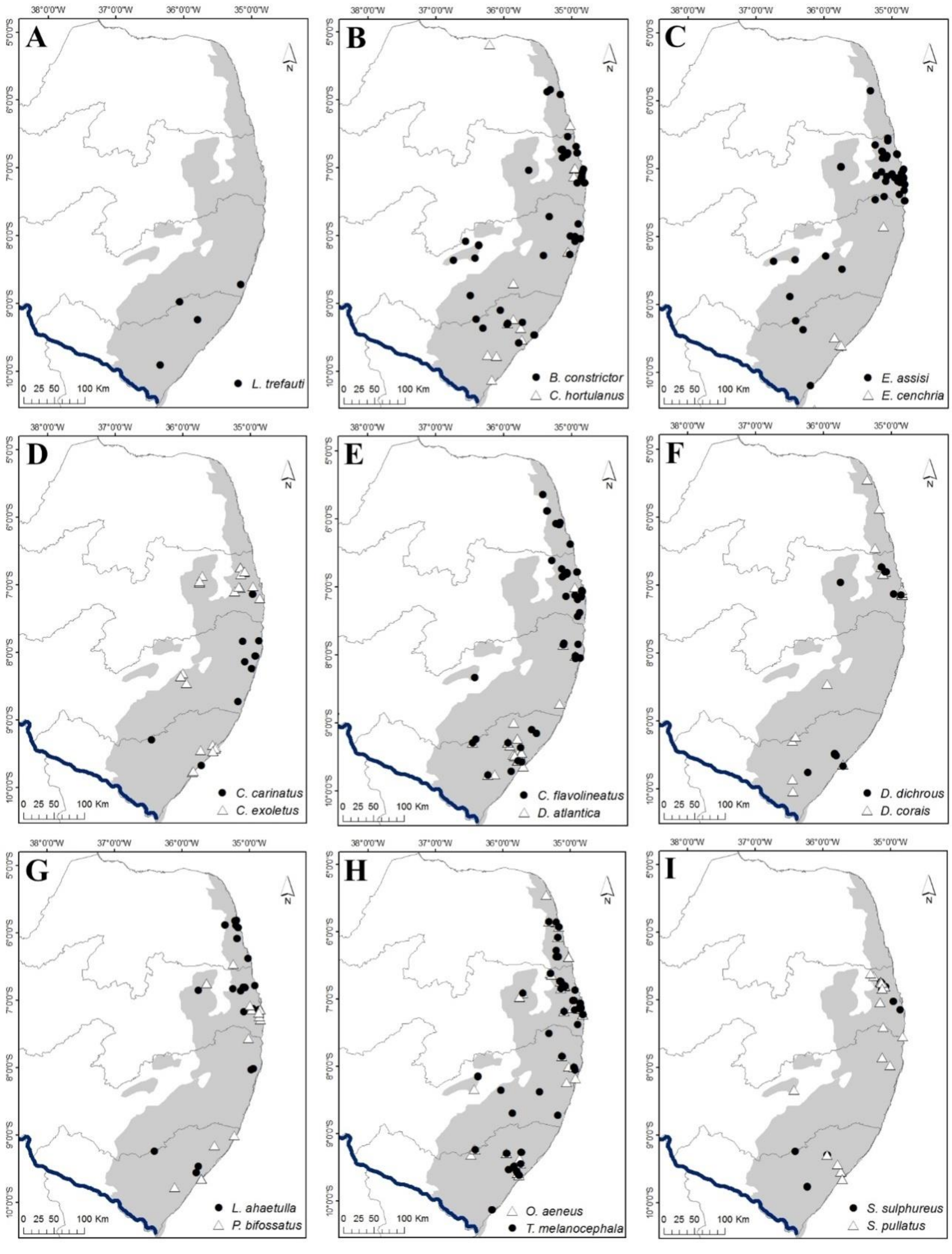

Figure 8. Geographic distribution records for snakes of the Pernambuco Endemism Center (PEC). **A** *Liotyphlops trefauti*, **B** *Boa constrictor* and *Corallus hortulanus*, **C** *Epicrates cenchria* and *E. assisi*, **D** *Chironius carinatus* and *C. exoletus*, **E** *Chironius flavolineatus* and *Dendrophidion atlantica*, **F** *Drymarchon corais* and *Drymoluber dichrous*, **G** *Leptophis ahaetulla* and *Palusophis bifossatus*, **H** *Oxybelis aeneus* and *Tantilla melanocephala*, **I** *Spilotes sulphureus* and *S. pullatus*.

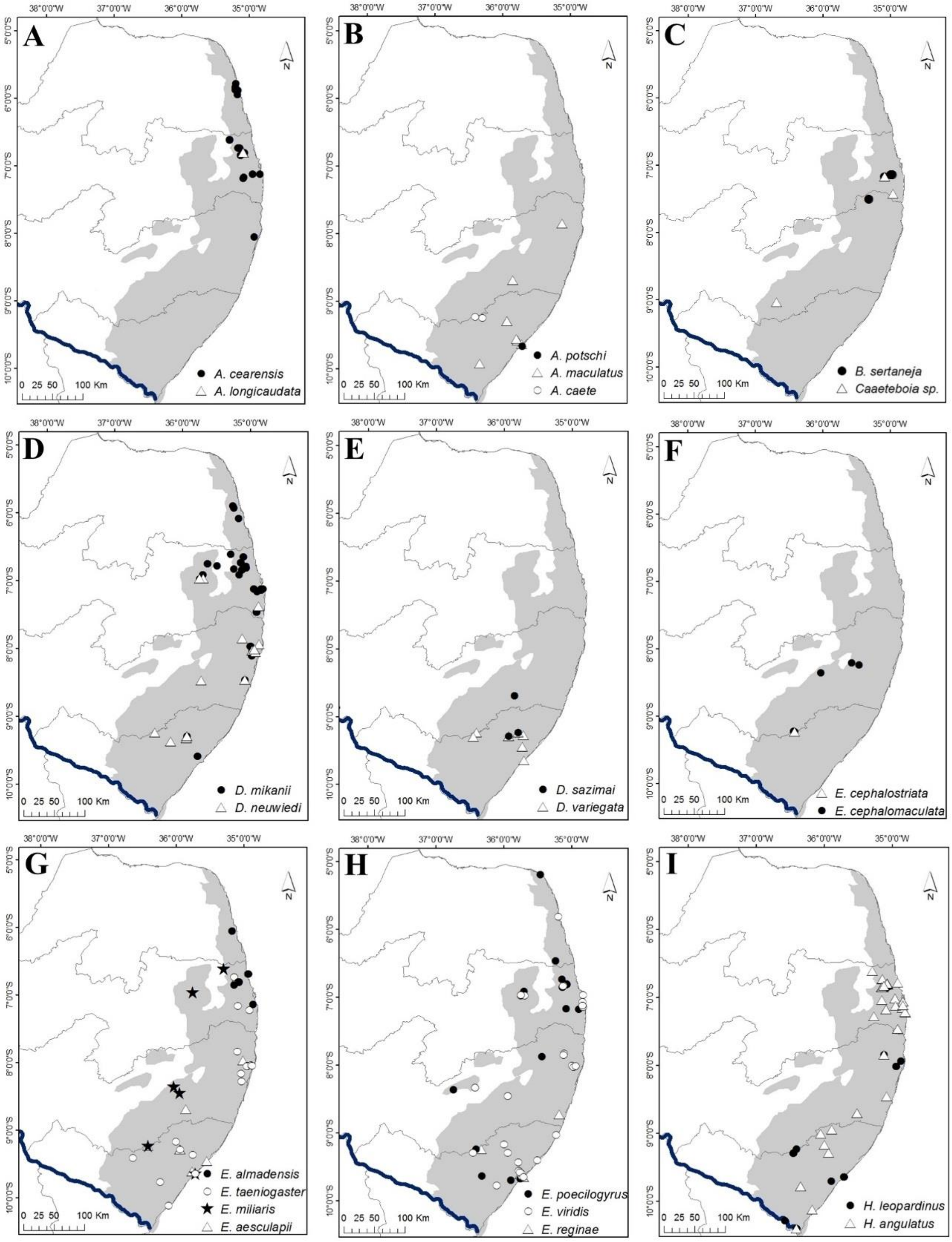

Figure 9. Geographic distribution records for snakes of the Pernambuco Endemism Center (PEC). **A** *Apostolepis longicaudata* and *A. cearensis*, **B** *Atractus caete*, *A. maculatus* and *A. potschi*, **C** *Boiruna sertaneja* and *Caaeteboia* sp., **D** *Dipsas mikanii* and *D. neuwiedi*, **E** *D. sazimai* and *D. variegata*, **F** *Echinanthera cephalomaculata* and *E. cephalostriata*, **G** *Erythrolamprus almadensis*, *E. taeniogaster*, *E. miliaris*, and *E. aesculapii*, **H** *E. poecilogyrus*, *E. viridis* and *E. reginae*. **I** *Helicops angulatus* and *H. leopardinus*.

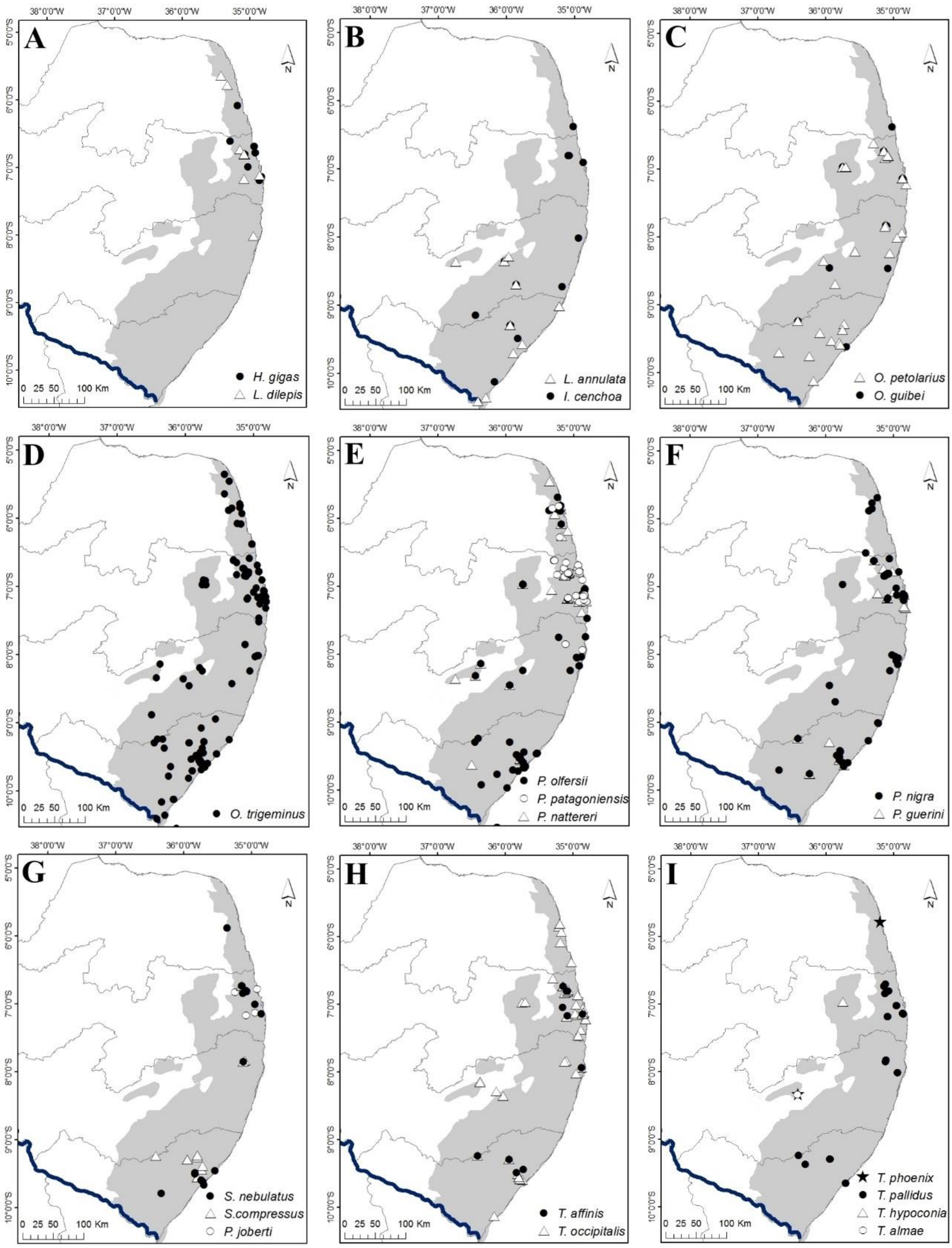

Figure 10. Geographic distribution records for snakes of the Pernambuco Endemism Center (PEC). **A**. *Hydrodynastes gigas* and *Lygophis dilepis*, **B**. *Imantodes cenchoa* and *Leptodeira annulata*, **C**. *Oxyrhopus guibei* and *O. petolarius*, **D**. *O. trigeminus*, **E**. *Philodryas nattereri*, *P. olfersii* and *P. patagoniensis*, **F**. *Phimophis guerini* and *Pseudoboa nigra*, **G**. *Psomophis joberti*, *Sibon nebulatus* and *Siphlophis compressus*, **H**. *Taeniophallus affinis* and *T. occipitalis*, **I**. *Thamnodynastes almae*, *T. hypoconia*, *T. pallidus* and *T. phoenix*.

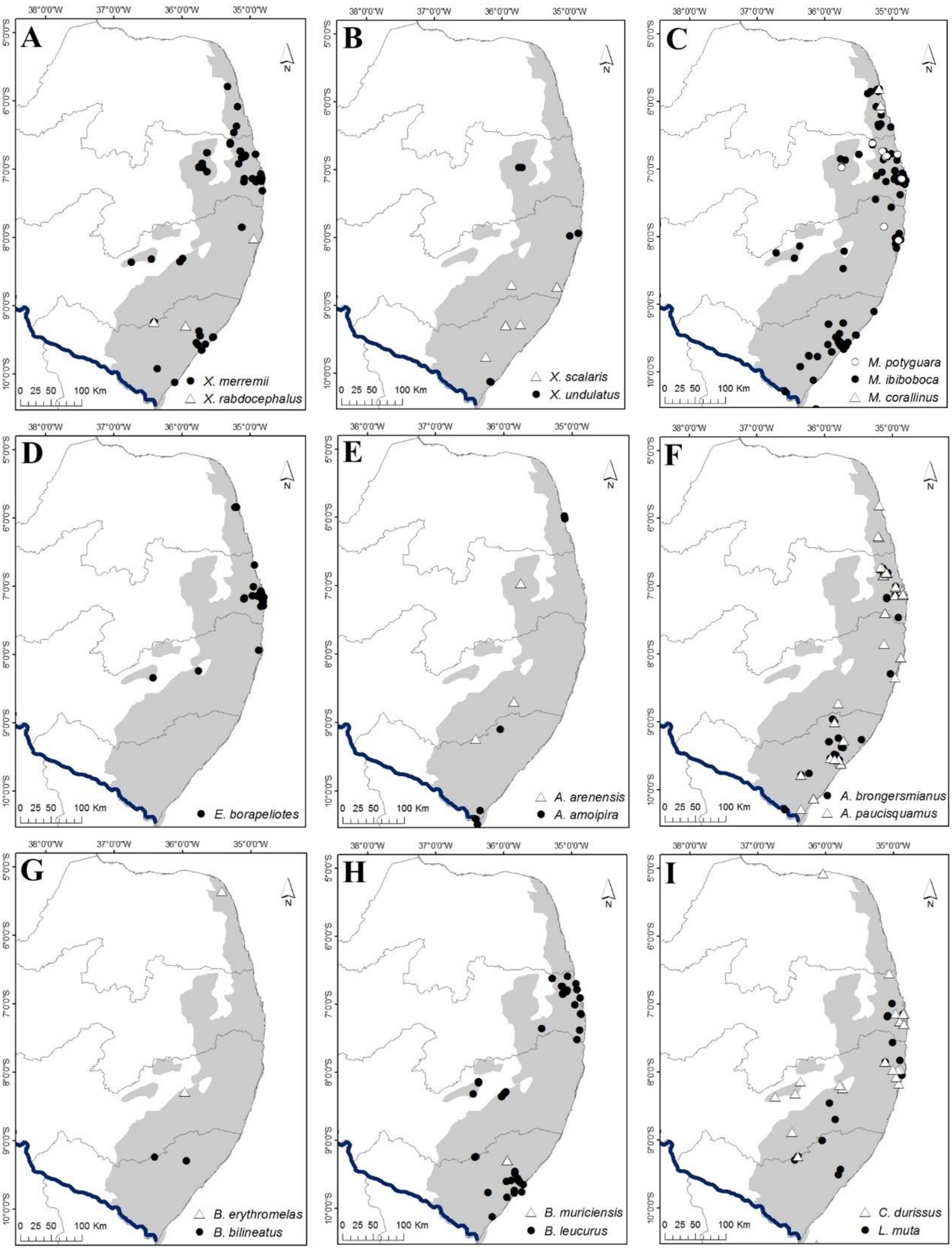

Figure 11. Geographic distribution records for snakes of the Pernambuco Endemism Center (PEC). **A**. *Xenodon merremii* and *X. rabdocephalus*, **B**. *Xenopholis scalaris* and *X. undulatus*, **C**. *Micrurus corallinus*, *M. ibiboboca* and *M. potyguara*, **D**. *Epictia borapeliotes*, **E**. *Amerotyphlops amoipira* and *A. arenensis*, **F**. *A. brongersmianus* and *A. paucisquamus*, **G**. *Bothrops bilineatus* and *B. erythromelas*, **H**. *B. leucurus* and *B. muriciensis*, **I**. *Crotalus durissus* and *Lachesis muta*.

Discussion

Our results show a broad view of PEC's snake fauna, including distribution data, natural history, and diversity. According to Marques et al. (2019), about 142 species of snakes occur in the Brazilian Atlantic Forest, the 78 species recorded in the PEC represent 51.3% of this total, which we can consider a high richness. In addition, new species are still being discovered in this region, for example, the species *D. atlantica* (Freire et al. 2010), *M. potyguara* (Pires et al. 2014), and *A. arenensis* (Graboski et al. 2015) have been described in the last ten years and at least one new species (*Caaeteboia* sp.) is being described at the moment (Pereira Filho et al. 2017).

The mixed composition of snake species that inhabit the Atlantic Forest located north of the São Francisco River can be considered a remarkable characteristic of this fauna (Pereira Filho et al. 2017). We can highlight that the main difference between the PEC and other portions of the biome is due to the large number of species of open areas and also of wide distribution that are present in this region. The PEC shares more species with the Caatinga and the Cerrado (74.3% and 56.4% of the shared species, respectively) than with the southern and southeastern regions of the Atlantic Forest (30% of the species are shared). This may be due to the fact that the PEC presents different physiognomic features, such as patches of Tabuleiros, which are natural enclaves of savannah found even in the middle of forests and which may provide adequate conditions for the establishment of populations of species from open areas (Mesquita et al. 2018). In addition, the proximity to the Caatinga may also have favoured the penetration and establishment of these populations (Pereira Filho et al. 2017). These arguments are supported by historical factors that are based on the expansion and retraction of the boundaries of dry and open habitat ecoregions, due to climatic fluctuations over geological time, which have reached coastal areas of northeastern Brazil (Ab'Saber 1977, Pennington et al. 2006). Thus, species considered previously endemic to the Caatinga, for example, *E. borapeliotes* and *E. assisi* (Guedes et al. 2014), and species considered endemic to the Cerrado, for example *C. flavolineatus* (Nogueira et al. 2010), are also abundant in the PEC.

Most reptiles are considered habitat specialists, which means that many species can only survive in one or a few distinct environments (Martins and Molina 2008). In the PEC, the great majority of snake species were found in forest areas and 26 species were collected only in this environment. Due to the occupation of the area for agriculture and urbanization, most of the forest in the PEC was lost or reduced to small fragments, mostly smaller than ten hectares, which represent less than 2% of the original coverage of the Center (Ranta et al. 1998, Tabarelli et al. 2005). This is especially worrying because species that do not use the surrounding matrix as part of their area of use or that cannot use these environments to move between the fragments, can become extinct regionally as the populations are becoming isolated, making them unviable in the long term, due to the reduced population size (Nunney and Campbell 1993). On the other hand, some species seem to be generalists in terms of habitat and can be found in different physiognomies of the PEC and even urban areas, as is the case of *B. constrictor*, *P. olfersii*, *B. leucurus* and *O. trigeminus*.

Most snake species found in the PEC mainly use soil as substrate, as well as snakes in other regions of Brazil, such as the Caatinga (Guedes et al. 2014), Atlantic Forest (Marques et al. 2017b), Cerrado (França and Braz 2013), Pantanal (Strussmann and Sazima 1993) and Amazon (Martins and Oliveira 1998, Bernarde and Abe 2006). However, PEC also harbours a great variety of semi-arboreal and arboreal species, which is a characteristic of forest biomes, such as the Atlantic Forest and Amazon (Martins and Oliveira 1998, Argôlo 2004, Marques and Sazima 2004, Bernarde and Abe 2006).

More than half of PEC snakes feed on lizards or amphibians. These types of prey are commonly found in the snake diet, although other vertebrates like mammals, birds, and snakes are also important preys (Bernarde and Abe 2006, Hartmann et al. 2009, Mesquita et al. 2009). Some species of the PEC are generalists, as boids and snakes of the genus *Philodryas* and *Oxyrhopus*. Snakes belonging to the genera *Apostolepis*, *Dipsas*, and *Atractus* have specialized diet, feeding on snakes, mollusks and earthworms, respectively, as well as the genera *Xenodon* and *Xenopholis*, which are specialists in amphibians. (Vitt and Vangilder 1983, Laporta-Ferreira et al. 1986, Cunha and Nascimento 1993, Martins and Oliveira 1998, Mesquita et al. 2009, Bernarde and Abe 2010, Fernandes et al. 2010, Kokubum and Maciel 2010).

It is important to emphasize that the PEC presents at least seven endemic species (*A. caete*, *A. maculatus*, *B. muriciensis*, *Caaeteboia* sp., *D. atlantica*, *E. cephalomaculata*, and *M. potyguara*) of which basic information on natural history and ecology are scarce. Most of these species have a very restricted distribution, have been little recorded in nature and consequently are poorly represented in scientific collections. For example, *B. muriciensis* has only nine records and was found only in a single location (Freitas et al. 2012), the *E. cephalomaculata* has seven known records and was found only in four locations (Freitas et al. 2019b) and *Caaeteboia* sp., which has only three records and should be a new species for the region (Pereira Filho et al. 2017). Moreover, some species have confused taxonomy, such as *M. ibiboboca* and *D. neuwiedi*, being a complex of different taxa. Some of these taxa could figure as endemic species in PEC in the future. Besides the endemic species, other PEC species deserve special attention due to the absence of information on natural history and ecology, for being rare in the region and for presenting a restricted distribution in the PEC, for example, *L. trefauti, A. potschi, D. sazimai, D. variegata, E. cephalostriata,* and *A. arenensis.*

The conservation status of PEC snake species is still little known. Of the 78 species registered in the region, only 25 species have been evaluated by the IUCN (International Union for Conservation of Nature) to date. On the Brazilian list of threatened species, some PEC species are present, they are: *A. amoipira, A. caete, and B. muriciensis* as "endangered" and *A. paucisquamus* and *E. cephalomaculata* as "vulnerable" (ICMBio 2018). Given the high richness of snake species, the number of endemic species and the fragmented conditions of the region's forests, regional conservation efforts need to be intensified, because few forests north of the São Francisco River are formally protected, and the majority are small, which means that many species in the region may be threatened with extinction (Ranta et al. 1998, Uchoa Neto and Tabarelli 2002, Tabarelli et al. 2006a).

In general, many studies still need to be developed in the PEC region, so that we can better understand the snake fauna of this region. Fauna inventories in areas that are not well sampled, population dynamics studies and distribution patterns are important for better conservation planning of PEC snake species.

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CAPÍTULO 2

WHAT MAKES A SPECIES VULNERABLE TO EXTINCTION? AN OVERALL REVIEW OF THE MAIN FACTORS THAT THREATEN REPTILES

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What makes a species vulnerable to extinction? An overall review of the main factors that threaten reptiles

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Abstract

We present a review of the intrinsic and extrinsic threat factors used to assess vulnerability to reptile extinction around the world based on 30 published articles. Here, we consider which threat factors are most commonly used, the reasons why these factors are used, and how they are applied. In addition, we have reviewed the articles that performed comparative analyses to test the hypotheses related to the threat factors used in these assessments. The most commonly used intrinsic factors were the distribution breadth, habitat use, litter size, and body size. The most used extrinsic factors were species-specific direct anthropogenic effects and body color. We have found support in the literature for the use of practically all intrinsic threat factors most commonly used in assessments, but body size does not seem to be a good predictor of threat to snakes and so we suggest that it be tested more specifically in other reptile groups. Most of the studies that tested the hypotheses related to the threat factors

obtained very specific results for certain rates and in certain regions. Therefore, we emphasize the need for more studies contemplating different rates and at different geographical scales in order to understand more clearly how these factors act on the vulnerability to extinction of reptiles.

Keywords: Biodiversity, declines, extrinsic traits, intrinsic traits, prediction, prioritization

1. Introduction

One of the main challenges faced by conservation biology is to understand the ecological mechanisms that make some species more vulnerable to extinction than others (Caughley, 1994). The knowledge of these mechanisms would make it possible to predict the vulnerability to extinction of species before they even enter population decline, making conservation efforts more effective (Lee & Jetz, 2011).

Since resources for conservation are limited, conservation action plans generally use extinction vulnerability assessments to make decisions about which threats are most important and how to prioritize species based on their vulnerability to these threats (Collar, 1996; Miller et al., 2007). Among the existing extinction vulnerability assessments, the best known and used is that of the International Union for the Conservation of Nature (IUCN). Although the criteria for species assessment established by IUCN are designed to be applied on a global scale, they have inspired several other lists, such as the national and state lists, which apply the procedure at the regional level (Gärdenfors, Hilton-Taylor, Mace, & Rodríguez, 2001). These regional lists are also important because they encourage regional efforts to collect information on species, which is essential especially in the case of species that are in the "Data Deficient" category (Gärdenfors et al., 2001).

Reptiles are one of the richest groups of terrestrial vertebrate species, but we do not yet have a comprehensive understanding of their risk of extinction (Tingley, Meiri, & Chapple, 2016). A review of the conservation status of reptiles has shown that the main sources threatening them are: habitat loss and degradation, introduction of invasive species, pollution, disease, unsustainable use and global climate change (Gibbons et al., 2000). More recently Böhm et al. (2013) assessed the conservation status of the world's reptiles, and argued that sources of threat, such as loss of habitat by agriculture, and the extraction and over-exploitation of timber, will shape the future fate of these animals.

Although the IUCN criteria work well to assess the extinction risk of many species (Rodrigues, Pilgrim, Lamoreux, Hoffmann, & Brooks, 2006), some groups, such as reptiles, are difficult to assess by these criteria due to the scarcity of knowledge about their population parameters, with the result that many species in this group are assessed only by their distribution, or even are not assessed (Böhm et al., 2013). Currently there are about 10,793 described reptile species (Uetz, 2019) and of these, 69 % were assessed by IUCN (2019) IUCN on a global scale, being 18% classified among the threatened species categories, and 14% in the data deficient (DD) category (Table 1).

Table 1. Number of known reptile species in their different orders, the number of species assessed, threatened and classified in the category Data Deficient (DD) by IUCN (2019).

Order	n° of species described (Uetz, 2018)	number of species assessed (IUCN)	n° threatened species (IUCN)	n° of DD species
	10793	7541	1367	1126
Crocodylia	24	23	11	0
Rhynchocephalia	1	1	0	0
Squamata	10417	7259	1194	1115
Testudines	351	258	162	11

In this perspective, some research has attempted to use other methods and parameters to conduct comparative studies of extinction risks. Studies of this nature have already taken as a basis several hypotheses that associate intrinsic (species characteristic ecological attributes) and extrinsic (external threatening factors, resulting from human activity) factors to the vulnerability to extinction of species, such as large body size, small litter size, diet specialization, and extrinsic factors, such as climate change and illegal trade of species (Filippi & Luiselli, 2000; França & Araújo, 2006; Luiselli, 2009; Tomović et al., 2015). Other studies have sought to reveal which factors provide the greatest risk for the decline of a species, and thus understand why some species are more vulnerable to extinction than others (O'Grady, Reed, Brook, & Frankham, 2004; Purvis, Gittleman, Cowlishaw, & Mace, 2000; Webb, Brook, & Shine, 2002). However, no study has been done to bring together all these alternative methodologies and to analyse the threat factors used in assessments of vulnerability to reptile extinction.

Thus, the objective of this work is to present a review of the intrinsic and extrinsic threat factors used to assess vulnerability to extinction of reptiles around the world. Here, we check which threat factors are most commonly used, the hypotheses associated with their use and how they are applied. This review can help inform current discussions on criteria that can be used to assess the risk of extinction of reptiles.

2. Material and methods

We conducted an extensive bibliographic review on the Internet through the platforms Web of Science, Scopus and Google Scholar in an aim to compile all articles that used intrinsic and extrinsic factors to assess the vulnerability to extinction of reptiles at a global and regional level. We analyzed all studies published until 2018, in which the following terms were identified in the abstract and/or keywords: [“snake”, OR “lizard”, OR “Reptile”, OR “Turtle”, OR “tortoise”, OR “Crocodylia” OR “Squamates”, OR “Squamata”, OR “Crocodiles”, OR “Alligators”, OR “Caimans”, OR “Testudines”] AND [“extinction” OR “vulnerability extinction” OR “conservation status” OR “conservation priorities” OR “correlates extinction” OR “extinction risk” OR “threatened species”]. We then compiled only those articles that fit our study objective, as described below.

First, we gathered the articles that used intrinsic and/or extrinsic threat factors to assess vulnerability to reptile extinction. We identified each factor used in these articles and the hypotheses related to the use of each of them. Since in several articles different names are used for the same threat factor, we standardized the names for the table construction presented in the results. All factors used in each study were recorded and quantified and classified into intrinsic or extrinsic threat factors. In the second section of our study, we gathered articles that had as main objective to test hypotheses associated with threat factors and thus identify which factors are the best correlates of extinction risk in reptiles. We did not use articles that only cited possible threat factors for a particular group, since our interest was in those that in some way tested the importance of these factors in comparative analyses of extinction risk.

3. Results

3.1 What intrinsic and extrinsic threat factors are most commonly used in assessments of vulnerability to reptile extinction?

We found 16 articles (published between 1998 and 2016) that assessed the vulnerability to extinction of reptile species using intrinsic and/or extrinsic factors. In these assessments, 14 intrinsic factors and 6 extrinsic threat factors are used. We present the articles, each threat factor and the hypotheses related to the use of each one of them in table 2. The most used intrinsic factors in the assessments were Distribution breadth (81% of the articles), Habitat use (56%), Litter size (50%), Body size (50%) and Habitat breadth (50%) and the least used factor was Reproduction mode (6%) (Fig. 1). The most used extrinsic factors were Species-specific direct anthropogenic effects (73% of the articles) and Body colour (46%) (Fig. 2).

Table 2. Intrinsic and extrinsic factors used in the assessment of vulnerability to reptile extinction, description of the factors and references of the articles that used each factor.

Factors	Hypotheses	References
	Intrinsic Factors	
Body size	Larger species tend to be more vulnerable as they generally have lower population density, need larger areas of life, reach sexual maturity later and are more difficult to recover from population declines and negative interventions in their habitat	(Filippi & Luiselli, 2000), (França & Araújo, 2006), (Santos, Brito, Pleguezuelos, & Llorente, 2007), (Luiselli, 2009), (Abdala et al., 2012), (Gaiarsa, Alencar, Valdujo, Tambosi, & Martins, 2015), (Tomović et al., 2015), (Maritz et al., 2016)
Population abundance	Small populations are more vulnerable to local extinction due to their greater vulnerability to demographic and environmental variation and loss of genetic variability	(Breininger, Barkaszi, Smith, Oddy, & Provancha, 1998), (França & Araújo, 2006), (Abdala et al., 2012)
Distribution breadth	Species with restricted areas of occurrence are more vulnerable because they have less capacity to withstand negative interventions in their habitats	(Wilson & Mccranie, 2003), (Filippi & Luiselli, 2000), (França & Araújo, 2006), (Santos et al., 2007), (Abdala et al., 2012), (Townsend et al., 2012), (Wilson, Mata-Silva, & Johnson, 2013), (Segniagbeto et al., 2014), (Townsend, 2014), (Tomović et al., 2015), (Maritz et al., 2016), (Gaiarsa et al., 2015), (Johnson, Mata-Silva, & Wilson, 2015)
Altitudinal range of distribution	Species with restricted vertical distribution tend to have lower tolerance to variations in physical factors of the environment and, therefore, have less capacity to withstand negative human interventions in their habitat	(Tomović et al., 2015), (Gaiarsa et al., 2015)
Endemicity	Endemic species have a more restricted distribution, the reduction of their population may cause the extinction of the species	(Abdala et al., 2012), (Tomović et al., 2015),
Frequency of reproduction	A species that has several breeding events throughout the year can recover more easily when habitats are changed, and thus are less vulnerable to extinction	(Filippi & Luiselli, 2000), (Santos et al., 2007), (Tomović et al., 2015)

Factors	Hypotheses	References
Reproduction mode	Viviparous species tend to produce fewer offspring than oviparous species, moreover the death of the female during gestation results in the loss of her offspring and viviparous species may be less able than oviparous to maximise genotypic diversity among their offspring and are more prone to the risk of extinction	(Tomović et al., 2015)
Longevity	Species with a longer lifespan tend to have lesser extinction risks	(Filippi & Luiselli, 2000), (Zhou & Jiang, 2008), (Tomović et al., 2015),
Litter size	Species with lower fecundity tend to have less capacity to recover from declines	(Filippi & Luiselli, 2000), (França & Araújo, 2006), (Santos et al., 2007), (Zhou & Jiang, 2008), (Abdala et al., 2012), (Tomović et al., 2015), (Gaiarsa et al., 2015), (Maritz et al., 2016)
Dietary specialization	Specialist species tend to be more vulnerable, due to their dependence on the availability of specific and fundamental food items in their diet, and which are other organisms that may be threatened due to a variety of factors	(Filippi & Luiselli, 2000), (França & Araújo, 2006), (Santos et al., 2007), (Abdala et al., 2012), (Tomović et al., 2015), (Gaiarsa et al., 2015), (Maritz et al., 2016)
Habitat breadth	Species that use habitats in a specialised way are more vulnerable to extinction, as they tend to have less capacity to withstand disturbances in their habitats	(Filippi & Luiselli, 2000), (França & Araújo, 2006) (Santos et al., 2007), (Luiselli, 2009), (Zhou & Jiang, 2008), (Abdala et al., 2012), (Tomović et al., 2015), (Maritz et al., 2016)
Habitat use	Species with more secret habits are less vulnerable as they are less subject to predation	(Filippi & Luiselli, 2000), (Wilson & Mccranie, 2003), (França & Araújo, 2006), (Santos et al., 2007), (Townsend et al., 2012), (Wilson, Mata-Silva, & Johnson, 2013), (Townsend, 2014), (Tomović et al., 2015), (Johnson et al., 2015)
Activity period	Species that have more secret habits (nocturnal) are less vulnerable because they are less subject to disturbances such as predation or collection for food, as pets, etc.	(Filippi & Luiselli, 2000), (Luiselli, 2009), (Tomović et al., 2015)

Factors	Hypotheses	References
Adaptability to altered environments	Vulnerability to extinction tends to be higher in animals that are less able to persist in altered habitats	(Filippi & Luiselli, 2000), (França & Araújo, 2006), (Santos et al., 2007), (Abdala et al., 2012), (Gaiarsa et al., 2015), (Tomović et al., 2015), (Maritz et al., 2016)
	Extrinsic factors	
Road mortality	Species that have never been found dead on roads are less vulnerable to extinction	(Breininger et al., 1998), (França & Araújo, 2006)
Body colour	Venomous or mimetic species (colour similar to venomous species) are more vulnerable because they are killed by humans more often	(Breininger et al., 1998), (Wilson & Mccranie, 2003), (França & Araújo, 2006), (Townsend et al., 2012), (Wilson, Mata-Silva, & Johnson, 2013), (Johnson et al., 2015)
Area fragmentation	The greater the fragmentation of a species' habitat, the more isolated populations are and the more vulnerable to extinction	(Tomović et al., 2015)
Species-specific direct anthropogenic effects	Direct anthropogenic influences (consumption as food, illegal trade, traditional use as "medicine") can cause a faster reduction in the size of the local population	(Breininger et al., 1998), (Filippi & Luiselli, 2000), (Wilson & Mccranie, 2003), (Santos et al., 2007), (Zhou & Jiang, 2008) (Townsend et al., 2012), (Wilson, Mata-Silva, & Johnson, 2013), (Segniagbeto et al., 2014), (Townsend, 2014), (Tomović et al., 2015), (Johnson et al., 2015)
Generalised effects of coexisting human population density	Species are more vulnerable to extinction the higher human density in their area of distribution	(Luiselli, 2009), (Gaiarsa et al., 2015) (Maritz et al., 2016)
Percentage of protected area in the distribution of the species	Species whose geographical distribution includes conservation units are less vulnerable to extinction	(Gaiarsa et al., 2015), (Maritz et al., 2016)

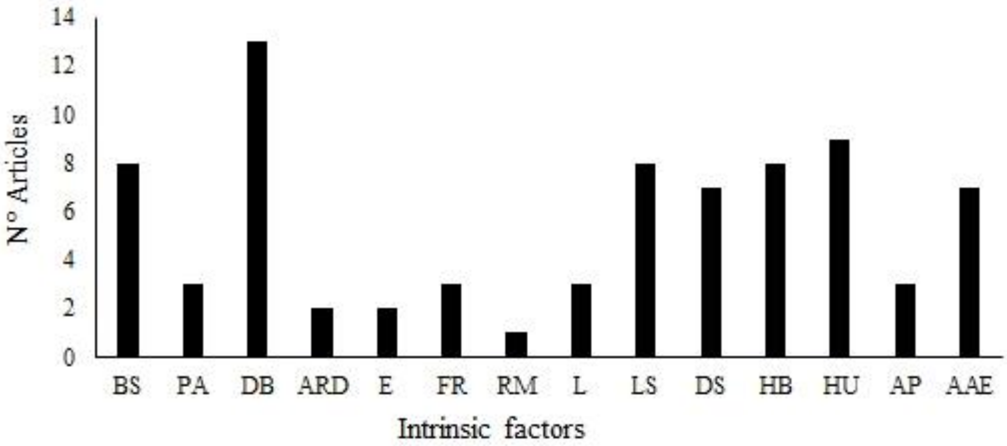

Fig. 1. Intrinsic threat factors used to assess vulnerability to reptile extinction. The x axis represents the threat factors and the y axis represents the number of articles that used the factor in assessments. The abbreviations are: Body size (BS), Population abundance (PA), Distribution breadth (DB), Altitudinal range of distribution (ARD), Endemicity (E), Frequency of reproduction (FR), Reproduction mode (RM), Longevity (L), Litter size (LS), Dietary specialization (DS), Habitat breadth (HB), Habitat use (HU), Activity period (AP), Adaptability to altered environments (AAE).

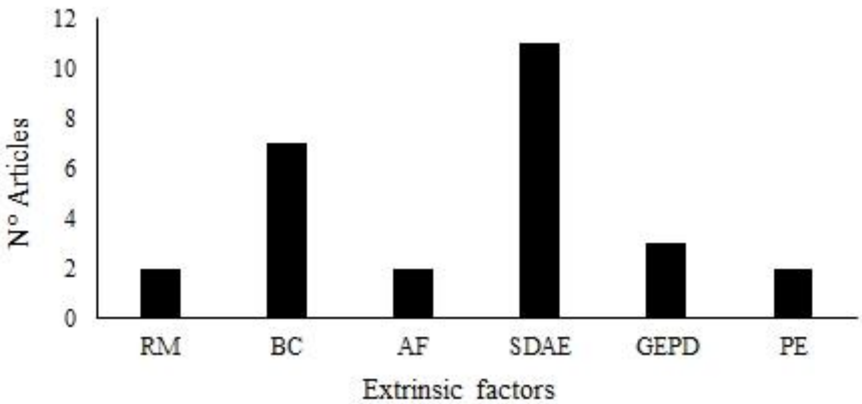

Fig. 2. Extrinsic threat factors used to assess vulnerability to reptile extinction. The x axis represents the threat factors and the y axis represents the number of articles that used the factor in assessments. The abbreviations are: Road mortality (RM), Body colour (BC), Area fragmentation (AF), Species-specific direct anthropogenic effects (SDAE), Generalised effects of coexisting human population density (GEPD), Percentage of protected area in the distribution of the species (PE).

3.2 What intrinsic and extrinsic threat factors are most important to the vulnerability to extinction of reptiles?

To test hypotheses associated with threat factors, the articles used two main methodologies. Some articles used vulnerability indices created from a scoring methodology, in which values are assigned for each species depending on the threat factor and a sum or average of all the values assigned to that species is performed. Each factor varies from values ranging from lower risk to higher risk. Once all the value assignments for each factor and each species have been completed, a later analysis can indicate the importance of each factor in the composition of this index (e.g., Filippi & Luiselli, 2000; França & Araújo, 2006). Other studies have used pre-existing threatened species lists, such as that of the IUCN, in an aim to perform a comparative analysis between the characteristics of species considered threatened, and those of species considered not threatened (e.g., Böhm, Williams, et al., 2016; Reed & Shine, 2002). In Table 3 we present the variables used in these studies and the main results regarding the selection of variables, identifying the factors with the greatest influence on the vulnerability of species to extinction. Of the 16 articles (Table 3) that addressed the importance of threat factors for reptile vulnerability to extinction, 50% addressed intrinsic and extrinsic factors (e.g., bioclimatic, anthropic) and 50% used only intrinsic factors. Most of the studies were conducted on a regional scale, with only two studies on a global scale.

Table 3. Articles that conducted comparative analysis of intrinsic and extrinsic factors related to vulnerability to extinction and reptiles, compiled from bibliographic review in Web of Science, Scopus and Google Scholar systems.

Taxa	**study area**	**Factores**	**Variables used in analyses**	**Factors correlated with vulnerability (Results)**	**Reference**
snakes	South-eastern Australia	Intrisic	Demographic parameters (reproduction and survival rates)	The results support the hypothesis that species with a slow life history (small litters, slow growth, late maturation) are more vulnerable to extinction	(Webb et al., 2002)
snakes	Australia	Intrisic and Extrinsic	Male combat, age structure, dietary specialization body size, dietary specialization, litter size, habitat breadth, measures of climatic tolerances (annual temperature and precipitation range), age at maturation, reproductive mode, foraging modes	The results showed that threatened species tend to be foraged by ambush and that these species generally do not have macho-male combat in the mating system	(Reed & Shine, 2002)
snakes	Italy	Intrisic and Extrinsic	Illegal trade, body size, distribution breadth, frequency of reproduction, litter size, dietary specialization, habitat breadth, habitat use, maximum age and adaptability to altered habitats	The factors related to the geographical distribution of the species are the predominant threats to snakes in Italy. However, factors related to natural history are the most important for vulnerability to extinction of some species	(Filippi & Luiselli, 2000)
Snakes	Distrito Federal, Brazil	Intrisic and Extrinsic	Body size, litter size, dietary specialization, Habitat breadth, habitat use, distribution breadth, adaptability to altered habitats, population abundance and body colour	Intrinsic and extrinsic factors contribute in the same way to the vulnerability to extinction of species	(França & Araújo, 2006)
Snakes	American continent	Intrisic	Body size	The known pattern of larger species being more vulnerable to extinction cannot be generalized for New World snakes	(Vilela, Villalobos, Rodríguez, & Terribile, 2014)
Snakes	South Carolina, USA	Intrisic	Estimate age at maturity, potential longevity, survival and habitat specialization	The results indicate that the slow life history and habitat specialization may be a risk factor for *Crotalus adamanteus*	(Waldron et al., 2006)

Taxa	study area	Factores	Variables used in analyses	Factors correlated with vulnerability (Results)	Reference
Snakes	Iberian Peninsula	Intrisic	Habitat specialization	The specialisation of habitats seems to be linked to the conservation status of the species	(Segura, Feriche, Pleguezuelos, & Santos, 2007)
Snakes	North and South Carolina, USA	Intrisic	Natural landscape of each species' range, body size, litter size, reproductive maturity, reproductive mode, dietary specialization, habitat breadth, distribution breadth and if the species is venomous	Snake species that feed mainly on vertebrates, which use a high proportion of aquatic habitats, are more sensitive to landscapes modified by humans	(Todd, Nowakowski, Rose, & Price, 2017)
Lizards	Western Palaearctic	Intrisic and Extrinsic	Distribution breadth, altitudinal range of distribution, body size, litter size and insularity	Litter size was a good predictor of extinction risk for the continent species, but in island species, it can predispose, but does not guarantee a high vulnerability to extinction	(Siliceo & Díaz, 2010)
Lizards	New Zealand	Intrisic and Extrinsic	Body size, habitat use, habitat breadth, activity period, dietary specialization, litter size, phylogenetic longevity (time since divergence [mya] from its most closely related extant species), reproductive mode, biogeographic affinity, mean annual temperature, annual precipitation, temperature seasonality, precipitation seasonality, human population density, human influence, and extent of habitat loss	Body size and amplitude of distribution were the strongest predictors of extinction risk. However, lizards that occupy areas with high levels of annual precipitation and are exposed to exotic predators and high human population densities are at higher risk. The findings illustrate that both extrinsic threats and intrinsic traits need to be considered in order to accurately predict, and hence prevent, future population declines	(Tingley, Hitchmough, & Chapple, 2013)
Lizards	Thousand Island Lake, China	Intrisic	Distribution breadth, body size, litter size and population abundance	The study showed that natural density at mainland sites was the key trait associated with the fragmentation vulnerability in lizards in the Thousand Island Lake, while lizards' body size, litter size or distribution breadth had little effects on fragmentation vulnerability	(Wang, Zhang, Feeley, Jiang, & Ding, 2009)
Reptiles	Morocco	Intrisic	Distribution breadth, habitat breadth, body size and litter size	The main intrinsic factor for the vulnerability to extinction of reptiles was distribution breadth	(Pleguezuelos et al., 2010)

Taxa	study area	Factores	Variables used in analyses	Factors correlated with vulnerability (Results)	Reference
Turtles and squamates	Islands in the Mediterranean Sea	Intrisic	Body mass, longevity, habitat breadth and population abundance	Only population abundance and habitat specialization explained the observed variation in species extinction rates. Body mass itself did not explain variation in extinction rates, although it was strongly correlated with abundance	(Foufopoulos & Ives, 1999)
Squamates	Global	Intrisic and Extrinsic	Distribution breadth, Island endemism habitat breadth, body size, litter size, reproduction mode, dietary specialization, mean annual temperature, annual precipitation, productivity (net primary productivity), human impact (human appropriation of net primary productivity, human population density, human footprint, accessibility (distance from road))	Range size was the most important predictor of extinction risk. Regardless of location, squamate reptiles that are range-restricted habitat specialists living in areas highly accessible to humans are likely to become extinct first.	(Böhm, Williams, et al., 2016)
Squamates	Global	Intrisic and Extrinsic	Sensitivity dimension (habitat specialization, microhabitat specialisation, restriction to high-altitude habitat, tolerance of changes to precipitation regimes, tolerance of temperature changes average, sensitivity to change in fire regime, sensitivity to change in flooding, temperature-dependent sex determination, dependence on narrow range of food types, interspecific dependencies), Adaptability dimension (barriers to dispersal, slow turnover of generations, reproductive capacity), Exposure dimension (exposure to sea level rise, changes in mean temperature, temperature variability change, changes in mean precipitation, precipitation variability change	80.5% of the species were highly sensitive to climate change, mainly due to habitat specialization, while 48% had low adaptability and 58% had high exposure	(Böhm, Cook, et al., 2016)
Lizard	Brazilian Amazon	Intrisic and Extrinsic	Thermal biology traits (preferred temperatures and critical thermal limits) and operative temperatures	The results support the hypothesis that tropical lizard taxa are at high risk of local extinction caused by rising temperatures.	(Pontes-da-Silva et al., 2018)

Taxa	study area	Factores	Variables used in analyses	Factors correlated with vulnerability (Results)	Reference
			(natural thermal environment) and geographic distribution		

4. Discussion

In this paper, we show the assessments that used both intrinsic and extrinsic factors to assess vulnerability to extinction in reptiles. These assessments are designed to highlight species most at risk of extinction, in order to focus attention on conservation measures designed to protect them (Collar, 1996; Miller et al., 2007). Comparative studies of the risk of extinction, which have also been discussed here, differ from the previous one, as they offer a more predictive approach based on statistical generalizations. Modelled extinction risk can help identify currently non-threatened species that could have a greater potential to become threatened in the future based on their set of characteristics (Cardillo, Mace, Gittleman, & Purvis, 2006; Cardillo et al., 2004; Larson & Olden, 2010; Lee & Jetz, 2011; Purvis et al., 2000). In addition, these studies can reveal which factors provide the greatest risk for the decline of a species, and thus help us to understand more precisely why some species are more vulnerable to extinction than others (e.g., Böhm et al., 2016; Tingley et al., 2013)

The distribution breadth, which was one of the most used factors in assessments of vulnerability to extinction in reptiles, was an important factor in assessing the vulnerability of Italian snake species (Filippi & Luiselli, 2000), and was also a good predictor of vulnerability for reptiles in Morocco (Pleguezuelos et al., 2010) and for lizards and snakes on a global scale (Böhm, Williams, et al., 2016). Another factor that was widely used in these assessments was habitat breadth. This is a factor found in practically all conservation manuals as an important characteristic linked to an increased vulnerability to extinction of species (McKinney, 1997). In a study that aimed to identify the relationship between reptile extinction rates on land islands in the Mediterranean Sea and body mass, longevity, habitat specialization and population abundance Foufopoulos and Ives (1999) observed that only population abundance and habitat specialization explained a significant amount of the observed variation in the extinction rates of these species. In another study by Waldron et al. (2006), it was possible to observe the importance of habitat specialization in the vulnerability to extinction of the *Crotalus adamanteus* snake.

With regard to litter size, which was another widely used factor for assessing vulnerability to extinction in reptiles. A study conducted with lizards that sought to test the relationships between the state of conservation, insularity, range of distribution and life history characteristics of these animals, showed that litter size was a good predictor of risk of extinction for the continent's species, but in island species, may predispose, but not ensure a high vulnerability to extinction (Siliceo & Díaz, 2010). Another study by Webb et al. (2002) compared the life history traits of two sympatric snake species, and the results obtained by them support the hypothesis that species with small litters, slow growth, late maturation, prolonged intervals between reproductions and high survival rates are more vulnerable to extinction.

In addition to the intrinsic factors already mentioned, another factor that is widely used in these evaluations is body size. In groups such as mammals (Cardillo et al., 2005; Fritz, Bininda-Emonds, & Purvis, 2009), birds (Gaston & Blackburn, 1995), and marine fish (Olden, Hogan, & Zanden, 2007), the larger body size seems to be related to the greater vulnerability to extinction of species, which suggests that such a relationship may also occur in other groups of organisms, especially vertebrates. In this regard the body size factor has often been used in vulnerability assessments (red list of threatened species) of reptiles, where larger species have been treated as more prone to extinction. for Colubroidea snakes from the new world this pattern was not found, moreover, the authors argued that if all snake species classified in the IUCN today as "data deficient" were classified as threatened in the future, the pattern would be the opposite, with smaller species more vulnerable to extinction. In other studies, body size was also not a good predictor of reptile vulnerability (e.g. Foufopoulos & Ives, 1999; Luiselli, Akani, Rugiero, & Politano, 2005).

Body size is often associated with other factors that are related to species vulnerability, for example, larger species tend to have low population densities and have larger areas of life (Purvis et al., 2000). As it needs a higher energy demand, endothermic animals need more resources per individual, and therefore tend to have a larger area of life (Gillooly, Brown, West, Savage, & Charnov, 2001; Reed & Shine, 2002). Energy demands for ectothermics, such as snakes, may not vary as much with body increase, moreover, litter size as well as population density tend to increase in larger snakes (Brooks, Allison, & Reynolds, 2007; Luiselli et al., 2005; Reed & Shine, 2002), thus, the impact of habitat loss may not be as strong for these animals as for large endothermics (Vilela et al., 2014), does not seem to be a good factor in assessing snakes.

As for extrinsic factors, although anthropogenic activities are widely cited as precursors to the current biodiversity extinction crisis (Gibbons et al., 2000), there are still few studies that have sought to test the importance of factors linked to these activities for the vulnerability to reptile extinction. Species-specific direct anthropogenic effects (consumption as food, illegal trade, traditional use as "medicine") were the most cited extrinsic factor in the articles that aimed to assess the vulnerability to extinction of reptiles. Some studies have raised evidence that excessive collection (harvesting) of reptiles for illegal trade, traditional use and consumption as food may be resulting in the decline or extinction of some species (e.g., Nijman, Shepherd, Mumpuni, & Sanders, 2012; Schlaepfer, Hoover, & Dodd, 2005; Zhou & Jiang, 2004). For Italian snakes, the illegal trade as well as factors linked to the biological characteristics of the species were considered threats only for a small group of species (Filippi & Luiselli, 2000).

Regarding the body colour factor, which is an extrinsic factor used in extinction vulnerability assessments in snakes (e.g., Breininger et al., 1998; França & Araújo, 2006), under the hypothesis that venomous or mimetic species (colours similar to venomous species) are more vulnerable because they are killed by humans more frequently (França & Araújo, 2006). We have not found any article that would test this hypothesis and so we suggest that future work may address this issue.

Our results revealed that intrinsic factors are used more in assessments of vulnerability to extinction than extrinsic factors. However, extrinsic factors are often significant predictors of extinction risk in reptiles (e.g., Böhm, Williams, et al., 2016; Tingley et al., 2013). The fact that these factors are less used than the intrinsic factors may be due to the fact that they are often more difficult to assess. For example, the direct and indirect effects of environmental pollution, disease and parasitism and global climate change are more difficult to quantify in many cases (Gibbons et al., 2000). However, the use of extrinsic factors has been increasing in parallel with a greater number of published studies, suggesting that the authors are increasingly aware of the important role of the use of extrinsic factors in these studies (Murray, Verde Arregoitia, Davidson, Di Marco, & Di Fonzo, 2014).

5. Conclusions

In this review, we showed which intrinsic and extrinsic factors are most used in assessments of vulnerability to reptile extinction, and we saw the articles that tested the hypotheses associated with the vulnerability factors to extinction of these animals on regional and global scales. The most commonly used intrinsic factors were distribution breadth, habitat use, litter size, and body size. We have found support in the literature for the use of practically all intrinsic threat factors most commonly used in assessments, but body size does not seem to be a good predictor of threat to snakes and so we suggest that it be tested more specifically in other reptile groups. We also suggest that the body colour factor can be tested specifically in comparative analyses. Although studies that have approached the importance of intrinsic and extrinsic threat factors are of great value for efficient assessments of vulnerability to reptile extinction, they are apparently not contributing in practice to changing the way species are assessed. Most of these studies have obtained very specific results for certain rates and in certain regions and perhaps this is the difficulty of using these results in practice. Therefore, we emphasize the need for more studies with different rates and at different geographical scales in order to understand more clearly how these factors act on the vulnerability to extinction of reptiles.

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CAPÍTULO 3

DETERMINATION OF THE CONSERVATION STATUS OF THE SNAKES OF THE PERNAMBUCO ENDEMISM CENTER

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Determination of the conservation status of the snakes of the Pernambuco Endemism Center

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ABSTRACT

Due to the high level of disturbance in natural ecosystems and the progressive loss of habitats resulting from anthropic occupation, biodiversity conservation represents one of the greatest challenges today. Red lists of threatened species are created to identify the species in danger of extinction and, thus, to guide actions and application of resources in conservation plans. In this study, we evaluated the vulnerability to extinction of 78 snake species that occur in the Pernambuco Endemism Center, northeastern of Brazil, producing vulnerability indices based on 12 factors that may influence the survival of snake populations. We used PCA and cluster analysis to assess how these species are ranked in terms of similarity to specific threats, assessed the relative threat level of each species within the community, and compared our results with pre-existing red lists of threatened species. Our results indicate that only 37% of the snake fauna in this region is free of any threat. The species *Helicops angulatus* and *Oxyrhopus trigeminus* were the snakes that presented the lowest risk of extinction, while *Caaeteboia* sp. and *Bothrops muriciensis* presented the greatest risk of extinction. Four groups of species were considered non-threatened and eight groups were considered threatened. This paper presents the first overview on the conservation status of snake species in the Pernambuco Endemism Center and contributes to a better evaluation of conservation planning for this group in the region.

Keywords: Atlantic Forest; red listing; distribution; ecology; extinction risk

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1. Introduction

Red lists of threatened species are produced based on various attributes of species biology, as well as the threats to which species are susceptible. The main objective of these lists is to identify the species that are in danger of extinction and, thus, to guide actions and application of resources in conservation plans (Collar 1996). Among the various red lists of threatened species, the best known is that produced by the International Union for Conservation of Nature (IUCN). The criteria it established depends mainly on estimates of population parameters (criteria A, C, and D1), distribution data (criteria B and D2), and probability of extinction (criterion E) (IUCN 2019). These criteria, while designed to be applied on a global scale, have inspired several other lists, which apply the procedure at the regional level (Gärdenfors et al. 2001). Although the IUCN criteria work well to assess the risk of extinction for many species (Rodrigues et al. 2006), some groups such as reptiles are difficult to assess by these criteria due to the scarcity of knowledge about their population parameters, resulting in many species of this group being evaluated only by their inferred distribution, or even not evaluated (Böhm et al. 2013).

Among the reptiles, snakes are the group that currently has the most underestimated extinction risks as there is still a scarcity of information about the natural history of most species, mainly because they have long periods of inactivity, are difficult to observe, and live in low population density (Seigel 1993), which makes it very difficult to assess their vulnerability to extinction according to IUCN criteria. From this perspective, some studies have attempted to use other parameters to evaluate the vulnerability of reptile species. These studies are based on several hypotheses related with greater vulnerability to extinction of species associated with intrinsic factors such as large body size, small litter size, and dietary specialization, and extrinsic factors such as climate change and illegal trade in species (Filippi and Luiselli 2000; França and Araújo 2006; Luiselli 2009; Tomović et al. 2015). These criteria may be especially important for prioritizing conservation actions in situations where accurate distribution and population data are not available (Tomović et al. 2015), as is the case for most species of Brazilian snakes.

In a study on the conservation status of biodiversity worldwide, Myers et al. (2000) proposed 25 priority areas for conservation, one of which is the Atlantic Forest. Even though it has undergone extensive fragmentation over a prolonged time, the Atlantic Forest still harbors astonishing biodiversity, with more than 8000 endemic species of vascular plants, amphibians, reptiles, birds, and mammals (Myers et al. 2000). In Brazil, this biome extends from Rio Grande do Norte and Paraíba in its northernmost distribution, to Santa Catarina and Rio Grande do Sul in its southern distribution. Although practically every Brazilian coast was occupied by European colonization, it was in the northeast that the Atlantic Forest was more rapidly degraded, mainly due to two economic priorities: brazilwood and sugar cane (Coimbra-Filho and Câmara 1996; Tabarelli et al. 2006b). This degradation is still more evident in the portion of the Atlantic Forest located north of the São Francisco River, which corresponds to the Pernambuco Endemism Center (Prance 1982). In this region, sugarcane is the main agricultural crop, being present in all states of the Pernambuco endemism center. In addition, other anthropic actions, such as animal and plant extractivism, have provided a reduction in biodiversity in this region (Coimbra-Filho and Câmara 1996; Tabarelli et al. 2002; Tabarelli and Roda 2005). In this scenario, there is a very high probability of population decline and local, regional and even global extinction of species in the center of Pernambuco endemism, if there is not a drastic reduction in their exploitation (Tabarelli et al. 2002).

Our objective was to evaluate the vulnerability to extinction of snake species occurring in the Pernambuco Endemism Center, northeast Brazil, to analyze the main factors that may threaten the viability of populations, to classify species in groups vulnerable to specific threats, and to compare our results with pre-existing red lists of threatened species.

2. Material and methods

2.1 Study Area

The study area comprises the Atlantic Forest located north of the São Francisco River, which corresponds to the Pernambuco Endemism Center (PEC) (Prance 1982), located between the states of Alagoas and Rio Grande do Norte. This region has a humid tropical climate (Köppen's As'), with autumn-winter rains and rainfall ranging from 750 to 1500 mm per year (Tabarelli et al. 2006b).

The PEC region is composed of different native forest formations and ecosystems associated with the Atlantic Forest domain. A mosaic of ombrophilous and semi-deciduous forests is present in this region (Tabarelli et al. 2006b). The PEC also includes the "Brejos de altitude" or "Brejos Nordestinos", which are "islands" of humid forests established in the semi-arid region, surrounded by Caatinga vegetation (Andrade-Lima 1982; Pôrto et al. 2004). Although the vegetation of the PEC is composed mainly of humid tropical forests, we can also find open physiognomies along the coast, which are called “restingas”, and in the interior, which are called “tabuleiros”. In this region we can also find mangrove areas (Tabarelli et al. 2006a).

2.2 Threat Factors

To evaluate the vulnerability to extinction of the snake species that occur in the PEC, we combined the approaches of Filippi and Luiselli (2000), França and Araújo (2006), and Tomović et al. (2015), who used ecological and geographic data of the species to characterize the conservation status of snakes from Italy, Brazil, and Serbia, respectively. Thus, using a ranking method, vulnerability indices were produced from 12 factors that may influence the survival of snake populations. Each threat factor was classified with scores ranging from 1 (lower risk) to 2–4 (higher risk).

The data for the classification of threat factors were obtained from literature, fieldwork, and the careful review of 3,192 specimens of snakes deposited in five scientific collections (Coleção Herpetológica da Universidade Federal da Paraíba - UFPB; Coleção do Laboratório de Anfíbios e Répteis da Universidade Federal do Rio Grande do Norte - CLAR; Coleção Herpetológica do Museu de História Natural da Universidade Federal de Alagoas – MUFAL; Coleção Herpetológica da Universidade Federal Rural de Pernambuco – CHUFRPE; Coleção Herpetológica da Universidade Federal de Pernambuco - CHUFPE). All threat factors, the justification for use, and defined categories are described below.

2.2.1 Distribution data

1. Distribution breadth (DB): It is based on the principle that species that have a smaller home range are more vulnerable to extinction, as small distribution areas do not allow large population densities, which may influence the probability of population persistence, limiting their survival potential in a crisis of extinction (Purvis et al. 2000; Primack and Rodrigues 2001). Data on the breadth of distribution were obtained from records of the species found in the municipalities that are part of the Atlantic Forest domain of the PEC. Thus, 1 = wide distribution (present in > 80% of the territory); 2 = less broad (present in 50–80%); 3 = moderately restricted (present in 20–50%); 4 = restricted (present in <20%). We estimate the distribution area of the species through the minimum convex polygon (MCP) method.

2. Habitat breadth (HB): It is based on the principle that species that use more specialized form of habitats are more vulnerable to extinction because they tend to have less ability to withstand disturbances caused by human activities in their habitats (Purvis et al. 2000; Primack and Rodrigues 2001). This threat factor was motivated by the occurrence of species in five habitat types of the Atlantic Forest of the PEC (see

Pereira-Filho et al. 2017): brejos nordestinos, stational semidecidual forest (closed forest), stational semidecidual forest (tabuleiros or savannahs), mangrove, and restinga. 1 = generalist (found in at least four categories); 2 = less generalist (found in three categories); 3 = moderate specialist (found in two categories); 4 = specialist (found in only one category).

3. Endemicity (E): It is based on the principle that endemic species with a more restricted distribution may be especially vulnerable to extinction (Andreone and Luiselli 2000; Işik 2011; Tomović et al. 2015). The categories are: 1 = 0–10% of the species' distribution occurs in the PEC; 2 = >10 % of the species' distribution occurs in the PEC.

4. Rarity in the PEC (RR): It is based on the principle that small and isolated populations are more vulnerable to extinction because they suffer accelerated inbreeding, are subjected to more stochastic effects and genetic drift leading to loss of variability (Primack and Rodrigues 2001; Piratelli and Francisco 2013). Our rarity categories were created based on the percentage of the quantity of specimens (3149 records) found in the PEC. 1 = > 10% of total specimens; 2 = 6-10%; 3 = 2-6%; 4 = < 2%.

2.2.2 Ecological data

5. Dietary specialization (DS): It is based on the principle that species with a more specialist diet are more vulnerable to extinction due to the possibility of loss of prey or destruction of their prey's habitat caused by negative human interventions in their habitats (McKinney 1997; Purvis et al. 2000; Boyles and Storm 2007). The categories were created based on the level of taxonomic order of the prey and percentage of the main prey in the diet; 1 = generalist, main prey item < 30% of diet; 2 = low specialization, main prey 31–50% of diet; 3 = moderate specialization, main prey 51–70% of diet; 4 = highly specialized, main prey > 70% of diet.

6. Habitat use and activity period (HT): It is based on the principle that species that have more secretive habits like fossorial and cryptozoic tend to be less vulnerable to extinction, since they would be less seen by predators and less killed by human action (França and Araújo 2006). The categories are: 1 = fossorial species; 2 = species with nocturnal, cryptozoic, or aquatic activity; 3 = species with secretive diurnal activity; 4 = terrestrial species with diurnal activity.

7. Adaptability to altered environments (AH): It is based on the principle that species that are unable to tolerate man-altered environments tend to be more vulnerable to extinction because they are less able to

persist in place if such changes occur (Santos et al. 2007). This category was based on the presence/absence of species in protected areas of the Pernambuco Endemism Center: 1 = completely adapted (found even in urban environments); 2 = adapted (found in suburbs if there is natural environment nearby); 3 = less adapted (found in and near large natural environments); 4 = not adapted (found only within conservation units).

8. Direct anthropogenic effects on species conservation status (AE): Presence of direct anthropogenic effects can cause greater and faster reduction in the size of the local population (Tomović et al. 2015). The categories were based on the presence of the following direct anthropogenic effects: roadkill (based on monitoring of road-killed snakes in the Paraíba Atlantic Forest (unpublished data), literature data (Barros et al. 2016; Pereira-Filho et al. 2017) and information recorded in scientific collections), consumption of snakes as human food, for medicinal, magic/religious, ornamental or decorative purposes, pets, target species of conflict (species that are commonly killed when in contact with humans) (Alves and Pereira-Filho 2007; Alves et al. 2009; Pereira-Filho et al. 2017). The categories are: 1 = no effect; 2 = low effect (presence of one or two types of human impacts); 3 = medium effect (presence of three types of human impacts); 4 = high effect (presence of four or more types of human impacts) on the species.

2.2.3 Life-history data

9. Body size (BS): It is based on the principle that larger species tend to occur in a lower density, have larger home ranges, and reach sexual maturity late, therefore are more vulnerable when there are negative human interventions in their habitats (McKinney 1997; Purvis et al. 2000; Dulvy and Reynolds 2002). The categories are (Based on the average size of mature individuals): 1 = < 50 cm length; 2 = 51–100 cm length; 3 = 101–150 cm length; 4 = > 150 cm length.

10. Litter size (LS): Eggs or younglings; it is based on the principle that species with low fecundity are more vulnerable to extinction, because if this species suffers a large decrease in the size of its population, it would be more difficult to recuperate its original population size (Purvis et al. 2000; Dulvy and Reynolds 2002; Webb et al. 2002). The categories are: 1 = The maximum number of litters > 15; 2 = 11–15; 3 = 5–10; 4 = < 5.

11. Reproduction mode (RM): Viviparous species tend to produce fewer offspring than oviparous and are more prone to extinction risks (Andreone and Luiselli 2000). The categories are: 1 = oviparity; 2 = viviparity.

12. Frequency of reproduction (FR): A taxon that can reproduce throughout the year can recuperate more easily when habitats are altered. The categories are: 1 = aseasonal reproduction; 2 = seasonal reproduction.

2.3 Statistical procedures

To determine the relative threat levels for each species of snake, the mean scores for the 12 threat factors mentioned above were calculated. Before calculating the mean score, the scores for each variable were standardized to range from zero to one. Thus, values close to 1 indicate higher risks of threat, and those close to zero indicate low risks.

We used principal component analysis (PCA) and cluster analysis to evaluate how species are classified in terms of similarity to specific threats. The cluster analysis was performed using the UPGMA model, which results in an agglomerative hierarchical classification dendrogram. All analyzes were conducted using the software R, version 3.2.0.

To assess the relative threat level for each species within the community of snakes, we follow Tomović et al. (2015) and distribute the mean scores in five categories proposed by the IUCN. Thus, 40% of the lowest mean scores were considered of Least Concern (LC, 0–40%) and the remaining 60% were equally distributed among the four categories of threatened species: near threatened (NT, 41–55%); vulnerable (VU, 56–70%); endangered (EN, 71–85%) and critically endangered (CR, 86–100%).

The results obtained in this study for the Pernambuco Endemism Center snakes were compared with the results obtained by França and Araújo (2006) who used intrinsic and extrinsic factors to evaluate the vulnerability to extinction of the snakes occurring in central Brazil. For a better comparison with our results, we modified the results obtained by França and Araújo (2006) to fit the IUCN categories, following Tomović et al. (2015), as described in the previous paragraph. We also compare our results with pre-existing assessments that used the IUCN methodology in order to verify if the same species presents the same degree of vulnerability in different regions and between different methodologies. In this way, we use the red list of threatened species of the IUCN (IUCN 2019), the Brazilian red list of threatened species (ICMBio 2018), and five regional lists: red list of threatened species of the Pernambuco state (SEMAS 2017), red list of threatened species of the Bahia (SEMA 2017), the Rio Grande do Sul state (Decreto n°51.797/2014), and of the Espírito Santo state (Decreto nº1499-R).

3. Results

3.1 Comparison of mean scores and threat factors

In table 1 we present the scores for each species and each threat factor used to evaluate the vulnerability to extinction of the 78 snake species that were found in the Pernambuco Endemism Center (more details see supplementary material, Table 1). The mean values of the scores for all species varied between 0.28 (lower risk) and 0.72 (higher risk). The categories, criteria, and amplitude of the scores for the five categories proposed by IUCN (LC, NT, VU, EN, CR) are presented in table 2.

Our results indicate that only 29 species (37.1%) of snakes present no risk of decline, 13 species (16.6%) are considered near threatened, 22 (28.2%) are considered vulnerable, 9 (11.5%) species are considered endangered, and 5 species (6.4%) are considered critically endangered. *Helicops angulatus* and *Oxyrhopus trigeminus* had the lowest mean scores of 0.28, while *Caaeteboia sp*. and *Bothrops muriciensis* presented the highest mean scores of 0.72.

Threat factors related to species distribution contributed more to the mean scores of 40 species (*Amerotyphlops amoipira*, *A. arenensis*, *A. brongersmianus*, *A. paucisquamus*, *Apostolepis cearensis*, *A. longicaudata*, *Atractus caete*, *A. maculatus*, *A. potschi*, *Boiruna sertaneja*, *Bothrops bilineatus*, *B. erythromelas*, *B. muriciensis*, *Caaeteboia* sp., *Chironius carinatus*, *Dendrophidion atlantica*, *Dipsas sazimai*, *D. variegata*, *Drymarchon corais*, *Echinanthera cephalomaculata*, *Epicrates cenchria*, *Epictia borapeliotes*, *Erythrolamprus aesculapii*, *E. almadensis*, *E. miliaris*, *E. reginae*, *Helicops leopardinus*, *Hydrodynastes gigas*, *Liotyphlops trefauti*, *Micrurus corallinus*, *M. potyguara*, *Oxyrhopus petolarius*, *Philodryas patagoniensis*, *Psomophis joberti*, *Taeniophallus affinis*, *Thamnodynastes hypoconia*, *T. almae*, *T. phoenix*, *Xenopholis scalaris* and *X. undulatus*). The factors most related to ecology contributed more to the mean scores of 20 species *Chironius exoletus*, *Drymoluber dichrous*, *Leptophis ahaetulla*, *Palusophis bifossatus*, *Spilotes pullatus*, *Tantilla melanocephala*, *Dipsas mikanii*, *Erythrolamprus poecilogyrus*, *E. viridis*, *Helicops angulatus*, *Imantodes cenchoa*, *Oxyrhopus guibei*, *O. trigeminus*, *Philodryas nattereri*, *P. olfersii*, *Phimophis guerini*, *Pseudoboa nigra*, *Xenodon merremii*, *Crotalus durissus* and *Lachesis muta*) and the factors most related to natural history contributed more to the mean scores of 6 species (*Boa constrictor*, *Corallus hortulanus*, *Epicrates assisi*, *Taeniophallus occipitalis*, *Thamnodynastes pallidus* and *Bothrops leucurus*). For 9 species (*Chironius flavolineatus*, *Spilotes sulphureus*, *Dipsas neuwiedi*, *Echinanthera cephalostriata*, *Erythrolamprus taeniogaster*, *Leptodeira annulata*, *Lygophis dilepis*, *Siphlophis compressus*, *Xenodon rabdocephalus*), factors related to both distribution and ecology were the main contributors to the mean scores, while for two species (*Oxybelis aeneus, Micrurus ibiboboca*), factors related to both ecology and natural history were the main contributors and for *Sibon nebulatus* the factors related to both distribution and natural history were the main contributors (Fig. 1).

3.2 Principal component analysis and cluster analysis

We used PCA to classify the snake species that occur in the Pernambuco Endemism Center into groups of threat to specific factors; however, these groups are not easily visualized in the graph of the analysis (Fig. 2), and so it was combined with the cluster analysis.

The values of the variables for the first three main components are presented in table 3. The first two axes explained 49% of the variation in the data. The variables most significantly associated with the main component 1 were the Distribution breadth and Habitat breadth, which were positively related, and the Direct anthropogenic effects on species conservation status, which was negatively related. The variables most significantly associated with the main component 2 were frequency of reproduction and reproduction mode, both negatively related.

We used PCA and cluster analysis to distinguish 16 groups of snake species in the Pernambuco Endemism Center (Fig. 3). Of these, five groups were considered non-threatened and 8 groups were considered threatened. All information about natural history, distribution, and other threat factors refer to the data obtained for PEC snakes. The groups are described below.

Group 1= Endemic species, rare in the PEC, with specialist diet, with a small body size, fossorial or cryptozoic species, oviparous, and with seasonal reproduction (Threatened). *Liotyphlops trefauti*, *Atractus caete*, *Atractus maculatus*, *Micrurus potyguara*, *Epictia borapeliotes*, *Amerotyphlops arenensis*, *Amerotyphlops paucisquamus*.

Group 2= Species with restricted distribution, specialists in habitat use, endemic, rare in the PEC, with specialist diet, with a small body size, terrestrial species with diurnal activity, oviparous, and with seasonal reproduction (Threatened). *Caaeteboia* sp., *Echinanthera cephalomaculata*.

Group 3= Specialists species in habitat use, endemic, rare in the PEC, with specialist diet, not adapted to altered environments, oviparous, and with aseasonal reproduction (Threatened). *Dendrophidion atlantica*.

Group 4= Species with restricted distribution, non-endemic, oviparous, and with seasonal reproduction (Non-threatened and Threatened). *Philodryas patagoniensis*, *Psomophis joberti*.

Group 5= Species with restricted distribution, non-endemic, rare in the PEC, with a large body size, produce large numbers of offspring, oviparous, and with seasonal reproduction (Threatened). *Hydrodynastes gigas*.

Group 6= Non-endemic species, rare in the PEC, little affected by direct anthropogenic effects, oviparous, and with seasonal reproduction. (Non-threatened and Threatened). *Chironius exoletus*, *Oxybelis aeneus*, *Palusophis bifossatus*, *Atractus potschi*, *Dipsas mikanii*, *D. neuwiedi*, *Echinanthera cephalostriata*, *Sibon nebulatus*, *Siphlophis compressus*, *Taeniophallus affinis*, *T. occipitalis*, *Xenopholis scalaris*, *Micrurus corallinus*, *Amerotyphlops amoipira*, *A. brongersmianus*.

Group 7= Non-endemic species, rare in the PEC, with specialist diet, with a large body size, oviparous, and with seasonal reproduction (Threatened). *Spilotes pullatus*, *Boiruna sertaneja*, *Lachesis muta*.

Group 8= Non-endemic species, with a small body size, fossorial species, oviparous, and with aseasonal reproduction (Not Threatened). *Apostolepis cearensis, Tantilla melanocephala*.

Group 9= Non-endemic species, little affected by direct anthropogenic effects, oviparous, and with aseasonal reproduction (Non-threatened and Threatened). *Apostolepis longicaudata*, *Chironius carinatus*, *C. flavolineatus*, *Dipsas sazimai*, *D. variegata*, *Drymoluber dichrous, Erythrolamprus aesculapii*, *E. almadensis*, *E. miliaris, E. reginae*, *E. taeniogaster*, *E. viridis, Helicops angulatus*, *Imantodes cenchoa*, *Leptodeira annulata*, *Leptophis ahaetulla*, *Lygophis dilepis*, *Oxyrhopus guibei*, *O. petolarius*, *Phimophis guerini*, *Pseudoboa nigra*, *Spilotes sulphureus*, *Xenodon rabdocephalus*, *Xenopholis undulatus*.

Group 10= Species with wide distribution, generalists in habitat use, non-endemic, adapted to altered environments, oviparous and with aseasonal reproduction (Non-threatened). *Erythrolamprus poecilogyrus*, *Oxyrhopus trigeminus*, *Philodryas nattereri*.

Group 11= Species with wide distribution, generalists in habitat use, non-endemic, adapted to altered environments, oviparous and with seasonal reproduction (Non-threatened). *Micrurus ibiboboca*, *Philodryas olfersii*, *Xenodon merremii*.

Group 12= Non-endemic species, rare in the PEC, with generalist diet, with large body size, oviparous, and with aseasonal reproduction (Not Threatened). *Drymarchon corais.*

Group 13= Species with wide distribution, non-endemic, rare in the PEC, produce large numbers of offspring, viviparous, and with seasonal reproduction (Threatened). *Boa constrictor*, *Corallus hortulanus*, *Crotalus durissus*, *Epicrates assisi*.

Group 14= Non-endemic species, generalists in habitat use, with generalist diet, little affected by direct anthropogenic effects, adapted to altered environments, viviparous, and with seasonal reproduction (Not Threatened). *Bothrops leucurus*.

Group 15= Species with restricted distribution in the PEC, specialists in habitat use, non-endemic, rare in the PEC, little affected by direct anthropogenic effects, viviparous, and with seasonal reproduction (Threatened). *Bothrops bilineatus*, *B. erythromelas*, *Epicrates cenchria*, *Helicops leopardinus*, *Thamnodynastes hypoconia*, *T. almae*, *T. pallidus*, *T. phoenix*.

Group 16= Species with restricted distribution in the PEC, specialists in habitat use, endemic, rare in the PEC, not adapted to altered environments, and viviparous (Threatened). *Bothrops muriciensis*.

3.3 Vulnerability to extinction: Comparison with pre-existing assessments

Of the 78 species found in the PEC, 29 species are also found in Central Brazil where the Cerrado Biome is present (Table 4). The species *Erythrolamprus poecilogyrus, Philodryas nattereri, P. olfersii, P. patagoniensis* and *Xenodon merremii* were considered least concern in both localities, whereas *Crotalus durissus, Erythrolamprus aesculapii* and *Palusophis bifossatus* were considered vulnerable for both localities. The species *Chironius exoletus* and *Oxybelis aeneus* are in the categories of threatened species in both localities, but at different levels of threat (Table 4), whereas the species *Chironius flavolineatus, Dipsas mikanii, Drymarchon corais, Leptodeira annulata, Oxyrhopus guibei, Taeniophallus occipitalis* and *Tantilla melanocephala* considered as least concern in the PEC, were considered vulnerable for Central Brazil; the species *Erythrolamprus almadensis*, *Helicops angulatus, Oxyrhopus trigeminus, Phimophis guerini, Pseudoboa nigra* and *Xenopholis undulatus* considered as least concern in the PEC, were considered threatened for Central Brazil.

Fifty species that occur in the PEC are listed in the IUCN, all are classified as least concern, except *Liotyphlops trefauti* which is classified as Data Deficient. In the Brazilian list of threatened species, the species *Atractus maculatus, Atractus potschi, Dendrophidion atlantica*, *Liotyphlops trefauti* and *Micrurus ibiboboca* are classified as data deficient, whereas the species *Amerotyphlops amoipira*, *Atractus caete* and *Bothrops muriciensis* and *Echinanthera cephalomaculata* are in the threatened species category, as well as in the PEC (Table 4).

Among the regional red lists of threatened species compared here (Pernambuco, Bahia, Rio Grande do Sul, and Espírito Santo states) the one from Pernambuco state, which a part of the state is inserted in the PEC, presented some similarities and differences in the degree of vulnerability of the species when compared with the PEC. The species *Apostolepis cearensis, Bothrops leucurus, Chironius flavolineatus*, *Drymarchon corais*, *Leptophis ahaetulla*, *Erythrolamprus almadensis*, *E. miliaris*, *E. poecilogyrus*, *E. taeniogaster*, *E. viridis*, *Helicops angulatus*, *Imantodes cenchoa*, *Leptodeira annulata*, *Oxyrhopus guibei, O. petolarius, O. trigeminus, Philodryas nattereri, P. olfersii, P. patagoniensis, Pseudoboa nigra*, *Taeniophallus occipitalis, Tantilla melanocephala* and *Xenodon merremii* were considered least concern on both lists. The species *Bothrops bilineatus*, *Dipsas sazimai*, *Erythrolamprus reginae, Siphlophis compressus*, *Xenopholis scalaris* and *Lachesis muta* are in the endangered species category on both lists. However, the species *Amerotyphlops brongersmianus, Atractus maculatus, A. potschi, Boa constrictor*, *Boiruna sertaneja*, *Bothrops erythromelas*, *Chironius carinatus*, *C. exoletus*, *Corallus hortulanus, Crotalus durissus, Dipsas neuwiedi, D. variegata*, *Epicrates assisi*, *E. cenchria*, *Epictia borapeliotes*, *Helicops leopardinus*, *Lygophis dilepis*, *Oxybelis aeneus*, *Palusophis bifossatus*, *Spilotes pullatus*, *Thamnodynastes almae* and *T. Pallidus* considered as least concern in the Pernambuco, are in the categories of threatened species in the PEC.

In the list of threatened species from Bahia we can find the species *Dipsas sazimai*, *Echinanthera cephalomaculata*, *Thamnodynastes almae* and *Amerotyphlops amoipira* which are also in the PEC threatened species category. The species *Hydrodynastes gigas* considered vulnerable for the state of Rio Grande do Sul, was considered near threatened in the PEC. Finally, *Lachesis muta* and *Bothrops bilineatus* which is vulnerable in the state of Espírito Santo, Pernambuco, and Bahia, was found to be endangered and vulnerable respectively in the present study. Although the faunas of Rio Grande do Sul and Espírito Santo states share few similar species with PEC, some species of the genus *Corallus*, *Apostolepis*, and *Bothrops* that were considered threatened in the PEC were also considered threatened in these other lists.

4. Discussion

The authors Filippi and Luiselli (2000) proposed that the factors related to geographic distribution are the most important threats to the Italian snake fauna; however, factors related to the natural history of the species could also be influencing the viability of some species. For the Cerrado of Central Brazil (França and Araújo 2006), the results indicated that both factors related to the geographical distribution as well as to the natural history of the species may affect the viability of snake populations. However, for Serbian snakes (Tomović et al. 2015), the factors related to the natural history of the species contributed more to the conservation scores of the species. As for PEC snakes and for Filippi and Luiselli (2000), the results indicate that factors related to species distribution (1–4) contribute more to the threat scores of snake species.

Our results indicate that most of the species found in the PEC have a restricted distribution, are rare, and show specialist diets, which are three factors that increase the vulnerability of species. Over the years, forest cover in the PEC region has been drastically reduced due mainly being a consequence of economic cycles such as the Brazilwood, the cattle cycle and the sugar cane cycle (Coimbra-Filho and Câmara 1996). Therefore, only small forest fragments remain in the region immersed in urban and agricultural matrices (Silva and Tabarelli 2000), which often are not large enough to allow the survival of some animal populations (See Silva Jr and Pontes 2008; Canale et al. 2012). Thus, even species that present a very wide distribution, such as *Lachesis muta*, which occur throughout half of the Atlantic Forest and the Amazon, but only in large and well preserved areas (Campbell and Lamar 2004; Pereira-Filho et al. 2017), could become locally or regionally extinct in the PEC.

Studies have shown that species with specialist diets should be more vulnerable to extinction than generalists due to the possibility of loss of prey or destruction of their prey’s habitat (Boyles and Storm 2007). The diet factor has presented high values of vulnerability for snakes in different regions, such as PEC, in the Cerrado of Central Brazil (França and Araújo 2006), and for Italian snakes (Filippi and Luiselli 2000), suggesting that this factor should be analyzed carefully to verify the threat levels of snake species. When comparing the groups of species formed by the PCA in the present study with those of França and Araújo (2006), it was possible to observe both similar and different results among some groups. The species of the Boidae family are vulnerable or threatened in the PEC and Cerrado, due mainly to their large size and by being significantly affected by direct anthropogenic effects, whereas contradictory results were observed among the Viperidae family. The viperids found in the PEC are mainly threatened by having small populations and being rare, while in the Cerrado most species of this family are widely distributed and have large populations, reflecting low vulnerability.

Out of 29 species shared by PEC and the Cerrado (França and Araújo 2006), the species *Crotalus durissus, Erythrolamprus aesculapii, E. poecilogyrus, Philodryas nattereri, P. olfersii, P. patagoniensis*, *Xenodon merremii* showed similar results in their degree of vulnerability. In addition, some other (*Chironius exoletus* and *Oxybelis aeneus*) are considered threatened in both localities, but at different levels. These results indicate that some species are subject to similar threats even in different Biomes. For example, the species *Chironius exoletus* is rare species, with restricted distribution, and low adaptability to live in altered environments in both regions, while the conservation status of the species *Crotalus durissus* is greatly affected by direct anthropogenic effects in both regions. Additionally, the comparison of the conservation status of the species in such dissimilar habitats and by means of different methodologies but which present similar results, shows that some species, which maintain degrees of vulnerability/threat in the different biomes, should be evaluated more carefully.

The species *Caaeteboia* sp. presented the highest vulnerability index for the Pernambuco Endemism Center (0.72), being considered critically endangered. The distribution of the genus *Caaeteboia* is known for the states of Bahia, Minas Gerais, São Paulo, Paraná, and Santa Catarina, being considered rare. The species *Caaeteboia amarali*, at present, is the only representative of the genus and is underrepresented in herpetological collections, and until 2012 there were no more than 15 specimens registered in collections (Passos et al. 2012). In the red list of threatened species, this snake was considered endangered in the state of Bahia (SEMA 2017) and Santa Catarina (CONSEMA 2011), data deficient in São Paulo (Decreto_nº63.853 2018) and Paraná (Mikich and Bérnils 2004). The species found in the PEC differs from *C. amarali* mainly because it presents 15 rows of dorsal scales without reduction, while *C. amarali* presents 17 rows of dorsal scales without reduction. In addition, there is a strong variation between the number of ventral and subcaudal scales between the two species (Pereira-Filho et al. 2017). In our study, *Caaeteboia* sp. was considered threatened, mainly because it is a rare species (only 3 known specimens), specialized in habitat and diet, and has not been found in altered environments. According to Marques et al. (2009), the main threats to *C. amarali* in the state of São Paulo come mainly from the destruction and alteration of its habitat due to the occupation of housing and other tourist developments along the whole coast.

The results of our studies indicate that the species *Bothrops muriciensis* is critically endangered in the PEC (vulnerability index 0.72), mainly because it has a restricted distribution in the PEC, it is endemic and rare. This species is found only in Estação Ecológica de Murici, a conservation unit with 6,131.63 hectares located in the state of Alagoas. *B. muriciensis* presents only nine records since its description in 2001, and there is still a large gap of knowledge about its ecology and population dynamics, which makes it difficult to assess its conservation status (Freitas et al. 2012). *B. muriciensis* is on the Brazilian list of threatened species, being in the endangered category (ICMBio 2018).

Another species that presented a high vulnerability index (0.67) is *Dendrophidion atlantica*. This species is considered critically endangered in the region mainly because it is endemic, rare and has low adaptability to live in altered environments. Until recently, *D. atlantica* was known only for the Atlantic Forest of the state of Alagoas, but recent studies have registered this species in the states of Pernambuco (Nacimento and Santos 2016; Barbosa et al. 2019) and Paraíba (Pereira-Filho et al. 2017). Few specimens are known yet for this species and there is a knowledge gap on basic information of ecology and population dynamics. So far this species is found as deficient data in the Brazilian list of threatened (ICMBio 2018) species and in the list of threatened species of the state of Pernambuco (SEMAS 2017).

The species *Atractus caete* also had a high vulnerability index in the PEC (0.67), being considered critically endangered in the region, mainly because it has a restricted distribution, is endemic and is rare in the PEC. This species was described in 2010, based on an adult female collected in 1986 and a second specimen was photographed in 2008, both in the state of Alagoas. According to Passos et al. (2010) this species may occur in small remnants of Submontana Forest with altude varying between 300 and 500 meters, but the knowledge about the species is based only on its description. *A. caete* is on the Brazilian red list of threatened species, being in the endangered category (ICMBio 2018).

The species *Echinanthera cephalomaculata* presented a high vulnerability index in the PEC (0.67), being also considered critically endangered for the region, mainly because it has a restricted distribution, is endemic and is rare. Until recently, only two specimens collected in the 90's were known in the state of Alagoas , but in 2015 two individuals were registered in the same conservation unit (Reserva Biológica de Pedra Talhada) (Roberto et al. 2015) and more recently three specimens were observed in the state of Pernambuco (Freitas et al. 2019). *E. cephalomaculata* is on the Brazilian red list of threatened species, being in the vulnerable category (ICMBio 2018).

In addition to the species mentioned above, other species obtained a high vulnerability index in the PEC, for exemple the espécies *Lachesis muta* (EN), *Spilotes pullatus* (EN) *Epicrates assisi* (VU) and *Crotalus durissus* (VU). These species had vulnerability to extinction index greatly influenced by direct anthropogenic effects, such as roadkill, consumption as a human food, and use of the species for medicinal, magic/religious, ornamental or decorative purposes. These factors need attention due to their uniqueness and growth in the last decades (Pereira-Filho et al. 2017). For example, it is known that the skin and the rattle of *Crotalus durissus* (Rattlesnake) have been registered in magical/religious rituals, being frequently associated with Afro-Brazilian religions (Alves et al. 2012). Products such as the rattle are often found in markets or stores specializing in religious mystical articles, and are mainly sought after by followers of Afro-Brazilian cults (Pereira-Filho et al. 2017). In addition, the species is used in folk medicine where parts of the body such as skin, tail, cloaca, rattle, and its fat are used in the treatment of various diseases, such as asthma, thrombosis, rheumatism, skin diseases, tuberculosis, hanseniasis, and osteoporosis (Alves et al. 2009). The use of part of the body of this species has also been recorded in practices for ornamental and decorative purposes in the Paraíba state. For example, rattlesnakes are commonly used in the manufacture of keyrings by some hunters and their skin can be used in belt manufacturing (Mendonça et al. 2014). Another direct anthropogenic effect, the impact on wild animal species due to roadkill, has been receiving the attention of researchers worldwide (Trombulak and Frissell 2000). Among the studies that address this theme in Brazil, some have shown that the records of road-killed snakes are quite common (Turci and Bernarde 2009; Santos et al. 2012). In addition, studies show the existence of the practice of intentional roadkill, and explain that people generally try to kill snakes, especially for the belief that they are dangerous and pose a threat to human life (Secco et al. 2014). Even in species that present periods of nocturnal activities where car traffic would be less intense, such as *Epicrates assisi*, *Oxyrhopus trigeminus*, and *Micrurus potyguara*, the rate of road-killed animals is high on roads in the state of Paraíba. This threat factor, as well as others used here, are not included in the IUCN criteria for extinction risk assessments (IUCN 2019) and their inclusion deserves to be assessed.

One of the main objectives of conservation biology is to understand the ecological mechanisms that make some species more vulnerable to decline than others (Caughley 1994). This information allows researchers to predict the vulnerability to extinction of species before they even decline, thus improving the chances of a species survival. Our results indicate that only 37% of snake species in the Pernambuco Endemism Center have no risk of decline and revealed some patterns that can help to direct the conservation efforts of this fauna. In general, the snakes of the PEC have restricted distribution, are rare and show diet specialization. The fact that we have obtained some results similar to those in the red list of threatened species using a different method indicates that similar results can be obtained using different approaches (e.g., data related to natural history and species ecology). However, some species with high vulnerability indexes in the present study are not present in the pre-existing red lists. We emphasize that some species that have been considered threatened in the present study are also found in other ecologically dissimilar areas (such as *Epicrates cenchria*, *Oxybelis aeneus*, *Palusophis bifossatus*, *Erythrolamprus aesculapii*, *Chironius exoletus*, *Crotalus durissus*, *Spilotes pullatus*, and *Thamnodynastes hypoconia*) and which are found as least concern or data deficient in the lists of threatened species, deserve to be evaluated more carefully in the future.

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Figure captions

Fig. 1 Mean scores for the distribution, ecology, and life-history data contributing to extinction risk of the Pernambuco Endemism Center Snakes

Fig. 2 Scores of threat factors for the main components of the snake species of the Pernambuco Endemism Center (PEC), showing some threatened groups. Abbreviations are: DB= Distribution breadth; HB= Habitat breadth; E= Endemicity; RR= Rarity in the PEC; DS= Dietary specialization; HT= Habitat use and activity period; AH= Adaptability to altered environments; AE= Direct anthropogenic effects on species conservation status; BS= Body size; LS= Litter size; RM= Reproduction mode; FR= Frequency of reproduction; Ama=*Amerotyphlops amoipira*; Amb=*A. brongersmianus*; Amp=*A. paucisquamus*; Apc=*Apostolepis cearensis*; Apl=*A. longicaudata*; Are=*A. arenensis*; Atc=*Atractus caete*; Atm=*A.*

maculatus; Atp=*A. potschi*; Bob=*Bothrops bilineatus*; Boc=*Boa constrictor*; Boe=*B. erythromelas*; Bol=*B. leucurus*; Bom=*B. muriciensis*; Bos=*Boiruna sertaneja*; Cas=*Caaeteboia* sp.; Chc=*Chironius carinatus*; Che=*C. exoletus*; Chf=*C. flavolineatus*; Coh=*Corallus hortulanus*; Crd=*Crotalus durissus*; Dea=*Dendrophidion atlantica*; Dim=*Dipsas mikanii*; Din=*D. neuwiedi*; Dis=*D. sazimai*; Div=*D. variegata*; Drc=*Drymarchon corais*; Drd=*Drymoluber dichrous*; Ecc=*Echinanthera cephalomaculata*; Ece=*E. cephalostriata*; Epa=*Epicrates assisi*; Epb=*Epictia borapeliotes*; Epc=*E.* cenchria; Era=*Erythrolamprus aesculapii*; Erl=*E. almadensis*; Erm=*E. miliaris*; Erp=*E. poecilogyrus*; Err=*E. reginae*; Ert=*E. taeniogaster*; Hea=*Helicops angulatus*; Hel=*H. leopardinus*; Hyg=*Hydrodynastes gigas*; Imc=*Imantodes cenchoa*; Lam=*Lachesis muta*; Lea=*Leptodeira annulata*; Leh=*Leptophis ahaetulla*; Lit=*Liotyphlops trefauti*; Lyd=*Lygophis dilepis*; Mic=*Micrurus corallinus*; Mii=*M. ibiboboca*; Mip=*M. potyguara*; Oxa=*Oxybelis aeneus*; Oxg=*Oxyrhopus guibei*; Oxp=*Oxyrhopus petolarius*; Oxt=*Oxyrhopus trigeminus*; Pab=*Palusophis bifossatus*; Phg=*Phimophis guerini*; Phn=*Philodryas nattereri*; Pho=*P. olfersii*; Php=*Philodryas patagoniensis*; Psj=*Psomophis joberti*; Psn=*Pseudoboa nigra*; Sic=*Siphlophis compressus*; Sin=*Sibon nebulatus*; Spp=*Spilotes pullatus*; Sps=*S. sulphureus*; Taa=*Taeniophallus affinis*; Tam=*Tantilla melanocephala*; Tao=*T. occipitalis*; Tha=*Thamnodynastes almae*; Thh=*T. hypoconia*; Thp=*T. pallidus*; Tph=*T. phoenix*; Ver=*E. viridis*; Xem=*Xenodon merremii*; Xen=*X. rabdocephalus*; Xes=*Xenopholis scalaris*; Xeu=*X. undulatus*.

Fig. 3 Cluster diagram showing the similarity groups for threatening factors among seventy-eight snake species of Pernambuco Endemism Center. Diamond indicates the point in cluster diagram where significance is achieved. Numbers to the right of species indicate the groups. The abbreviations are the same as those used in figure 2.

Figures

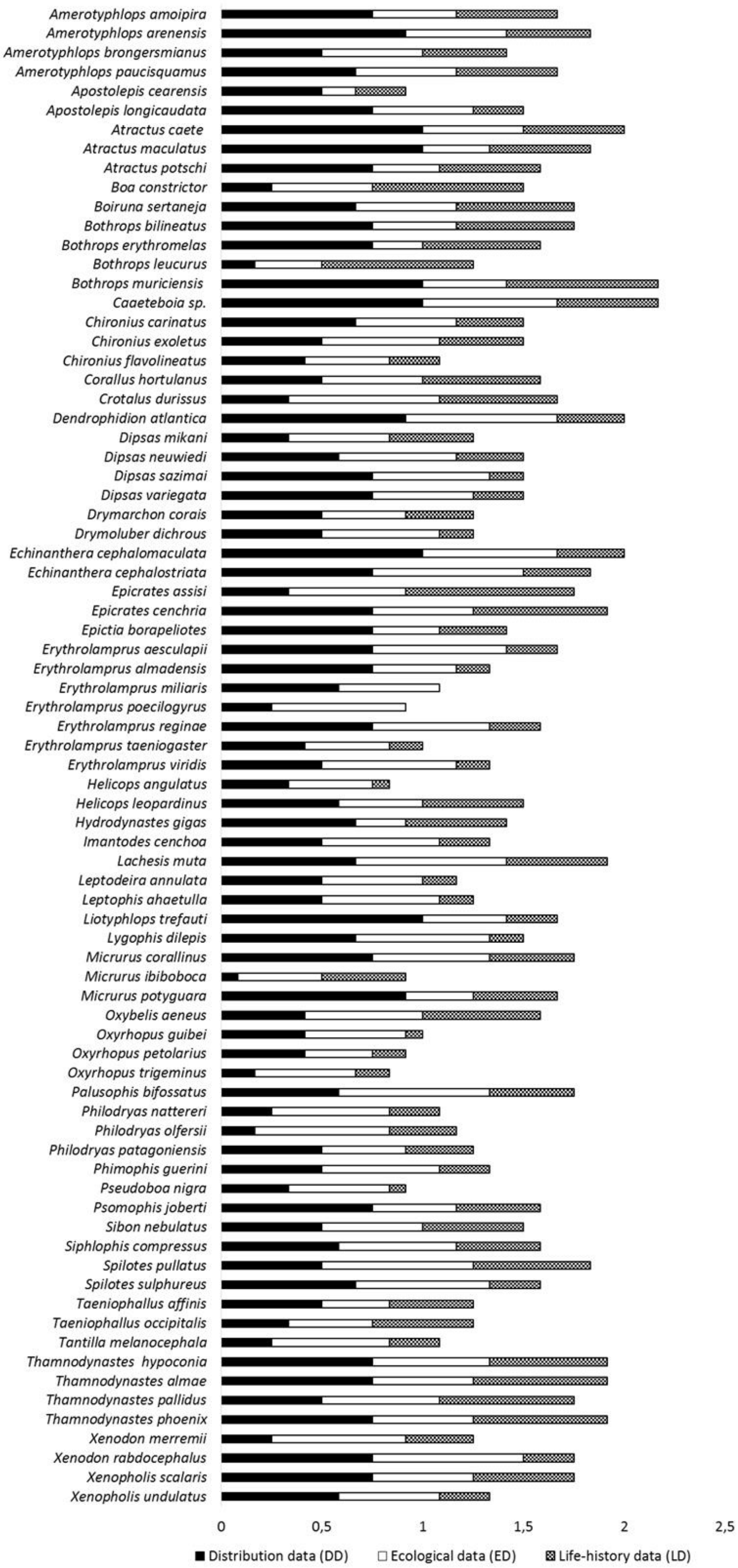

Fig. 1

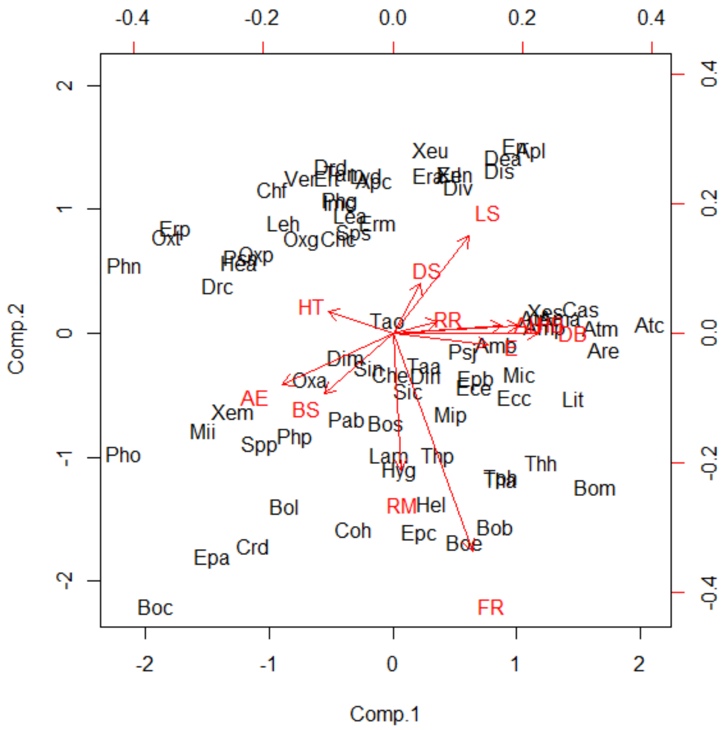
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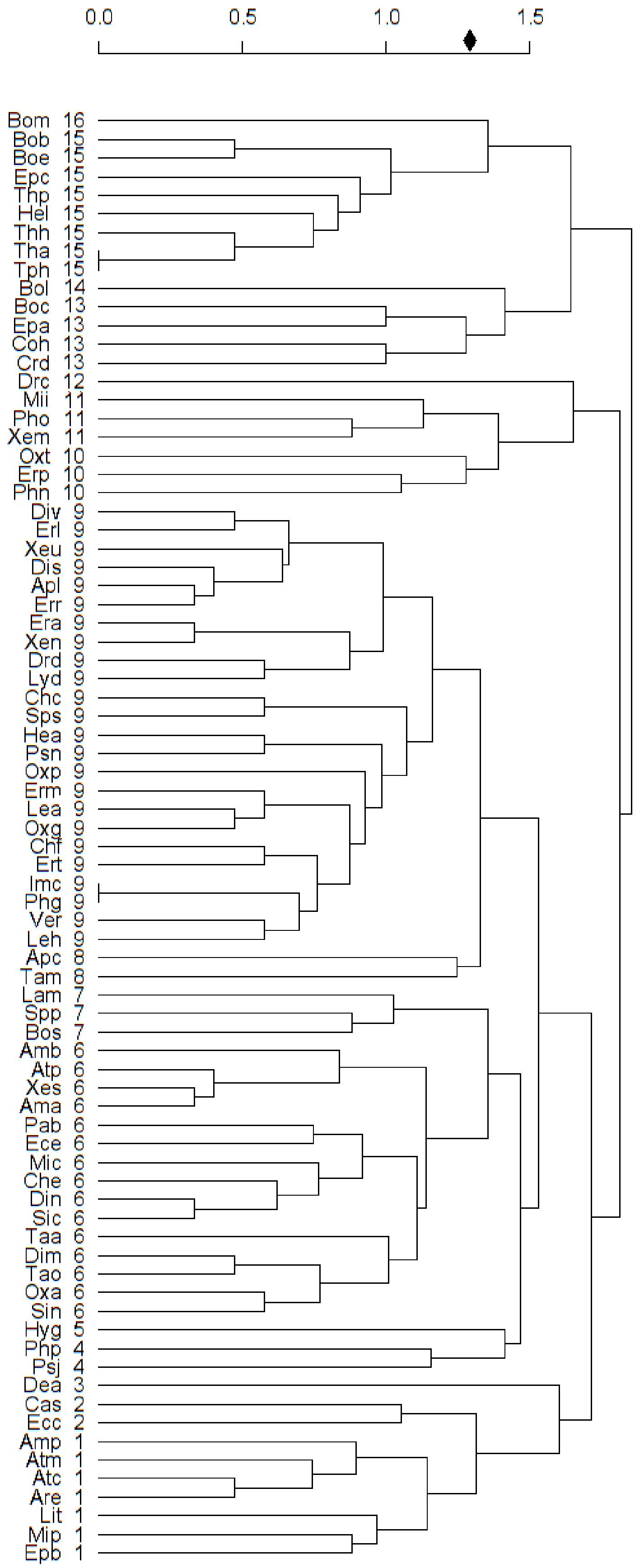
Fig. 2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Era 9
Xen 9
Drd 9
Lyd 9
Chc 9
Sps 9
Hea 9
Psn 9
Oxp 9
Erm 9
Lea 9
Oxg 9
Chf 9
Ert 9
Imc 9
Phg 9
Ver 9
Leh 9
Apc 8
Tam 8
Lam 7
Spp 7
Bos 7
Amb 6
Atp 6
Xes 6
Ama 6
Pab 6
Ece 6
Mic 6
Che 6
Din 6
Sic 6
Taa 6
Dim 6
Tao 6
Oxa 6
Sin 6
Hyg 5
Php 4
Psj 4
Dea 3
Cas 2
Ecc 2
Amp 1
Atm 1
Atc 1
Are 1
Lit 1
Mip 1
Epb 1

Fig. 3

Table 1 Values for the 12 threat factors that may affect the survival of snakes of the Pernambuco Endemism Center. The abbreviations are: Distribution breadth (DB); Habitat breadth (HB); Endemicity (E); Rarity in the Paraíba Atlantic Forest (RR); Dietary specialization (DS); Habitat use and activity period (HT); Adaptability to altered environments (AH); Direct anthropogenic effects on species conservation status (AE); Body size (BS); Litter size (LS); Reproduction mode (RM); Frequency of reproduction (FR). The values in bold and italics were inferred from known information for very close species phylogenetically

	Distribution				**Ecological data**				**Life-history data**				
Família/Species	**DB**	**HB**	**E**	**RR**	**DS**	**HT**	**AH**	**AE**	**BS**	**LS**	**RM**	**FR**	**Mean score**
Anomalepididae													
Liotyphlops trefauti	4	4	2	4	4	1	3	1	1	***1***	1	2	0,56
Boidae													
Boa constrictor	1	1	1	4	2	2	2	4	4	1	2	2	0,5
Corallus hortulanus	1	4	1	4	3	2	3	2	2	1	2	2	0.53
Epicrates assisi	2	2	1	3	4	2	1	4	4	2	2	2	0.58
Epicrates cenchria	4	4	1	4	4	2	2	2	3	1	2	2	0.64
Colubridae													
Chironius carinatus	3	4	1	4	4	3	2	1	4	2	1	1	0.5
Chironius exoletus	3	2	1	4	4	3	3	1	2	2	1	2	0.5
Chironius flavolineatus	2	2	1	4	4	3	1	1	2	3	1	1	0.36
Dendrophidion atlantica	3	4	2	4	***4***	4	4	1	2	4	1	***1***	0.67
Drymarchon corais	2	3	1	4	1	4	2	2	4	2	1	1	0.42
Drymoluber dichrous	3	2	1	4	4	4	2	1	1	3	1	1	0.42
Leptophis ahaetulla	2	3	1	4	4	3	2	2	2	2	1	1	0.42
Oxybelis aeneus	2	2	1	4	4	3	2	2	3	3	1	2	0.53
Palusophis bifossatus	3	3	1	4	4	4	3	2	3	1	1	2	0.58
Spilotes pullatus	3	2	1	4	4	3	2	4	4	2	1	2	0.61
Spilotes sulphureus	3	4	1	4	4	3	3	2	3	2	1	1	0.53
Tantilla melanocephala	2	1	1	3	4	1	4	2	1	4	1	1	0.36
Dipsadidae													
Apostolepis cearensis	2	3	1	4	2	1	2	1	1	***4***	1	***1***	0.31
Apostolepis longicaudata	4	4	1	4	4	1	4	1	1	4	1	***1***	0.5
Atractus caete	4	4	2	4	4	1	4	1	1	***4***	1	***2***	0.67
Atractus maculatus	4	4	2	4	4	1	2	1	1	***4***	1	***2***	0.61
Atractus potschi	4	4	1	4	4	1	2	1	1	***4***	1	2	0.53
Boiruna sertaneja	4	3	1	4	4	2	2	2	4	2	1	2	0.58
Caaeteboia sp.	4	4	2	4	4	4	3	1	1	***4***	1	***2***	0.72
Dipsas mikanii	2	2	1	3	4	2	2	2	1	3	1	2	0.42
Dipsas neuwiedi	3	3	1	4	4	2	3	2	1	2	1	2	0.5
Dipsas sazimai	4	4	1	4	4	2	4	1	1	3	1	***1***	0.5
Dipsas variegata	4	4	1	4	4	2	3	1	2	***3***	1	1	0.5

	Distribution				Ecological data				Life-history data				
Família/Species	**DB**	**HB**	**E**	**RR**	**DS**	**HT**	**AH**	**AE**	**BS**	**LS**	**RM**	**FR**	**Mean score**
Echinanthera cephalomaculata	4	4	2	4	4	4	3	1	2	***1***	1	***2***	0.67
Echinanthera cephalostriata	4	4	1	4	4	4	4	1	2	***1***	1	***2***	0.61
Erythrolamprus aesculapii	4	4	1	4	4	4	3	1	2	3	1	1	0.56
Erythrolamprus almadensis	4	4	1	4	4	2	2	1	1	3	1	***1***	0.44
Erythrolamprus miliaris	3	3	1	4	4	2	3	1	1	1	1	1	0.36
Erythrolamprus poecilogyrus	1	1	1	4	4	4	2	2	1	1	1	1	0.31
Erythrolamprus reginae	4	4	1	4	4	2	4	1	1	4	1	1	0.53
Erythrolamprus taeniogaster	2	2	1	4	4	2	2	1	1	3	1	1	0.33
Erythrolamprus viridis	2	3	1	4	4	4	2	2	1	3	1	1	0.44
Helicops angulatus	3	2	1	2	4	2	1	2	2	1	1	1	0.28
Helicops leopardinus	3	3	1	4	3	2	3	1	1	1	2	2	0.5
Hydrodynastes gigas	4	3	1	4	1	2	3	1	4	1	1	2	0.47
Imantodes cenchoa	2	3	1	4	4	2	3	2	2	3	1	1	0.44
Leptodeira annulata	3	2	1	4	4	2	3	1	2	2	1	1	0.39
Lygophis dilepis	4	3	1	4	4	4	2	2	1	3	1	1	0.5
Oxyrhopus guibei	2	2	1	4	4	2	3	1	2	1	1	1	0.33
Oxyrhopus petolarius	2	2	1	4	2	2	2	2	2	2	1	1	0.31
Oxyrhopus trigeminus	1	2	1	2	3	2	1	4	1	3	1	1	0.28
Philodryas nattereri	1	2	1	3	3	4	1	3	3	2	1	1	0.36
Philodryas olfersii	1	1	1	3	3	4	1	4	2	1	1	2	0.39
Philodryas patagoniensis	4	2	1	3	2	4	1	2	2	1	1	2	0.42
Phimophis guerini	2	3	1	4	4	2	3	2	2	3	1	***1***	0.44
Pseudoboa nigra	2	2	1	3	4	2	2	2	2	1	1	1	0.31
Psomophis joberti	4	4	1	4	2	4	2	1	1	3	1	2	0.53
Sibon nebulatus	2	3	1	4	4	2	2	2	2	3	1	***2***	0.5
Siphlophis compressus	3	3	1	4	4	2	3	2	2	2	1	2	0.53
Taeniophallus affinis	3	2	1	4	2	2	3	1	1	3	1	2	0.42
Taeniophallus occipitalis	2	2	1	3	4	2	2	1	1	4	1	2	0.42
Thamnodynastes hypoconia	4	4	1	4	4	2	4	1	1	2	2	2	0.64
Thamnodynastes almae	4	4	1	4	***4***	2	3	1	2	***2***	2	***2***	0.64
Thamnodynastes pallidus	3	3	1	3	4	2	3	2	1	3	2	2	0,58
Thamnodynastes phoenix	4	4	1	4	4	2	3	1	2	***2***	2	***2***	0.64
Xenodon merremii	1	2	1	3	4	4	2	2	2	1	1	2	0.42
Xenodon rabdocephalus	4	4	1	4	4	4	4	1	2	3	1	1	0.58
Xenopholis scalaris	4	4	1	4	4	2	3	1	1	4	1	2	0.58
Xenopholis undulatus	3	3	1	4	4	2	3	1	1	4	1	1	0.44
Elapidae													
Micrurus corallinus	4	4	1	4	4	2	4	1	2	2	1	2	0.58
Micrurus ibiboboca	1	2	1	1	3	2	1	3	2	2	1	2	0.31
Micrurus potyguara	4	3	2	4	***3***	2	1	2	2	***2***	1	2	0.56
Leptotyphlopidae													
Epictia borapeliotes	3	2	2	4	4	1	2	1	1	***2***	1	***2***	0.47

	Distribution				Ecological data				Life-history data				
Família/Species	**DB**	**HB**	**E**	**RR**	**DS**	**HT**	**AH**	**AE**	**BS**	**LS**	**RM**	**FR**	**Mean score**
Typhlopidae													
Amerotyphlops amoipira	4	4	1	4	4	1	3	1	1	***4***	1	***2***	0.56
Amerotyphlops arenensis	4	3	2	4	4	1	4	1	1	3	1	***2***	0.61
Amerotyphlops brongersmianus	3	3	1	3	4	1	4	1	1	3	1	2	0.47
Amerotyphlops paucisquamus	2	3	2	3	4	1	4	1	1	4	1	***2***	0.56
Viperidae													
Bothrops bilineatus	4	4	1	4	2	2	4	1	2	1	2	***2***	0.58
Bothrops erythromelas	4	4	1	4	1	2	3	1	2	1	2	2	0.53
Bothrops leucurus	2	1	1	2	2	2	2	2	2	3	2	2	0.42
Bothrops muriciensis	4	4	2	4	***2***	2	4	1	2	***3***	2	***2***	0.72
Crotalus durissus	1	2	1	4	4	2	3	4	2	1	2	2	0.56
Lachesis muta	3	4	1	4	4	2	4	3	4	1	1	2	0.64

Table 2 Categories, criteria and score ranges for species of snakes of the Pernambuco Endemism Center

Category	Criteria	Range
LC	Lowest 40 % of score range of complete assemblage	0.28-0.45
NT	41–55 % of score range of complete assemblage	0.46-0.52
VU	56–70 % of score range of complete assemblage	0.53-0.58
EN	71–85 % of score range of complete assemblage	0.59-0.65
CR	85-100 % of score range of complete assemblage	0.65-0.72

Table 3 Factor loadings of each variable on the first three principal components and proportion of the variance explained by each component

Variable	**Factor I**	**Factor II**	**Factor III**
Distribution breadth	0.80312325	0.001987978	0.3695292
Habitat breadth	0.75942570	0.045797422	0.4556551
Endemicity	0.52987424	-0.060964698	-0.3455859
Rarity in the PEC	0.43229010	0.115801137	0.4702724
Dietary specialization	0.19271983	0.347422886	-0.1411357
Habitat use and activity period	-0.37900906	0.129797531	0.4616027
Adaptability to altered environments	0.67803028	0.046562743	0.2297653
Direct anthropogenic effects on species conservation status	-0.72991284	-0.334671619	-0.1567242
Body size	-0.42589889	-0.371717892	0.4651132
Litter size	0.41285767	0.527876567	-0.4591830
Reproduction mode	0.04015793	-0.686501637	0.1962910
Frequency of reproduction	0.31414075	-0.856135000	-0.2541500
% Variance	0.2570054	0.2315453	0.1185227
% Cumulative variance	0.2570054	0.4885506	0.6070733

Table 4 Comparison between the degree of vulnerability to extinction of the snakes species of the Pernambuco Endemism Center with preexisting assessments: International Union for Conservation of Nature (IUCN, 2019-3), the Brazilian red list of threatened species (ICMBio, 2018), Central Brazil (França and Araújo, 2008); Pernambuco state (PE) (SEMAS, 2017); Bahia state (BA) (SEMA 2017), Rio Grande do Sul state (RS) (Decreto n°51.797/2014) and Espírito Santo state (ES) (Decreto no1499-R). The abbreviations are: LC- least concern, NT- Near threatened; VU- vulnerable; EN- endangered; CR- critically endangered; TH- threatened; NR- no risk.

Species	IUCN	Brazilian	PEC	PE	BA	RS	ES	Central Brazil
Anomalepididae								
Liotyphlops trefauti	DD	DD	VU					
Boidae								
Boa constrictor		LC	NT	LC				VU
Corallus hortulanus	LC	LC	VU	LC				
Epicrates assisi		LC	VU	LC				
Epicrates cenchria		LC	EN	LC				VU
Colubridae								
Chironius carinatus		LC	NT	LC				
Chironius exoletus	LC	LC	NT	LC				TH
Chironius flavolineatus	LC	LC	LC	LC				VU
Dendrophidion atlantica		DD	CR	DD				
Drymarchon corais	LC	LC	LC	LC				VU
Drymoluber dichrous	LC	LC	LC	VU				
Leptophis ahaetulla	LC	LC	LC	LC				
Oxybelis aeneus	LC	LC	VU	LC				TH
Palusophis bifossatus	LC	LC	VU	LC				VU
Spilotes pullatus	LC	LC	EN	LC				VU
Spilotes sulphureus	LC	LC	VU					
Tantilla melanocephala	LC	LC	LC	LC				VU
Dipsadidae								
Apostolepis cearensis		LC	LC	LC				
Apostolepis longicaudata	LC	LC	NT	DD				
Atractus caete		EN	CR					
Atractus maculatus		DD	EN	LC				
Atractus potschi		DD	VU	LC				
Boiruna sertaneja		LC	VU	LC				
Caaeteboia sp.			CR					
Dipsas mikanii	LC	LC	LC					VU
Dipsas neuwiedi	LC	LC	NT	LC				
Dipsas sazimai	LC	LC	NT	VU	VU			
Dipsas variegata	LC	LC	NT	LC				

Species	IUCN	Brazilian	PEC	PE	BA	RS	ES	Central Brazil
Echinanthera cephalomaculata		VU	CR		EN			
Echinanthera cephalostriata	LC	LC	EN					
Erythrolamprus aesculapii	LC	LC	VU					VU
Erythrolamprus almadensis	LC	LC	LC	LC				TH
Erythrolamprus miliaris	LC	LC	LC	LC				
Erythrolamprus poecilogyrus		LC	LC	LC				NR
Erythrolamprus reginae	LC	LC	VU	VU				NR
Erythrolamprus taeniogaster	LC	LC	LC	LC				
Erythrolamprus viridis	LC	LC	LC	LC				
Helicops angulatus	LC	LC	LC	LC				TH
Helicops leopardinus	LC	LC	NT	LC				VU
Hydrodynastes gigas		LC	NT			VU		
Imantodes cenchoa	LC	LC	LC	LC				
Leptodeira annulata	LC	LC	LC	LC				VU
Lygophis dilepis	LC	LC	NT	LC				
Oxyrhopus guibei	LC	LC	LC	LC				VU
Oxyrhopus petolarius	LC	LC	LC	LC				
Oxyrhopus trigeminus	LC	LC	LC	LC				TH
Philodryas nattereri	LC	LC	LC	LC				NR
Philodryas olfersii	LC	LC	LC	LC				NR
Philodryas patagoniensis	LC	LC	LC	LC				NR
Phimophis guerini		LC	LC					TH
Pseudoboa nigra	LC	LC	LC	LC				TH
Psomophis joberti	LC	LC	VU					
Sibon nebulatus	LC	LC	NT					
Siphlophis compressus	LC	LC	VU	VU				
Taeniophallus affinis	LC	LC	LC					
Taeniophallus occipitalis	LC	LC	LC	LC				VU
Thamnodynastes hypoconia	LC	LC	EN	DD				VU
Thamnodynastes almae	LC	LC	EN	LC	VU			
Thamnodynastes pallidus	LC	LC	VU	LC				
Thamnodynastes phoenix			EN					
Xenodon merremii		LC	LC	LC				NR
Xenodon rabdocephalus	LC	LC	VU					
Xenopholis scalaris	LC	LC	VU	VU				
Xenopholis undulatus		LC	LC	DD				TH
Elapidae								
Micrurus corallinus		LC	VU					
Micrurus ibiboboca		DD	LC	DD				
Micrurus potyguara			VU	DD				
Leptotyphlopidae								
Epictia borapeliotes		LC	NT	LC				
Typhlopidae								

Species	IUCN	Brazilian	PEC	PE	BA	RS	ES	Central Brazil
Amerotyphlops amoipira	LC	EN	VU		EN			
Amerotyphlops arenensis			EN					
Amerotyphlops brongersmianus	LC	LC	NT	LC				
Amerotyphlops paucisquamus	LC	VU	VU	LC				
Viperidae								
Bothrops bilineatus		LC	VU	VU	VU		VU	
Bothrops erythromelas	LC	LC	VU	LC				
Bothrops leucurus		LC	LC	LC				
Bothrops muriciensis		EN	CR					
Crotalus durissus		LC	VU	LC				VU
Lachesis muta		LC	EN	VU	VU		VU	

Supplementary material

Table 1 Information used to create threat factor scores that may affect the survival of snakes in the Pernambuco Endemism Center. Abbreviations are: HB (BN = Brejos Nordestinos, Fl = Closed forest, Tb = Tabuleiro, Rt = Restinga, Mg = Mangrove); DT (abn = amphisbaenian, amp = amphibian, ann = annelids, art = arthropods, bi = birds, cro = crocodylians, fi = fish, Mo = mollusks, li = lizard, mam = mammals, sn=snake; HT (Di=Diurnal, No=Nocturnal; SAB = semi-arboreal, AB = arboreal, TE = terrestrial, AQ = aquatic, CR = cryptozoic, FS=Fossorial); AE (A= Consumption as food, M=medicinal, MR= magic/religious, P=Pets, O= ornamental or decorative, C= conflict, Rk= road killing); RM (Vi= viviparous, Ov= oviparous). The numbers in brackets represent the reference number from which the information was taken.

	Distribution				**Ecological data**			**Life-history data**			
Species	DB (ha)	HB	E (%)	RR	DS	HT	AE	BS (cm)	LS	RM	FR
Amerotyphlops amoipira	198229	Rt	<10	3	art (100%) [81]	FS		15	~*A. paucisquamus*	Ov	~*A. brongersmianus*, seasonal [78]
Amerotyphlops arenensis	588409	BN, Fl	13	13	art (100%) [81]	FS		18.7	7-8 [this work]	Ov	~*A. brongersmianus*, seasonal [78]
Amerotyphlops brongersmianus	2556956	Fl, Tb	<10	120	art (100%) [33]	FS		22	4-5 [33]	Ov	seasonal [78]
Amerotyphlops paucisquamus	3839637	Fl, Tb	14	153	art (100%) [80]	FS		14	3-4 [this work]	Ov	~*A. brongersmianus*, seasonal [78]
Apostolepis cearensis	3219125	Fl, Tb	<10	44	sn (50%), abn (50%) [112, 127]	FS		36.8	~*A. longicaudata*	Ov	~ *A. assimilis*, aseasonal

Apostolepis longicaudata	339	Fl	<10	8	sn (100%)[11]	FS		27.4	2 [this work]	Ov	~ *A. assimilis*, aseasonal
Atractus caete	6781	Fl	100	2	ann (100%) [91]	FS		40.8	~*A. ronnie* 1-4 [111]	Ov	~*A. ronnie*, seasonal [111]
Atractus maculatus	971562	Fl	100	5	ann (100%) [91]	FS		36.5	~*A. ronnie* 1-4 [111]	Ov	~*A. ronnie*, seasonal [111]
Atractus potschi	69	Fl	<10	3	ann (100%) [91]	FS		30.1	~*A. ronnie* 1-4 [111]	Ov	seasonal [110]
Boa constrictor	5377422	BN, Fl, Tb, Rt	<10	42	mam (47.3%), li(36.8%), bi (15%)[1]	No, SAB, TE	A, M, MR, P, O, C, Rk	206	18-60 [39,40,12]	Vi	seasonal [39]
Boiruna sertaneja	28326	Tb, Fl	<10	2	sn(71.4), li(28.5%) [21]	No, TE	C, Rk	157.3	4-14 [12,13]	Ov	seasonal [12]
Bothrops bilineatus	21151	Fl	<10	5	amp (50%), mam (35.7%), li (7.1%), sn (7.1%) [82]	No, AB		56.8	4-16 [103]	Vi	~*B. leucurus*
Bothrops erythromelas	182329	Fl	5	3	amp (30.8%), li (30.8%), art (23.1%), mam (15.4%) [82]	No, TE		51.4	2-21 [104, 105]	Vi	seasonal [104]
Bothrops leucurus	3723343	Fl, BN, Tb, Mg	5	207	amp(33%), li(24%), sn(9%), bi(2%), mam (18%) [this work]	No, TE	M, C	69.9	5-7 [106]	Vi	seasonal
Bothrops muriciensis	6131	Fl	100	6	~ (B. leucurus)	No, TE		58.9	~*B. leucurus*	Vi	~*B. leucurus*
Caaeteboia sp.	396869	Fl	100	3	amp (100%) [11]	Di, TE		41.1	~*Echinanthera occipitalis* <5 [15]	Ov	~ *E. undulata*, seasonal [67]
Chironius carinatus	2106817	Fl	<10	15	amp (92.8%), bi (3.5%), li (1.7%), mam (1.7%) [41, 83]	Di, AB, TE		150.6	5-12 [41, 42]	Ov	aseasonal [42]
Chironius exoletus	2631050	BN, Fl, Tb	<10	16	amp (100%) [2, 121, 60]	Di, AB, TE		81.5	4-12 [41,42]	Ov	seasonal [60]
Chironius flavolineatus	4902081	BN, Fl, Tb	<10	60	amp (100%)[122]	Di, SAB		90	3-8 [41,43]	Ov	aseasonal [123]

Corallus hortulanus	5519435	Fl	<10	11	mam (57%), bi (38.75%), li(2.5%), amp (1.25%) [1]	No, AB	M, C	81.5	3-24 [39,40]	Vi	seasonal [39]
Crotalus durissus	5650901	BN, Fl, Rt	<10	13	mam (100%) [2, 25]	No, TE	M, MR, O, C	90.2	21-31 [12]	Vi	seasonal [79]
Dendrophidion atlantica	2149230	Fl	100	24	~ (D. dendrophis) amp (100%) [3]	Di, TE		59.8	3 [this work]	Ov	~ *D. dendrophis*, aseasonal [3]
Dipsas mikanii	3101502	BN, Fl, Tb	<10	72	mo (100%) [92]	No, TE	Rk	38.1	3-10 [49]	Ov	seasonal [49]
Dipsas neuwiedi	2531693	BN, Fl	<10	17	mo (100%) [92]	No, TE	Rk	44.9	4-12 [49]	Ov	seasonal [60, 49]
Dipsas sazimai	76616	Fl	<10	1	mo (100%) [93]	No, AB, TE		42.9	~*D. variegata*	Ov	~*D. variegata*, aseasonal [49]
Dipsas variegata	261513	Fl	<10	4	mo (100%) [80]	No, AB, TE		60.3	1-8 [49]	Ov	aseasonal [49]
Drymarchon corais	4303073	Fl, Tb	<10	7	amp (27.2%), abn (3%) li (15.1%), sn (24.2%), bi (18.2%), mam (12.1%)[4]	Di, TE	C, Rk	158.6	3-15 [4]	Ov	aseasonal [4]
Drymoluber dichrous	2654824	BN, Fl, Tb	<10	15	li (70%), amp (30%)[124]	Di, TE		48.9	2-6 [40,5]	Ov	aseasonal [62]
Echinanthera cephalomaculata	332299	Fl	100	5	amp (100%) [80]	Di, TE		67.1	~*E. undulata* 1-19 [109]	Ov	~*E. undulata*, seasonal [109]
Echinanthera cephalostriata	4382	Fl	<10	1	amp (100%) [80]	Di, TE		91.5	~*E. undulata* 1-19 [109]	Ov	~*E. undulata*, seasonal [109]
Epicrates assisi	4813988	BN, Fl, Tb	<10	135	mam (85.7%), li (14.2%) [this work]	No, TE	M, P, C, Rk	78.2	7-14 [39]	Vi	seasonal [39]
Epicrates cenchria	273671	Fl	<10	6	mam (94%), bi (6%) [1]	No, TE, SAB	M	125.3	8-25 [39]	Vi	seasonal [39]
Epictia borapeliotes	2273479	Fl, BN, Rt	>10	34	art (100%)[80]	FS		20.6	~*Leptotyphlos koppesi* ~10-15 [47]	Ov	~ *Liotyphlops beui*, seasonal [77]
Erythrolamprus aesculapii	1003677	Fl	<10	7	sn (96%), li (4%) [85]	Di, TE		65.1	1-8 [96]	Ov	aseasonal [96]
Erythrolamprus almadensis	196564	Fl	<10	4	amp (100%)[2, 90]	Di, TE, AQ		36.8	5 [this work]	Ov	~ *E. miliaris*, aseasonal [36]

Erythrolamprus miliaris	2059277	Fl, BN	<10	7	amp (76%), fi (24%) [14]	No, TE, AQ		46.7	1-30 [36]	Ov	aseasonal [36]
Erythrolamprus poecilogyrus	5671447	BN, Fl, Tb, Mg	<10	35	amp (98.5%), li (1.4%)[15]	Di, TE	Rk	37.8	3-17[8,12]	Ov	aseasonal [68]
Erythrolamprus reginae	448691	Fl	<10	4	amp (95%), li (5%) [113]	Di, TE, AQ		49.4	1-4 [97-98]	Ov	aseasonal [113, 115]
Erythrolamprus taeniogaster	3127351	Fl, Tb, Rt	<10	45	amp (73%), fi(26.9%) [113]	Di, TE, AQ		45.6	7-10 [16]	Ov	aseasonal [113]
Erythrolamprus viridis	4595323	BN, Fl	<10	21	amp (90%), li (10%) [8]	Di, TE	C	32	2-7 [8,12]	Ov	aseasonal [12]
Helicops angulatus	2749736	Fl, Mg, Rt	<10	236	fi (75.6%), amp (24%) [this work]	No, AQ	Rk	95.2	1-21 [this work,40,5, 119]	Ov	aseasonal [this work]
Helicops leopardinus	2101210	Rt, Fl	<10	9	fi (70%), amp (30%) [87]	No, AQ		44	3-31 [99, 119]	Vi	seasonal [120]
Hydrodynastes gigas	333223	Fl, Rt	<10	10	amp (29.1%), fi (25%), sn(25%), mam (20.8%)[17]	Di, AQ, TE		164.3	14-42 [40, 48]	Ov	seasonal [69]
Imantodes cenchoa	3096419	Fl, Tb	<10	23	Li (100%) [18]	No, AB	Rk	93.3	1-7 [40,5,49,18]	Ov	aseasonal [60, 49]
Lachesis muta	2176395	Fl	<10	4	mam (100%)[16, 5]	No, TE	A, M, C	202.5	1-18 [5, 35, 107]	Ov	seasonal [35]
Leptodeira annulata	2280440	Fl, Rt, BN	<10	6	amp (100%) [88, 89]	No, AB, TE		72.2	3-13 [49, 100]	Ov	aseasonal [49]
Leptophis ahaetulla	3795204	BN, Fl	<10	42	amp (92%) li (7.5%) [6]	Di, AB, TE	M, C	91.5	3-12 [8,12]	Ov	aseasonal [62]
Liotyphlops trefauti	461177	Fl	90	4	art (100%) [80]	FS		37.8	~ *L. Beui* 4-24 [108]	Ov	~*L. beui*, seasonal [108]
Lygophis dilepis	475601	BN, Fl	<10	9	amp (100%) [8, 12]	Di, TE	Rk	46.5	4-6 [8]	Ov	aseasonal [12]
Micrurus corallinus	1403	Fl	<10	1	abn (75.5%), li (13.9%), sn (9,3%) [95]	CR		53	2-12 [101, 102]	Ov	seasonal [102]
Micrurus ibiboboca	6079964	BN, Fl, Tb	3.6 <10	391	abn (58.3%), sna (33.3%), li (8.3%) [8, 12]	CR	M, C, Rk	57.7	9-14 [this work]	Ov	seasonal [76]

Micrurus potyguara	151532	Fl, Tb	100	14	~ (M. ibiboboca)	CR	Rk	56.7	~ (M. ibiboboca) 9-14	Ov	seasonal [76]
Oxybelis aeneus	4469951	BN, Fl, Tb	<10	46	li (92,9%), amp (7.1)[8]	Di, AB	C, Rk	125.8	4-9 [40,8,12]	Ov	seasonal [64]
Oxyrhopus guibei	3253230	BN, Fl, Tb	<10	10	mam (86.1%), li(13.8%) [19,20]	No, Di, TE		55.32	3-20 [50]	Ov	aseasonal [19, 50, 115]
Oxyrhopus petolarius	4016741	BN, Fl, Tb	<10	36	li (35%), mam (30%), bi (25%), amp (5%) [21]	No, TE	Rk	54.7	2-12 [13,51]	Ov	aseasonal
Oxyrhopus trigeminus	7622212	BN, Fl, Tb, Rt	<10	237	mam (46.7%), li (33,3%), bi (20%)[22]	No, Di, TE	M, MR, C, Rk	44.7	6-9 [8,12]	Ov	aseasonal [22]
Palusophis bifossatus	2792950	Fl, BN	<10	5	amp (79.5%), mam (9.7%) li (2.4%) [7]	Di, TE	Rk, M	108.1	4-24 [44]	Ov	seasonal [63]
Philodryas nattereri	6179019	BN, Fl, Tb	<10	76	li (70%), mam (19.3%), amp (3.2%), sn (3.2%), bi (3.2%) [23]	Di, TE, SAB	MR, C, Rk	100.2	4-13 [8,12]	Ov	aseasonal [118]
Philodryas olfersii	8922751	BN, Fl, Tb, Mg	<10	123	amp (52%), li (4.3%), bi (19%), mam (24%) [24]	Di, TE, SAB	M, MR, C, Rk	76.8	1-16 [8,12, 52]	Ov	seasonal [71]
Philodryas patagoniensis	909389	Fl, Tb, Rt	<10	68	amp(38.7%), li(23%), mam (16%), bi (10.3%), sn (5.1%)[24]	Di, TE	Rk	59.4	3-19 [52]	Ov	seasonal [70]
Phimophis guerini	3125290	Fl, Tb	<10	15	li (92%) mam (8%)[21]	No, TE	Rk	59.7	3-7 [13]	Ov	~*P. nigra*, aseasonal [53]
Pseudoboa nigra	4898213	BN, Fl, Tb	<10	64	li (86%), mam (5%), sn (2%) [21]	No, TE	C, Rk	71.4	3-24 [13, 53]	Ov	aseasonal [53]
Psomophis joberti	158891	Fl	<10	11	amp (50%), li (50%)[2,25]	Di, TE		42.6	7 [8, 54]	Ov	seasonal
Sibon nebulatus	3173717	Fl, Tb	<10	21	mo (100%)[26]	No, AB	Rk	51.6	5 [56]	Ov	~*S. sanniola*, seasonal [72]
Siphlophis compressus	2017130	Fl, Tb	<10	13	li (96%), sn (4%) [21]	No, AB, TE	Rk	69	3-12 [40,13,5]	Ov	seasonal [73]
Spilotes pullatus	3042935	BN, Fl, Tb	<10	21	mam [86%], bi [14%] [10]	Di, SAB	C, M, MR, Rk	184.9	5-12 [10, 40,46]	Ov	seasonal [10, 60, 65]
Spilotes sulphureus	1796398	Fl	<10	20	bi [75%] mam (25%) [9, 126]	Di, SAB	Rk	124	7-15 [40,8, 125]	Ov	aseasonal [5, 62]

Taeniophallus affinis	2425002	BN, F, Tb	<10	9	li(33.3%), amp (33.3%), abn (16.6%), mam (16.6%) [27,28,29, 30]	CR		21.20	5-7 [55]	Ov	seasonal [30]
Taeniophallus occipitalis	4504775	BN, Fl, Tb	<10	63	li (91%), amp(8%) [30]	CR		37.2	2 [this work]	Ov	seasonal [30]
Tantilla melanocephala	4755325	BN, Fl, Tb, Rt	<10	172	chi (100%) [this work]	FS	C	29.2	1-3 [4,9]	Ov	aseasonal [this work]
Thamnodynastes hypoconia	353400	BN	<10	3	amp (96%), li (4%) [34]	No, TE, AB		23.8	4-13[34]	Vi	seasonal [34]
Thamnodynastes almae	353400	BN	<10	1	~*T. hypoconia*	No, TE, AB		65.2	~ *T. hypoconia*	Vi	~*T. hypoconia*, seasonal[34]
Thamnodynastes pallidus	2628809	Fl, Tb	<10	92	amp (90.1%), li (9%) [116, 129]	No, TE, AB	Rk	45.2	3-6 [57,58]	Vi	seasonal [116]
Thamnodynastes phoenix	1084187	BN	<10	3	amp (100%) [94]	No, TE, AB		51.1	~ *T. hypoconia*	Vi	~*T. hypoconia*, seasonal[34]
Xenodon merremii	5844146	BN, Fl, Tb	<10	97	amp (100%)[8,12]	Di, TE	MR, Rk	51.9	4-30[12]	Ov	seasonal [74]
Xenodon rabdocephalus	401308	BN	<10	2	amp (100%) [5]	Di, TE		71	6- 8 [5]	Ov	aseasonal [114]
Xenopholis scalaris	549262	Fl	<10	10	amp (100%) [5, 90]	No, TE		16.7	2-3 [5]	Ov	seasonal
Xenopholis undulatus	2083408	BN, F	<10	2	amp (100%)[16,32]	No, TE		31.6	3 [59]	Ov	aseasonal

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CAPÍTULO 4

ARE THREATENED SNAKES PROTECTED IN PRIORITY AREAS OF PERNAMBUCO ENDEMISM CENTER, BRAZIL?

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Are threatened snakes protected in priority areas of Pernambuco Endemism Center, Brazil?

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Abstract

The Pernambuco Endemism Center, located in the Northeast of Brazil, is the most degraded, least known and least protected sector of the entire Atlantic Forest. Despite the high level of fragmentation, 78 snake species persist in the region, but recent studies indicate that at least 46% of these species may be threatened with regional extinction. We use a geostatistical modeling technique (kriging) to analyze the potential distribution of threatened snake species in the region, and to verify if the distribution of conservation units overlaps with the points where more species are concentrated. We have observed that some representative points of threatened species are near protected areas (REBIO Guaribas and APA of Rio Mamanguape, REBIO Pedra Talhada and APA Murici), located in the states of Paraíba, Pernambuco and Alagoas, however some of these areas are too for effective protection. In addition, other points of these species have not been contemplated by any of these areas. This work presents a first insight into the distribution of threatened snake species in the Pernambuco Endemism Center and contributes to a better conservation planning for these species in the region.

Keywords: neotropical snakes, threatened snakes, endemism, Atlantic Forest, conservation

1. Introduction

Global biodiversity, as well as ecological functions, are suffering unprecedented threats due to the accelerated loss of species resulting from the numerous transformations of natural systems. These are directly related to anthropic activities, aimed at the production of energy and food, as well as the exploitation of natural resources (Piratelli & Francisco, 2013; Primack & Rodrigues, 2001). This problem is getting worse as deforestation intensifies in tropical ecosystems, which is where most of the biodiversity is concentrated (Ganem, 2011).

The Atlantic Forest, considered one of the world's biodiversity hotspots, was the first Brazilian ecoregion to be degraded, when europeans found vast areas to be exploited in the early 1500s, both to extract their natural resources and for land use, initially for the purpose of planting sugarcane and also for the creation of the first villages (Coimbra-Filho & Câmara, 1996; Myers, Mittermeier, Mittermeier, Fonseca, & Kent, 2000; Tabarelli & Roda, 2005; Tabarelli, Siqueira Filho, & Santos, 2006). This degradation is even more evident in the portion of the Atlantic Forest located north of the São Francisco River, where an important center of endemism is located in South America – The Pernambuco Endemism Center (hereafter PEC) (Prance, 1982; Silva & Casteleti, 2003). The conservation and recovery of this Biome, which currently retains only 16% of its original coverage (Ribeiro, Metzger, Martensen, Ponzoni, & Hirota, 2009), constitutes a major challenge, once the strategies, actions and necessary interventions are faced with the difficulties imposed by the lack of knowledge about the functioning of its ecosystems, in an environment under strong anthropic pressure (Pinto et al., 2006).

Due to this current economic model, many species are threatened with extinction and others have become extinct (Piratelli & Francisco, 2013). One way to prevent this threat is to create protected areas. These areas can be created in various ways, but the two most common mechanisms are government action (most often at the national level, but also at the regional or local level) and land acquisition by individuals and conservation organizations (Primack & Rodrigues, 2001).

In 2000, the Brazilian National System of Conservation Units (SNUC-Law 9985/ 2000) was sanctioned, which divides the conservation units (UC) into two large groups according to specific characteristics: The UC's of integral protection, whose main objective is to preserve nature, allowing only an indirect use of natural resources (Ecological Stations (ESEC); Biological Reserves (REBIO); National Park (PN); Natural Monument (MONA); Wildlife Refuges (RVS)) and the UC's of sustainable use, whose main objective is nature conservation with the sustainable use of parts of its natural resources (Environmental Protection Area (APA); Area of Relevant Ecological Interest (ARIE); National Forest (FLONA); Extractive Reserve (RESEX); Fauna Reserve (REFAU); Sustainable Development Reserve (RDS); Private Reserves of Natural Heritage (RPPN)).

Today, protected areas of PEC are small forest fragments within urban and agricultural matrices (mainly sugarcane crops), which account for less than 2% of the Center's original coverage (Silva & Tabarelli, 2000; Tabarelli & Roda, 2005). Despite the high level of fragmentation, 78 snake species persist in the region, seven of them are endemic (Capítulo 1), but recent studies indicate that at least 46% of these species may be threatened with extinction (Capítulo 3).

Therefore, the aims of this study are: to create a potential distribution model for threatened snake species in the PEC, to analyze the distribution of these species within that region, and to overlay these data with the protected areas present in the region and to indicate areas suitable for studies focused on the conservation of these species.

2. Materials and methods

2.1 Study area

The study area comprises the Atlantic Forest located north of the São Francisco River, which corresponds to the Pernambuco Endemism Center (PEC) (Fig. 1) (Prance, 1982), located between the states of Alagoas and Rio Grande do Norte. This region has a humid tropical climate (Köppen's As'), with autumn-winter rains and rainfall ranging from 750 to 1500 mm per year (Tabarelli et al., 2006).

The PEC region is composed of different native forest formations and ecosystems associated with the Atlantic Forest domain. A mosaic of ombrophilous and semi-deciduous forests is present in this region (Tabarelli et al., 2006). The PEC also includes the "Brejos de altitude" or "Brejos Nordestinos", which are "islands" of humid forests established in the semi-arid region, surrounded by Caatinga vegetation (Andrade-Lima, 1982; Pôrto, Cabral, & Tabarelli, 2004). According to Uchoa Neto and Tabarelli (2002), The PEC presents the largest amount of remaining area of Atlantic Forest in the state of Pernambuco (1,363.23 km²), followed by the states of Alagoas (807.95 km²), Rio Grande do Norte (567.67 km²) and Paraíba (566.09 km²).

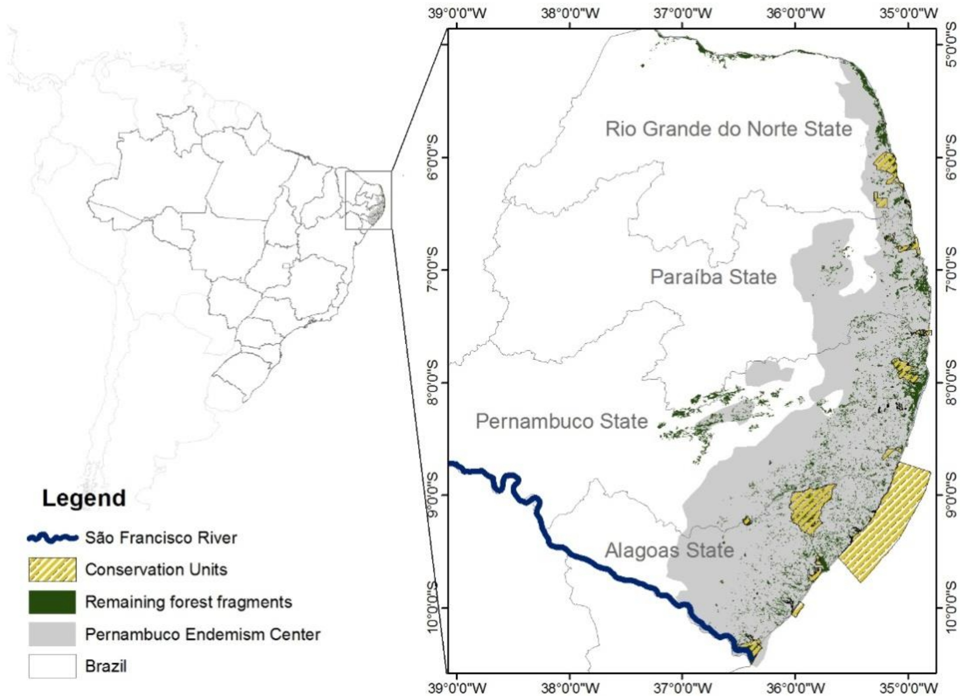

Fig. 1: Map of the location of the Pernambuco Endemism Center, its forest remnants and the conservation units that are located in the region.

A total of 157 conservation units are present in the PEC (Paula, 2012). The state of Alagoas has the largest amount of protected area (184.404,30 ha; 47 UCs), followed by the states of Pernambuco (157.936,95 ha; 76 UCs), Rio Grande do Norte (75.614,20; 12 UCs) and Paraíba (55.575,52; 22 UCs) (Paula, 2012). These areas vary in their purposes, sizes (ranging from 10 to 6.116 hectares) and shapes. Among these, the Integral Protection Conservation Units with the largest areas are ESEC Murici (6.116,00 ha), REBIO Pedra Talhada (4.469,00 ha) and REBIO Guaribas (4.32,00 ha).

2.2 Sampling

The information on the distribution and occurrence of species was obtained through the records of the scientific collections (Coleção Herpetológica da Universidade Federal da Paraíba - UFPB; Coleção do Laboratório de Anfíbios e Répteis da Universidade Federal do Rio Grande do Norte - CLAR; Coleção Herpetológica do Museu de História Natural da Universidade Federal de Alagoas – MUFAL; Coleção Herpetológica da Universidade Federal Rural de Pernambuco – CHUFRPE; Coleção Herpetológica da Universidade Federal de Pernambuco - CHUFPE) and literature data, and was subsequently georeferenced. We include records of occurrence of species in the literature only when we were able to confirm the record by direct observation, photo or through museum records or documented vouchers.

From these points, a database was generated of the 49 snake species (target species) (Table 1) that are found in four categories of threatened species (near threatened (NT); vulnerable (VU); endangered (EN) and critically endangered (CR)), according to the article "*Determination of the conservation status of the snakes of the Pernambuco Endemism Center*" (Capítulo 3).

Table 1. Snake species found in four threatened species category at the Pernambuco Endemism Center (Capítulo 2). The abbreviations are: near threatened (NT); vulnerable (VU); endangered (EN) and critically endangered (CR).

Family	Species	PEC
Anomalepididae	*Liotyphlops trefauti*	VU
Boidae	*Boa constrictor*	NT
	Corallus hortulanus	VU
	Epicrates assisi	VU
	Epicrates cenchria	EN
Colubridae	*Chironius carinatus*	NT
	Chironius exoletus	NT
	Dendrophidion atlantica	CR
	Oxybelis aeneus	VU
	Palusophis bifossatus	VU

	Spilotes pullatus	EN
	Spilotes sulphureus	VU
Dipsadidae	*Apostolepis longicaudata*	NT
	Atractus caete	CR
	Atractus maculatus	EN
	Atractus potschi	VU
	Boiruna sertaneja	VU
	Dipsas neuwiedi	NT
	Dipsas sazimai	NT
	Dipsas variegata	NT
	Caaeteboia sp.	CR
	Echinanthera cephalomaculata	CR
	Echinanthera cephalostriata	EN
	Erythrolamprus aesculapii	VU
	Erythrolamprus reginae	VU
	Helicops leopardinus	NT
	Hydrodynastes gigas	NT
	Lygophis dilepis	NT
	Psomophis joberti	VU
	Sibon nebulatus	NT
	Siphlophis compressus	VU
	Thamnodynastes almae	EN
	Thamnodynastes hypoconia	EN
	Thamnodynastes pallidus	VU
	Thamnodynastes phoenix	EN
	Xenodon rabdocephalus	VU
	Xenopholis scalaris	VU
Elapidae	*Micrurus corallinus*	VU
	Micrurus potyguara	VU
Leptotyphlopidae	*Epictia borapeliotes*	NT
Typhlopidae	*Amerotyphlops amoipira*	VU
	Amerotyphlops arenensis	EN
	Amerotyphlops brongersmianus	NT

	Amerotyphlops paucisquamus	VU
Viperidae	*Bothrops bilineatus*	VU
	Bothrops erythromelas	VU
	Bothrops muriciensis	CR
	Crotalus durissus	VU
	Lachesis muta	EN

2.3 Data analysis

The perimeter of the study area was delimited from the map of forest remnants in the "Diagnóstico e estratégia de conservação do Centro de Endemismo Pernambuco" (Uchoa Neto & Tabarelli, 2002). We georeferenced the map and divided the perimeter of the PEC into regular 10 x 10 km grids using ArcGIS 10.1 software developed by ESRI (2004), and the snake species present in each grid were counted.

2.4 Ordinary kriging

We used the spatial interpolation method called ordinary kriging, which uses mathematical functions to add more weight to the closest sample points and less weight to more distant sample points. From these data, new points are created based on these linear combinations. This procedure allows the generation of continuous surfaces from punctual sampling units. Three models were performed: the first included all snake species found in the threatened species category (VU, EN, CR), the second all species considered near threatened (NT) and finally, a model was build using all near threatened and threatened (NT, VU, EN, CR) species. Models were run in the Geostatistical Analyst extension of ArcGIS 10.1 software (ESRI, 2004).

Before executing the kriging, we analysed the spatial variability of the data. This was achieved by examining the semivariogram, which is a graphical representation of the semivariances and the distances between sampled points. ArcGIS 10.1 uses a least squares method to fit the models, and as a criterion for model selection it uses the coefficient of determination and the sum of squares of residuals. From this procedure, the exponential model was adjusted to the interpolation of variables and acquisition of their parameters (nugget effect, partial sill, and major range). These parameters were used to create a species richness map, originated by ordinary kriging. The major range was also used to determine the appropriate distance between sampling points, as it represents the influence of the point on its neighbours. Thus, variables located at distances greater than the range have random spatial distribution and are considered independent between locations (Ge, Carruthers, Ma, Zhang, & Li, 2005). As the maximum range found was 30.741 km, the dimensions of the sampling grid (10 x 10 km cells) yielded an appropriate and qualified accurate detection of the snake distributions.

Before choosing to use kriging, we compared the results generated by it with another geostatistical method called The Inverse Distance Weight (IDW). These two methods are used to model species richness (e.g. Carroll and Pearson 1998; Jiguet et al., 2005; Hernández-Stefanoni et al., 2011; Pereira et al., 2016). However, the method of kriging, proved to be more appropriate for our data set, because it produced lower average errors than IDW.

For the construction of the maps, a database of conservation units made available in polygon format by Ministério do Meio Ambiente (http://mapas.mma.gov.br/i3geo/datadownload.htm) was used.

3. Results

From the number of snake species present in each grid three maps of species richness concentration were produced (figures 2-4) originated by ordinary kriging. The first map, composed only by threatened species (VU, EN, CR) (Fig. 2) showed that the species richness is concentrated mainly in some points between the states of Paraíba and Alagoas. In Paraíba, in the northernmost region of the state, the points with the greatest richness of species are near REBIO Guaribas and APA of Rio Mamanguape, and in the southernmost region, between the RPPN Engenho Gargaú, Botanical Garden Benjamim Maranhão and State Park Mata do Xem-Xém. The other point with higher concentration of species is located between the states of Pernambuco and Alagoas, near REBIO Pedra Talhada.

In the second map (Fig. 3), we present only the near threatened species, and the area of distribution of these species was concentrated mainly in the states of Paraíba and Alagoas. In Paraíba, the region with the greatest richness of species is near REBIO Guaribas, APA of Rio Mamanguape, RPPN Engenho Gargaú, RPPN Pacatuba, Botanic

Garden Benjamim Maranhão and State Park Mata do Xem-Xém. The other point with higher concentration of species is in Alagoas, near REBIO Pedra Talhada, APA of Muricí, APA of Santa Rita and APA of catolé and Fernão Velho. We can also see that a large area is not covered by any conservation unit.

When we plot all categories of target species on a single map (Fig. 4), we find that the specimen concentration points are at three points. In Paraíba, the species are nearest to REBIO Guaribas and APA of Barra do Rio Mamanguape, in Pernambuco and Alagoas they are in the region near REBIO Pedra Talhada and in Alagoas in APA of Muricí.

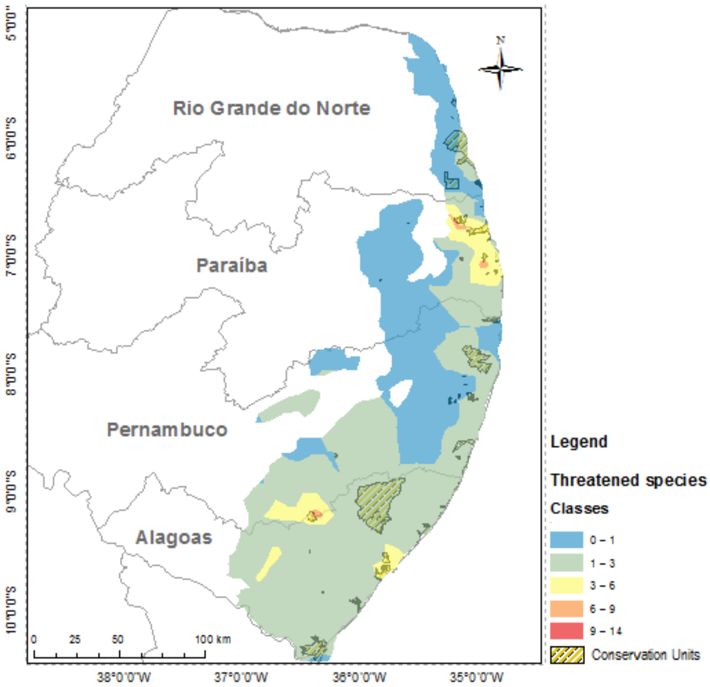

Fig. 2. Map of threatened snake species richness generated by Ordinary kriging and adjusted by exponential model. The redder colors represent points with greater richness of species.

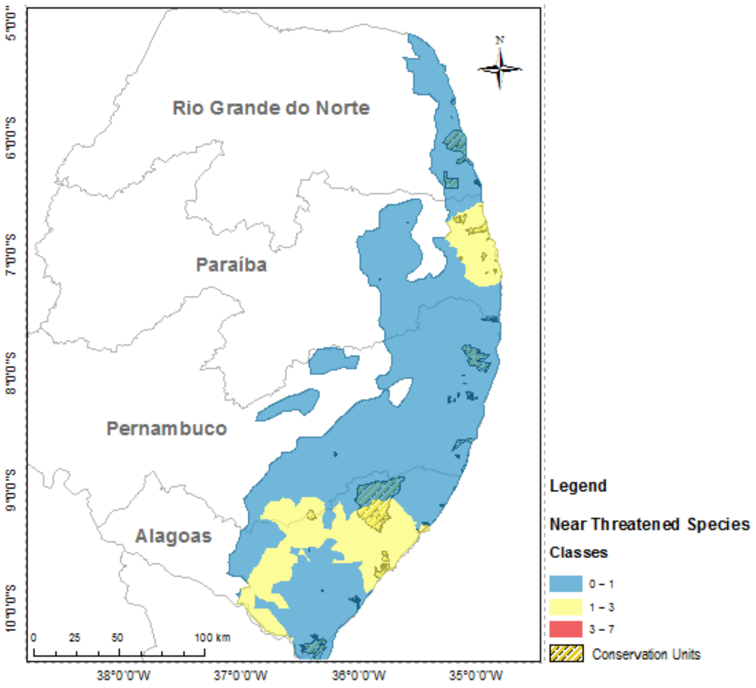

Fig. 3. Map of near threatened snake species richness generated by Ordinary kriging and adjusted by exponential model. The redder colors represent points with greater richness of species.

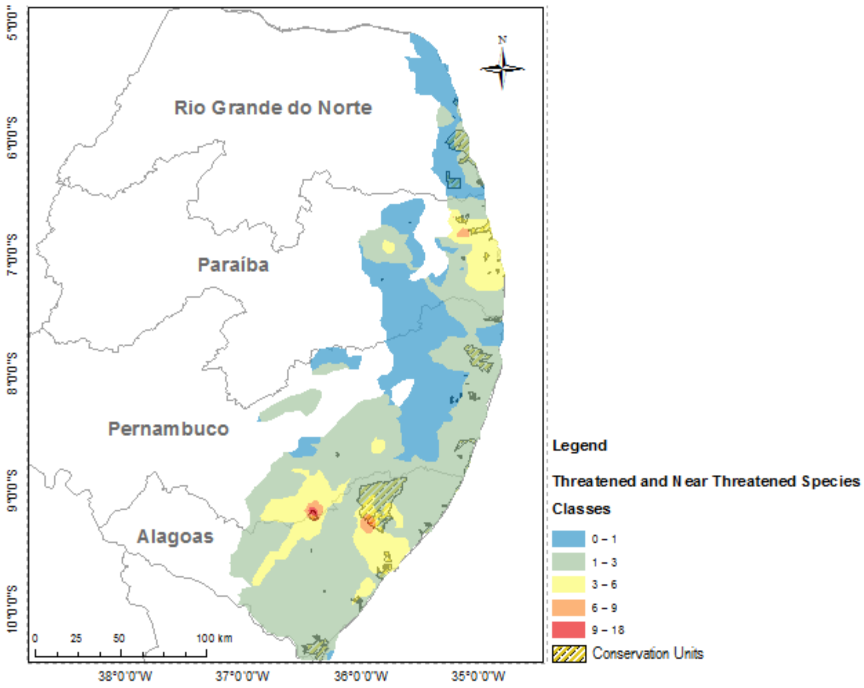

Fig. 4. Map of near threatened and threatened snake species richness generated by Ordinary kriging and adjusted by exponential model. The redder colors represent points with greater richness of species.

4. Discussion

The establishment of legally protected areas represents an important starting point for the preservation of biological communities, although it is one of the most debatable measures (Primack & Rodrigues, 2001). According to Rodrigues (2005), the implementation of these areas is the key strategy for the conservation of Reptiles in Brazil, but depending on their size and location, the extinction of at least a small part of their species is inevitable, since the preservation of the species in its interior is subject to fires and threats that are difficult to detect. The PEC is considered the most devastated, least known and least protected sector of the entire Atlantic Forest, being one of the regions on the planet where conservation efforts are most urgent (Coimbra-Filho & Câmara, 1996; Tabarelli, Marins, & Silva, 2002). The conservation units present in this region are few, small and are not properly implemented (Tabarelli, Pinto, Silva, & Costa, 2003; Uchoa Neto & Tabarelli, 2002).

The distribution maps of the species of snakes targeted for conservation in the PEC, made using the information generated by Ordinary kriging, were very accurate and showed species concentration points between the states of Paraíba and Alagoas. Analyzing the three maps together, we can see that the points are concentrated near some conservation units, REBIO Guaribas and APA of Rio Mamanguape, REBIO Pedra Talhada and APA Murici (where ESEC Murici is inserted), but much of the distribution of these species is outside the boundaries of these units.

As well as for the snake species found in the PEC, the REBIO Guaribas, REBIO Pedra Talhada and ESEC Murici are also known to be important for the conservation of endemic and threatened birds of the region (Bencke, Maurício, Develey, & Goerck, 2006; Pereira et al., 2016; Wege & Long, 1995). However, although snake specimens are near protected areas, some observations should be considered when the objective is the conservation of species in these areas.

First, REBIO Guaribas, which is divided into three distinct fragments, suffers from some situations that interfere with the dynamics of the ecosystem. For example, this area suffers constant anthropic pressure from neighbouring communities that are within its buffer zone, because as observed by Arruda et al. (2013), the limits of this zone are not well defined, and do not exceed an average of ten meters in width throughout, with the exception of places where there are no villages, or plantations of landowners that border the reserve. In addition, one of the fragments (which has only 338.82 ha) presents the most complicated situation when compared to the other two. This area is located on the surroundings of an urban area, and is limited to the south with the city, to the north with a village, to the east with a clay road that gives access to the landing field and connects the city to highway BR-101, and to the west with private areas cultivated mainly with sugar cane. We can find more than 80% of the species found within the fragment in the urban area of the city, however, many individuals are killed directly by the population living around the Reserve or are roadkilled on the roads bordering it (Albuquerque, 2013; França, Germano, & França, 2012; França & França, 2019).

According to Bensusa (2006), some conservation units, such as Environmental Protection Areas (APAs), do not seem to have a good reputation with respect to biodiversity conservation. However, this is often due to the low degree of implementation and, consequently, the inefficiency of some APAs. As this type of conservation unit is created in already populated areas, and its creation implies regulating the use and handling of the natural resources there, it is common that conflicts of interest arise between various economic groups, such as in the APA of Rio Mamanguape, which was created with the main objective of ensuring the conservation and protection of the West Indian Manatee (threatened species), but it faces some conflicts, one of them due to the particularity of overlapping with an Indigenous Land (Moreira & Andrade, 2008).

Not different from other conservation units in the PEC region, ESEC Murici and REBIO Pedra Talhada also face some problems that may interfere with the dynamics of the ecosystem. For example, ESEC Murici is composed of a set of fragments of varying sizes, most of them not reach 1,000 ha, and these are inserted in a matrix consisting of pastures for cattle and sugarcane (Silva & Pôrto, 2009, 2015). However, these conservation units have a peculiarity in relation to the other conservation units mentioned here and should therefore be treated more carefully. Some snake species are endemic to these conservation units. For example, the threatened snake species, *Atractus caete*, is rare and until now has only been found at REBIO Pedra Talhada (ICMBio, 2018). Besides this species, *Echinanthera cephalomaculata* is another species considered threatened and rare (ICMBio, 2018). Until recently, only two specimens of

E. cephalomaculata collected in this conservation unit in the 1990s were known, but in 2015 two individuals were registered in the same conservation unit (Roberto, Ávila, & Melgarejo, 2015) and more recently three specimens were observed in the state of Pernambuco (Freitas, Barbosa, Bernardino, Domingos, & Filho, 2019). *Bothrops muriciensis* is another threatened and rare species and has so far only been registered in ESEC Murici (Freitas, França, Graboski, Uhlig, & Veríssimo, 2012; ICMBio, 2018).

Some representative points of threatened snake species on the map are in conservation units (Figure 2), however some of these areas are quite small, such as the State Park Mata do Xem-Xém (182 ha), while other points did not contemplate any of these areas. Gap analysis aimed at assessing biodiversity priorities with existing protected areas in a region, as well as selecting areas that complement them (Scott et al., 1993), and may in the future provide a better view of the efficiency of protected areas in the PEC with threatened snake species in that region. In addition, future work with snakes in understudied areas of the Atlantic Forest of the Northeast may offer us a more complete overview of the situation of snake species present in this part of the biome.

In this work we present a first insight into the distribution of threatened snake species in the Pernambuco Endemism Center. In addition, we have shown that some conservation units in this region are extremely important to ensure the conservation of these species, since the points of concentration of species are close to these units. In this way, we hope that these areas can be analysed with special attention. Geostatistics, which is still a little used methodology, helps us to verify the positive and negative points of how the conservation scenario is affecting this group of animals and that consequently can reflect on other groups. The accumulation of data, and the extension of the area covered, may allow the use of other geospatial analyses which, together with geostatistics, will allow new assessments of the state of conservation of snakes in the PEC.

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CAPÍTULO 5

HISTORICAL COLLECTION OF SNAKES FROM BRAZIL BY PAUL MÜLLER, DEPOSITED AT THE ZOOLOGICAL RESEARCH MUSEUM ALEXANDER KOENIG, GERMANY

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Historical collection of snakes from Brazil by Paul Müller, deposited at the Zoological Research Museum Alexander Koenig, Germany

Collection of snakes by Paul Müller

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Abstract.

Natural history collections are constituted of a wide variety of biological specimens preserved around the world. They represent a continuous sources of new knowledge and play a fundamental role in the synthesis on the diversity, composition, distribution and conservation of species. Paul Müller (1940-2010) was a German zoologist who collected amphibians and reptiles in Brazil between 1964 and 1976, with the aim of increasing knowledge about the Brazilian fauna and understanding the general patterns of Neotropical biogeography. We examined and re-determined all snakes found in Paul Müller's collection, deposited at the Zoological Research Museum Alexander Koenig (ZFMK) and also recreated the itinerary of his journeys through Brazil. We identified 556 snakes specimens belonging to 80 species from six families (Aniliidae, Boidae, Colubridae, Dipsadidae, Elapidae and Viperidae). In this collection there are snake specimens from all regions of Brazil, although most are from the south (76% of the species) and southeast (14% of the species). This relevant material can contribute to historical, biogeographic and conservation studies of Brazilian snake fauna.

Key words. Biodiversity, Reptilia, Serpentes, Southeast Brazil, South Brazil, Scientific Collections.

Coleção Histórica de serpentes do Brasil por Paul Müller, depositada no Zoological Research Museum Alexander Koenig, Alemanha

Resumo. As coleções de história natural são constituídas de uma grande variedade de espécimes biológicos preservados em todo mundo. Elas são fontes contínuas de novos conhecimentos e apresentam um papel fundamental na síntese sobre a diversidade, composição, distribuição e conservação das espécies. Paul Müller (1940–2010) foi um zoólogo alemão que coletou espécies de anfíbios e répteis no Brasil entre os anos de 1964 à 1976, com o intuito de aumentar o conhecimento sobre a fauna brasileira e entender os padrões gerais da biogeografia neotropical. Nós examinamos e re-determinamos todos os indivíduos encontrados na coleção de Paul Müller, depositada no Zoological Research Museum Alexander Koenig (ZFMK) e também recriamos o roteiro de suas viagens pelo Brasil. Nós identificamos 556 espécimes de serpentes de 80 espécies pertencentes a seis famílias (Aniliidae, Boidae, Colubridae, Dipsadidae, Elapidae and Viperidae). Nessa coleção existem exemplares de serpentes de todas as regiões do Brasil, embora a maioria seja das regiões sul (76% das espécies) e sudeste (14 % das espécies). Este relevante material pode contribuir para estudos históricos, biogeográficos e conservacionistas da fauna de serpentes brasileiras.

Palavras-chave. Biodiversidade, Reptilia, Serpentes, Sudeste do Brasil, Sul do Brasil, Coleções científicas

INTRODUCTION

Natural history collections are made up of a wide variety of biological specimens preserved around the world and their purpose is to document biodiversity and its distribution and to serve as a resource for research and education (Winker 2004). This set of specimens comprise an invaluable record of the evolution of life and are the basis for many biological researches such as taxonomy and systematics, ecology, biogeography, mapping and monitoring (Renner & Ricklefs 1994; O'Connell et al. 2004; Winker 2004; Pyke & Ehrlich 2010; Ballard et al. 2017).

Paul Müller (1940-2010) was a German zoologist who studied and collected amphibians and reptiles in Brazil from 1964 to 1976. His main interests were related to zoogeographical-ecological issues and problems of the evolutionary genetics of amphibians and reptiles of the Neotropics (Müller 1971). Müller visited different regions of Brazil and gathered a huge collection of vertebrates, including more than 6000 herpetological specimens (Monzel 2016). His research on neotropical herpetofauna focused on processes of differentiation of amphibians and reptiles on islands on the east coast of Brazil, such as the island of São Sebastião in São Paulo and the island of Santa Catarina (e.g. Müller 1968c, a, 1969b, c). Biogeographical studies on the island of São Sebastião resulted in his PhD thesis (see Müller 1968). In addition, his research on islands has resulted in a large number of new species distribution records (e.g. Müller 1968c, b, d, 1974, 1975, 1978). He also studied important Brazilian herpetological collections, such as the Museu Goeldi in Belém (Pará), the Museu Nacional in Rio de Janeiro, and the Instituto Butantan in São Paulo, where he collected data to obtain an overview of the morphological variability of the species he collected in the field (Monzel & Böhme 2010). Müller completed his first investigations in neotropical biogeography in 1973, with his famous work "Dispersal centres of terrestrial vertebrates in the neotropic realm" (see Müller 1973).

Throughout his research in Brazil, Paul Müller met important Brazilian herpetologists such as Paulo Emílio Vanzolini, Afrânio do Amaral, Alphonso Richard Hoge, Thales de Lema and Paulo Sawaya, the latter became a friend and, to some extent, his "Brazilian supervisor" (Monzel & Böhme 2010). On his return to Germany, Paul Müller took his collection of amphibians and reptiles to the University of Saarbrücken, where he was a professor and appointed head of the Institute of Biogeography in 1971, and later, in 1999, moved his collection to the University of Trier, where he accepted an offer to establish a new biogeographic institute (Monzel & Böhme 2010). After he retired in 2006, Paul Müller donated his important herpetological collection to the Zoological Research Museum Alexander Koenig, Germany (Monzel & Böhme 2010).

In this study, we have examined and re-determined all snake individuals found in Paul Müller's collection and also recreated Paul Müller's journey through Brazil over the years.

MATERIAL AND METHODS

We analyzed all snake specimens from Paul Müller's collection at the Zoological Research Museum Alexander Koenig, located in Bonn, Germany. We identified all specimens using the current nomenclature (e.g. Campbell & Lamar 2004; Grazziotin et al. 2012; Pyron et al. 2013; Hoogmoed et al. 2019). In addition, we recovered some of the material that was poorly preserved, changed all the containers that were damaged and renewed the alcohol. After carefully analyzing all the samples, we inserted the museum label (ZFMK), but we also kept Paul Müller's field labels. We then entered the field information of the specimens into the Museum's database.

For the construction of the map with Paul Müller's travel itinerary through Brazil, we used the information of the location, and the date that the snake specimens were collected. We georeferenced the points of the locations where Paul Müller collected the species, that is, in this process we considered only the snake specimens that were collected by him. Then, we inserted all the information in ArcGIS 10.1 (ESRI 2004) and built the map taking into consideration the date the species were collected.

RESULTS

We identified 80 snake species distributed in 556 specimens and six families (Aniliidae, Boidae, Colubridae, Dipsadidae, Elapidae and Viperidae) in Paul Müller's collection (Table 1) (Fig. 1). The family Dipsadidae is the most represented in the collection, with the largest number of species (50 sp.) and specimens (N=357), followed by the family Viperidae, with 12 species and 109 specimens. *Bothrops jararaca* (N=65) and *Erythrolamprus poecilogyrus* (N=56) are the species with the highest number of specimens in the collection.

Most of the specimens (86%) were collected in Brazil between 1964 and 1976 (Fig. 2). During this period, Paul Müller made several herpetological expeditions to different states of the country (Fig. 3). However, Paul Müller did not collect all specimens, 29% of the specimens were collected by collaborators.

In the collection, there are five specimens of the genus *Bothrops* (*B. jararaca*, *B. leucurus*, *B. insularis*, *B. cotiara*, *B. pubescens*) collected in Brazil, between the years 1909 and 1963, which were donations, as well as five other specimens (*Bothrops bilineatus, Bothrops jararaca*, *Chironius exoletus, Philodryas argentea* (N=2) which are from Ecuador.

In Paul Müller's collection there are snake specimens from all regions of Brazil, although most are from the south (N=422; 76%) and southeast (N=81; 14%). Most of the specimens in the collection were collected in the state of Rio Grande do Sul (53%), in the municipalities of São Leopoldo, Campo Bom, Portão and Taquara, in the state of Santa Catarina (22%), on the island of Santa Catarina, and in the state of São Paulo (13%), on the island of São Sebastião (Fig. 4). There is only one specimen from the Northeast region, a *Bothrops leucurus* collected in Bahia in 1912 and which was donated to the collection.

DISCUSSION

Paul Müller's first expeditions to Brazil were aimed at obtaining as much information as possible about the vertebrate fauna and butterflies from all over the country and thus increasing knowledge about the diversity of the fauna and inferring patterns from neotropical biogeography (Müller 1971; Monzel & Böhme 2010). According to Müller (1971), Brazil is of extreme zoogeographical interest, since it is the largest country in South America, with a tropical climate and a very differentiated vegetation zoning, it presents a transition between the humid forests of Ecuador, Colombia and Guyanas, on the one hand, and the dry areas of the Pampa Argentina and Paraguay, on the other. Although Müller had a vast knowledge of several groups of animals, most of his studies were in the area of herpetology (Monzel & Böhme 2010).

During his expeditions to Brazil, Müller visited several states, but concentrated his collections in the Brazilian coastal states, mainly Rio Grande do Sul, São Paulo and Santa Catarina. Of these, Rio Grande do Sul was the state with the largest number of snake specimens collected. Although the focus of Paul Müller's work in Brazil was on island fauna (e.g. Müller 1968a, b, c, 1969c, b, a), most of the collection sites in Rio Grande do Sul are not islands. The number of specimens collected both in Rio Grande do Sul and Santa Catariana is also due to the help of Paul Müller's friends, who supported him in collecting the specimens and whom he thanked in his work. For example, Erno Böhler and Flavio Silva (both from São Leopoldo) and Canisius Ritter (Florianópolis) (e.g. Müller 1968c, 1971).

The most numerous species in Paul Müller's collection were *Bothrops jararaca* and *Erythrolamprus poecilogyrus*. *Bothrops jararaca* is a species widely distributed in the South and Southeast of Brazil (Sazima 1992; Grazziotin et al. 2006) and common in the Serra do Mar region (Centeno et al. 2008). *Erythrolamprus poecilogyrus* is common and widely distributed throughout Brazil (Dixon & Markezich 1992; Alencar & Nascimento 2014). No species registered in Paul Müller's collection is in the threatened species category of the Brazilian red list of threatened species, except the *Bothrops insularis* species which is Critically Endangered (ICMBio 2018). Among the snakes in the collection are two specimens of *Uromacerina ricardinii*, used by Paull Müller to make the first record of the species for the state of Santa Catarina (see Müller 1978). Recently the species underwent a synonymization process and today it is known as *Cercophis auratus* (Hoogmoed et al. 2019).

There are four individuals of *Xenodon dorbignyi* from São Sebastião Island, in São Paulo. However, we believe that it may be a locality error, since the distribution of *X. dorbignyi* is restricted to the extreme south of Brazil, Uruguay, southern Paraguay and central-northern Argentina (Orejas-Miranda 1966; Giraudo 2001; Nenda & Cacivio 2007; Kunz et al. 2011; Cacciali et al. 2016).

In the collection, there are still some species that present information from interesting collection locations. For example, there are two specimens of *Dipsas turgidus* collected in Florianópolis, Santa Catarina. In Brazil, the distribution of *D. turgidus* covers the states of Mato Grosso, Minas Gerais, Rio de Janeiro, Rio Grande do Sul and São Paulo (Wallach et al. 2014). In addition, other species with location information for São Sebastião and São Sebastião Island, in São Paulo, have not yet been registered in these locations. For example, *Bothrops alternatus* (n=4), *Micrurus frontalis* (n=1) and *Oxyrhopus petolarius* (n=1) collected in São Sebastião, and the species *Philodryas aestiva* (n=1), *Echinanthera melanostigma* (n=1) and *Erythrolamprus almadensis* (n=1) collected in São Sebastião Island (see, Cicchi et al. 2007; Centeno et al. 2008). These species may be rare in the region and, therefore, no records of these species have been found for these locations in scientific collections, there may be errors in the collection locations of these species or even some of these species may have disappeared from these locations.

The analysis of snake specimens from Paul Müller's collection can contribute to historical biogeographic and conservationist studies of Brazilian snake fauna. In addition, given the current scenario of material loss caused by recent incidents in large Brazilian collections, such as the fires at the Instituto Butantan in 2010 and the Museu Nacional in 2018, these collections can provide valuable information and help to "minimize" the impact of material loss.

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Table 1. Number of specimens (N) of each snake species in Paul Müller's collection, the respective catalogue number of the Zoological Research Museum Alexander Koenig (ZFMK) and the location where the species was collected. The abbreviations in the localities column correspond to the following Brazilian states: AM (Amazonas), BA(Bahia), MG (Minas Gerais), MT (Mato Grosso), PA (Pará), RJ Rio de Janeiro, RS (Rio Grande do Sul), SC (Santa Catarina) and SP (São Paulo).

Family/*Species*	**N**	**(ZFMK)**	**Localities**
Aniliidae			
Anilius scytale (Linnaeus, 1758)	1	102325	AM: Manaus
Boidae			
Boa constrictor Linnaeus, 1758	10	091896, 096323-28, 096357-59	AM: Manaus, Careiro; PA: Santarém, Belém, Marituba, Ilha de Marajo
Epicrates crassus Cope, 1862	1	102405	MG: Pedro Leopoldo
Colubridae			
Chironius bicarinatus (Wied-Neuwied, 1820)	7	102129-34, 102453	RS: São Leopoldo; SP: Ilha de São Sebastião, São Sebastião
Chironius exoletus (Linnaeus, 1758)	6	102374, 102448, 102463, 102591-92, 102609	RS: São Leopoldo, SC: Florianópolis; Ecuador
Chironius fuscus (Linnaeus, 1758)	1	102607	Brazil
Chironius quadricarinatus Boie, 1827	1	102608	MT: Cuiabá
Drymarchon corais (Boie, 1827)	1	102407	RS: Taquari
Leptophis ahaetulla (Linnaeus, 1758)	2	102380-81	AM: Uaupés, Manaus

Family/*Species*	N	(ZFMK)	Localities
Palusophis bifossatus (Raddi, 1820)	2	102170, 102624	RS: São Leopoldo
Spilotes pullatus (Linnaeus, 1758)	3	102110, 102602-03	RS: São Leopoldo; SC: Florianópolis; SP: Ilha de São Sebastião
Spilotes sulphureus (Wagler, 1824)	2	102090-91	AM: Manaus
Dipsadidae			
Apostolepis assimilis (Reinhardt, 1861)	1	102120	SC: Florianópolis
Atractus paraguayensis Werner, 1924	5	102191, 102439-43	RS: Taquara; SC: Florianópolis
Atractus reticulatus (Boulenger, 1885)	2	102140-102534	RS: São Leopoldo
Cercophis auratus (Schlegel, 1837)	2	102484-85	SC: Florianópolis
Dipsas albifrons	2	102510, 102517	SP: Ilha de São Sebastião
Dipsas indica Laurenti, 1768	1	102201	RS: São Leopoldo
Dipsas mikanii (Schlegel, 1837)	1	102458	RS: São Leopoldo
Dipsas neuwiedi (Ihering, 1911)	11	102660-69, 102671	SC: Ilha de Santa Catarina;
Dipsas turgida Cope, 1868	6	102203-04, 102541, 102459, 102613-14	SC: Ilha de Santa Catarina; RS: Campo Bom, Morro Reuter, São Leopoldo
Dipsas ventrimaculatus (Boulenger, 1885)	18	102193, 102198, 102460-62, 102569-79, 102606, 102622	RS: Santa Cruz do Sul; São Leopoldo

Family/*Species*	**N**	**(ZFMK)**	**Localities**
Echinanthera cephalostriata Di Bernardo, 1996	2	102491-92	SP: Ilha de São Sebastião
Echinanthera cyanopleura (Cope, 1885)	5	102449, 102530, 102610, 102615, 102617	RS: Campo Bom, São Leopoldo, Taquara; SC: Florianópolis
Echinanthera melanostigma (Wagler, 1824)	1	102092	SP: Ilha de São Sebastião
Erythrolamprus aesculapii (Linnaeus, 1758)	2	102178, 102383	MT: Cuiabá; SP: São Sebastião
Erythrolamprus almadensis (Wagler, 1824)	9	102207, 102209, 102445, 102475, 102483, 102493-94, 102513, 102605	MT: Cuiabá, RS: São Leopoldo; SC: Florianópolis; SP: Ilha de São Sebastião
Erythrolamprus jaegeri (Günther, 1858)	9	102126, 102206, 102496, 102542-43, 102600, 102648, 102673-74	RS: São Leopoldo, Taquara
Erythrolamprus miliaris (Linnaeus, 1758)	35	102128, 102136, 102137-39, 102165-69, 102438, 102456-57, 102473-74, 102488-90,102535-39, 102580, 102594-99, 102626, 102675-76, 102682-83	RS: Campo Bom, São Francisco de Paula, São Leopoldo, Taquara; SC: Florianópolis; SP: Ilha de São Sebastião
Erythrolamprus poecilogyrus (Wied-Neuwied, 1825)	56	102187, 102189, 102199, 102200, 102205, 102350-51, 102379, 102436-37, 102447, 10245052, 10246467, 102477, 102482, 102486-87,	MT: Cuiabá, PA: Marajó; RS: Balneário Pinhal, Campo Bom, São Leopoldo, Novo Hamburgo, Panambi, Passo Fundo, Portão, Porto Alegre,

Family/*Species*	**N**	**(ZFMK)**	**Localities**
		102514, 102524-29, 102544-48, 102618, 102625-28, 102640, 102649-58, 102677-80, 102684-87	Santa Cruz do Sul, São Francisco de Paula, São Leopoldo, Taquara, Viamão, SC: Florianópolis.
Erythrolamprus semiaureus (Cope, 1862)	3	102497-98, 102516	RS: São Leopoldo, São Sebastião do Caí
Erythrolamprus typhlus (Linnaeus, 1758)	1	102320	RS: Taquara
Helicops carinicaudus (Wied-Neuwied, 1825)	16	102153-58, 102384, 102469, 102499, 102500, 102504-58, 102561	RS: São Leopoldo,
Helicops infrataeniatus Jan, 1865	27	102159-64, 102501-09, 102515, 102559, 102612, 102616, 102630	RS: Campo Bom, Porto Alegre, São Leopoldo
Lygophis anomalus (Günther, 1858)	2	102152, 102468	RS: São Leopoldo, SC: Ilha de Santa Catarina
Lygophis flavifrenatus Cope, 1862	2	102481, 102672	RS: Passo Fundo, Viamão
Lygophis lineatus (Linnaeus, 1758)	4	102551-54	PA: Marajó
Oxyrhopus clathratus Duméril, Bibron & Duméril, 1854	6	102478-83	RS: São Leopoldo
Oxyrhopus formosus (Wied-Neuwied, 1820)	1	102633	AM: Manaus
Oxyrhopus guibei Hoge & Romano, 1977	1	102173	RS: São Sebastião do Caí

Family/*Species*	N	(ZFMK)	Localities
Oxyrhopus petolarius (Linnaeus, 1758)	1	102202	SP: São Sebastião
Oxyrhopus rhombifer Duméril, Bibron & Duméril, 1854	12	102143-51, 102195-97	RS: Morro Reuter, Novo Hamburgo, Santa Cruz do Sul, São Leopoldo
Phalotris lemniscatus (Duméril, Bibron & Duméril, 1854)	1	102194	RS: São Leopoldo
Phalotris reticulatus (Peters, 1860)	1	102639	RS: São Leopoldo
Philodryas aestiva (Duméril, Bibron & Duméril, 1854)	12	102121, 102122, 102171, 102179, 102454, 102471, 102495, 102587-90, 102643	RS: São Leopoldo, SC: Florianópolis, Ilha de Santa Catarina, SP: Ilha de São Sebastião
Philodryas argentea (Daudin, 1803)	3	102406, 102619-20	AM: Manaus; Ecuador
Philodryas olfersii (Lichtenstein, 1823)	19	102093-99, 102104, 102109, 102172, 102180, 102442, 102455, 102470, 102480, 102549, 102550, 102644, 102647	SC: Ilha de Santa Catarina; RS: General Câmara, Morro Reuter, Panambi, Portão, Santa Cruz do Sul, São Leopoldo, Taquara
Philodryas patagoniensis (Girard, 1858)	9	102135, 102446, 102472, 102476, 102547, 102611, 102631-32, 102670	RS: Passo Fundo, São Leopoldo, SC: Florianópolis; SP: Ilha de São Sebastião, São Sebastião
Pseudoboa haasi (Boettger, 1905)	1	102208	RS: São Leopoldo

Family/*Species*	**N**	**(ZFMK)**	**Localities**
Pseudoboa neuwiedii (Duméril, Bibron & Duméril, 1854)	1	102531	AM: Manaus
Siphlophis pulcher (Raddi, 1820)	1	102638	SC: Florianópolis
Taeniophallus bilineatus (Fischer, 1885)	2	102601, 102645	SC: Ilha de Santa Catarina; SP: Ilha de São Sebastião
Thamnodynastes sp.	1	102681	RS: São Leopoldo
Thamnodynastes nattereri (Mikan, 1828)	9	102182-86, 102511-12, 102532, 102584	SP: Ilha de São Sebastião
Thamnodynastes hypoconia (Cope, 1860)	1	102192	SP: Ilha de São Sebastião
Thamnodynastes lanei Bailey, Thomas & Silva-Jr, 2005	1	102533	PA: Ilha de Marajó
Tomodon sp.	1	102659	RS: Taquara
Tropidodryas serra (Schlegel, 1837)	3	102117, 102634-35	SC: Florianópolis
Tropidodryas striaticeps (Cope, 1870)	1	102636	SC: Florianópolis
Xenodon dorbignyi (Bibron, 1854)	13	102174-77, 102518-23, 102540, 102593, 102637	RS: Campo Bom, Praia da Pinhal, São Leopoldo; SC: Florianópolis; SP: Ilha de São Sebastião
Xenodon matogrossensis (Scrocchi & Cruz, 1993)	1	102604	MT: Rondonópolis

Family/*Species*	**N**	**(ZFMK)**	**Localities**
Xenodon merremii (Wagler, 1824)	26	102101-07, 102333-36, 102382, 102391-04, 102444	RS: Santa Cruz do Sul, São Francisco de Paula, São Leopoldo, Taquara
Xenodon neuwiedii Günther, 1863	4	102123, 102127, 102181, 102646	RS: Morro Reuter, São Leopoldo; SC: Florianópolis, Ilha de Santa Catarina
Elapidae			
Micrurus altirostris (Cope, 1860)	18	096392-01, 102111-15, 102188, 102190, 102621	RS: Campo Bom, Portão, Santa Cruz do Sul, São Leopoldo
Micrurus averyi Schmidt, 1939	1	102629	AM: Manaus
Micrurus corallinus (Merrem, 1820)	30	102141, 102387-90, 102408-32	SC: Florianópolis; SP: Ilha de São Sebastião
Micrurus frontalis Duméril, Bibron & Duméril, 1854	3	102386, 102623, 102108	MT: Cuiabá; SP: São Sebastião
Micrurus spixii Wagler, 1824	1		AM: Manaus
Viperidae			
Bothrops alternatus Duméril, Bibron & Duméril, 1854	9	102119, 102319, 102329, 102338-39, 102341, 102346, 102355, 102372	RS: Portão, São Leopoldo; SP: São Sebastião
Bothrops atrox (Linnaeus, 1758)	2	102142	AM: Manaus
Bothrops bilineatus (Wied-Neuwied, 1821)	1	102378	Ecuador: Quito
Bothrops cotiara (Gomes, 1913)	3	102118, 102310-11	RS: São Leopoldo

Family/*Species*	**N**	**(ZFMK)**	**Localities**
Bothrops diporus Cope, 1862	3	102124, 102125, 102344	RS: Erval seco, Portão
Bothrops insularis (Amaral, 1921)	1	93234	SP: Ilha de Queimada Grande
Bothrops jararaca (Wied-Neuwied, 1824)	65	32540, 102100, 102321-24, 102337, 102342, 102345, 102347, 102352-54, 102356-60, 102362-71, 102377, 102433-35, 102688-99	RJ: Rio de Janeiro; RS: São Leopoldo; SC: Florianópolis; SP: Ilha de São Sebastião, São Sebastião; Ecuador: Quito
Bothrops jararacussu Lacerda, 1884	3	102326, 102327, 102373	SP:Ilha de São Sebastião
Bothrops leucurus Wagler, 1824	1	102116	BA: Costa Oeste da Bahia
Bothrops moojeni Hoge, 1966	2	102328, 102343	MG: Pedro Leopoldo
Bothrops pubescens (Cope, 1870)	14	102312-18, 102330-32, 102340, 102348-49, 102361	RS: Panambi, Portão, São Leopoldo
Crotalus durissus Linnaeus, 1758	7	093229-33, 102375-76	MG: Belo Horizonte; RS: São Leopoldo; SP: Campinas

Figure captions

Fig. 1. Paul Müller's Snake Collection deposited at the Zoological Research Museum Alexander Koenig, Germany. *Philodryas olfersii* (ZFMK 102104), collected in Rio Grande do Sul (A), snake specimens from the collection (B), *Bothrops alternatus* (ZFMK 102119) collected in Rio Grande do Sul.

Fig. 2. Number of specimens collected per year (dotted line) and the cumulative percentage of specimens from Paull Müller's collection between 1964 and 1976 (non-dotted line).

Fig. 3. Paul Müller's journey through Brazil between 1964 and 1976 based on records of dates and locations of snake specimens. The color of the dotted lines represents the year of the journey and the arrow indicates the direction of movement throughout the year.

Fig. 4. Number of snake specimens from Paul Müller's collection collected in nine Brazilian states (Amazonas, Bahia, Minas Gerais, Mato Grosso, Pará, Rio de Janeiro, Rio Grande do Sul, Santa Catarina and São Paulo).

Figures

Fig. 1.

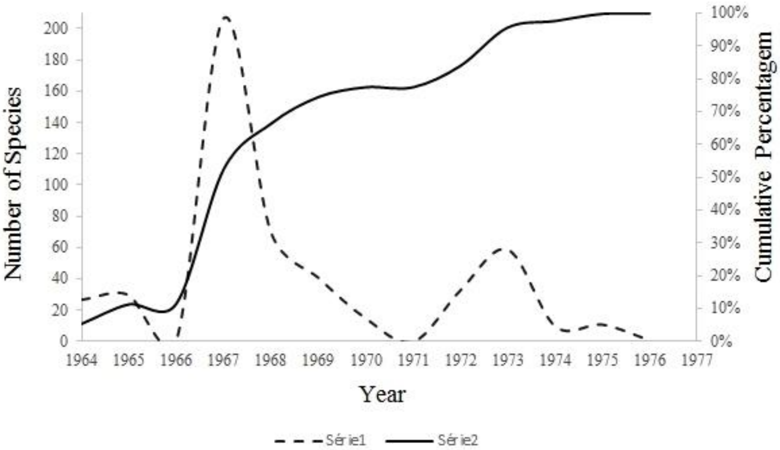

Fig. 2.

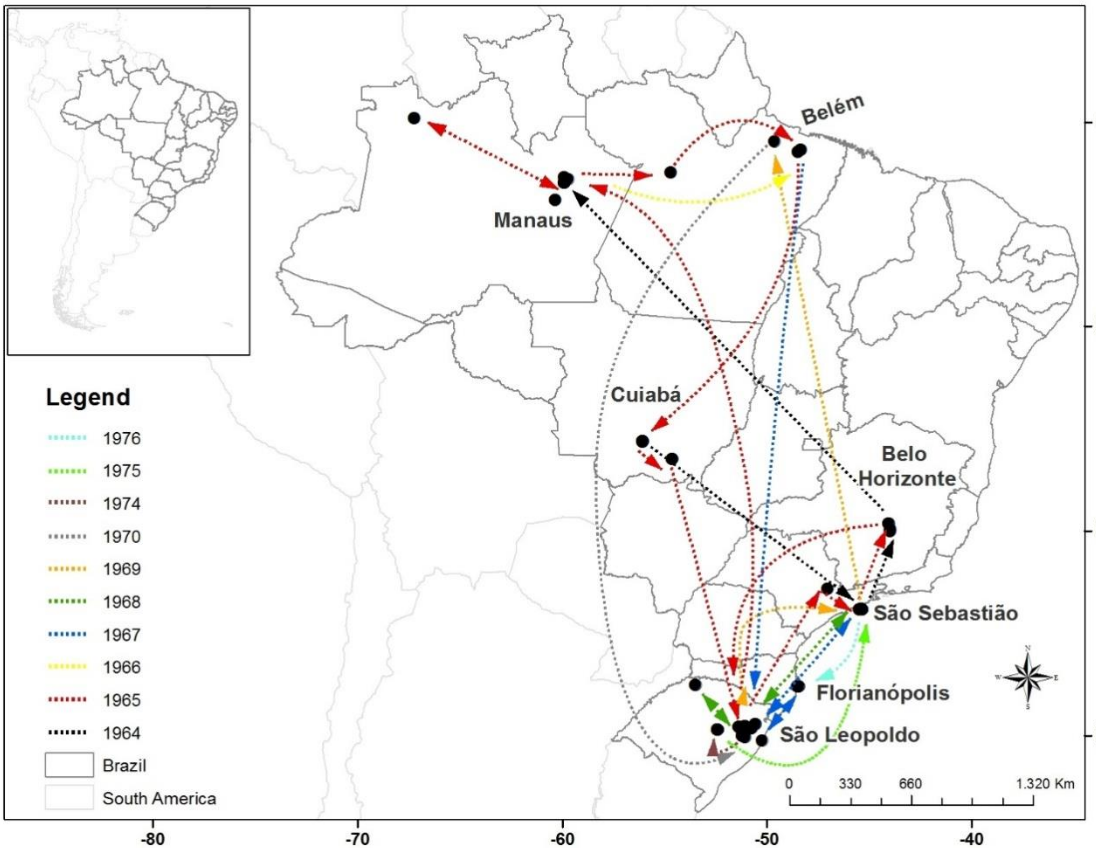

Fig. 3.

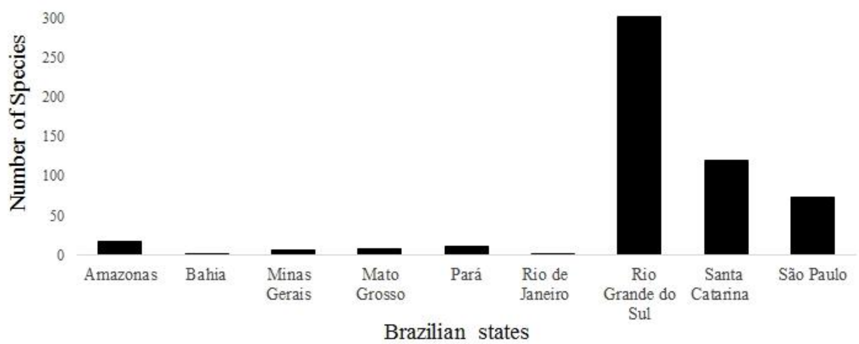

Fig. 4.

CONCLUSÕES GERAIS

No geral nossos resultados indicam que existe uma alta diversidade de espécies de serpentes no Centro de Endemismo Pernambuco, incluindo sete espécies endêmicas cujo conhecimento sobre história natural e ecologia são extremamente escassos. Revelamos que grande parte desta fauna de serpentes do CEP está ameaçada de extinção, principalmente pela maioria das espécies apresentarem uma distribuição restrita, serem raras e especialistas quanto a dietas, que são três fatores que aumentam a vulnerabilidade dessas espécies. Os nossos resultados também revelaram que as espécies de serpentes ameaçadas do CEP estão em três áreas específicas entre os estados da Paraíba e de Alagoas e que as unidades de conservação que estão presentes nestes locais (REBIO Guaribas, APA do Rio Mamanguape, REBIO de Pedra Talhada e a APA de Murici) são extremamente importantes para garantir a conservação destas espécies. Contudo, enfatizamos que esforços regionais de conservação precisam ser intensificados nessa região, pois poucas florestas são formalmente protegidas, e a maioria consiste de pequenos fragmentos mal protegidos.

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