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GEOGRAPHIC AND ALTITUDINAL DISTRIBUTION OF SNAKES OF THE FAMILY BOIDAE IN THE STATE OF BAHIA, NORTHEASTERN BRAZIL

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ABSTRACT

Documenting the current spatial distribution of species is one of the first steps for understanding the patterns and associated processes of biological evolution. We aim to map the geographical and altitudinal distribution, as well as identifying the predominant ecoregions of the presence of all species of snakes of the family Boidae in the state of Bahia, in northeastern Brazil. Thus, we expected to help describe and understand the patterns of the geographical distribution of Boidae species in South America. We analysed data from herpetological collections and literature to perform the distribution maps of Boidae species. Our results reported six species of Boidae in altitudes varying from four to 1,011 m above sea level, inhabiting the Atlantic coastal restingas, Atlantic dry forests, Bahia coastal forests, Bahia interior forests, Caatinga, Cerrado, Pernambuco interior forests, and campos rupestres montane savanna. No species widespread in all ecoregions though. The Brazilians herpetological collections consulted do not have a good representative sample for Boidae which may prejudice further biogeographic and evolutionary studies.

Key-words: Biological Collections; Ecoregions; Natural History; Range; Sampling gaps

RESUMO

Documentar a atual distribuição espacial das espécies é um dos primeiros passos para entender os padrões e processos associados à evolução biológica. Nosso objetivo é mapear a distribuição geográfica e altitudinal, bem como identificar as ecorregiões predominantes da presença de espécies de

serpentes da família Boidae no estado da Bahia, nordeste do Brasil. Assim, esperamos auxiliar na descrição e compreensão dos padrões de distribuição geográfica dos Boidae na América do Sul. Nós analisamos dados de coleções herpetológicas, complementados por dados da literatura, que serviram de base para construção dos mapas de distribuição. Nossos resultados reportaram seis espécies de boídeos, ocupando uma faixa altitudinal que variou de quatro a 1.011 metros acima do nível do mar, habitando as ecorregiões da restinga costeira Atlântica, floresta seca Atlântica, floresta da costa da Bahia, floresta do interior da Bahia, Caatinga, Cerrado, floresta do interior de Pernambuco e campos rupestres de savana montanhosa. No entanto, nós não registramos nenhuma espécie com ampla ocorrência em todas as ecorregiões. As coleções herpetológicas brasileiras consultadas parecem não ter boa representatividade de boídeos, o que pode prejudicar os estudos biogeográficos e evolutivos.

Palavras-chave: Coleções Biológicas; Distribuição; Ecorregiões; História Natural; Lacunas de amostragem.

INTRODUCTION

Documenting the current spatial distribution of species is one of the first steps to understand the patterns and associated processes that leads to genetic variability and diversification (see Avise, 2009). This includes all scales of distribution, from continents to micro locality, and may encompasses latitude, longitude and altitude data (e.g. Ramette & Tiedje, 2007). The access of robust information on natural history and geographic distribution of species may also become important tool in determining conservation strategies in a world with increasing anthropogenic pressure (see Graham *et al.,* 2004; Guedes *et al*., 2018).

Species distribution patterns are still scarcely documented for most faunal groups (Nogueira *et al*., 2019). Among Squamata, snakes still have a scarcity of distribution data, because the sampling effort is generally high, especially in the Neotropics (Nogueira *et al*., 2019; Guedes *et al.*, 2018). Snakes are known to be spatially organized by climatic gradients across

elevation and latitude, however these data are even more scarce (see McCain, 2010). Tropical regions present high differences in temperature in short distances, mostly due to the variation of altitude and haziness (Ometto, 1981). Thus, changes in the climate, vegetation, and soil can be attributed to altitude and temperature, influencing the species geographical distribution (McCain, 2010; Moura *et al.*, 2016). Consequently, the snakes are excluded from most large-scale studies of biodiversity and distribution patterns (Guedes *et al.,* 2018).

Boidae snakes representatives still suffer constant threats due to factors such as habitat loss, hunting and commercialization for medicinal, magic/religious purposes, or pets (Alves & Pereira-Filho, 2007; Alves *et al.*, 2012). Thus, mapping the occurrence records of the species in detail may also contribute to assist in developing appropriate conservation strategies (Nogueira *et al.*, 2019).

The Boidae (Squamata; Serpentes) snakes belong to the superfamily Booidea and include the genus *Boa* Linnaeus 1758*, Chilabothrus* Duméril & Bibron 1844*, Corallus* Daudin 1803*, Epicrates* Wagler 1830*,* and *Eunectes* Wagler 1830, are distributed along the New World tropics, from northern Mexico to Argentina, and the West Indies (Pyron *et al.*, 2014). There are 12 recorded species in Brazil (see Costa & Bérnils, 2018), six of them occurring in the state of Bahia: *Boa constrictor* Linnaeus 1758*, Corallus hortulanus* (Linnaeus 1758)*, Epicrates assisi* Machado, 1944*, E. cenchria* (Linnaeus 1758)*, E. crassus* Cope, 1862, and *Eunectes murinus* (Linnaeus 1758) (Hamdan & Lira-da-Silva, 2012; Costa & Bérnils, 2018). Nevertheless, there are no refined data on ecoregion, altitude and range distribution for Boidae within the Bahia state.

Here we provide updated maps of the geographical and altitudinal distribution of all Boidae species recorded for the state of Bahia, as well as identify its predominant ecoregions. We expect (1) to help describe and understand the patterns of the geographical distribution of Boidae species in South America; (2) to point out the occurrence of species in priority areas for conservation, since all species of the Boidae family listed for Bahia, despite not

currently presenting threat status, can become threatened, if their exploitation is not properly controlled (CITIES, 2020).

MATERIALS AND METHODS

Study area

The state of Bahia is located in Northeastern Brazil, between the 8' and 18' south latitude and 37' and 45' west longitude of the Greenwich meridian. The state covers an area of approximately 565,000 km^2, which represents nearly 7% of the Brazilian territory and 37% of the Northeastern region of Brazil (IBGE, 2017). Bahia State possesses a rich vegetal cover, comprising the Atlantic rainforest, Caatinga, and Savanna dominions (Ab'saber 1977; 2003), and their respective phytophysiognomies: ombrophilous forest, semi-deciduous seasonal forest, deciduous seasonal forest, and restingas (IBGE, 1992). The altitudes varying from sea level, such as in the district of Canavieiras and Prado, to 2,033 m, such as the Pico do Barbado in the Chapada Diamantina. The average annual temperature is approximately 28°C and the climate ranges from arid to semi-arid, sub-humid to dry, humid to sub-humid or humid, with annual rainfall ranging from 300 to 2,000 mm (SEI, 1998; INMET, 2010).

The state of Bahia harbors nine ecoregions: 1) Atlantic coastal restingas, 2) Atlantic dry forests, 3) Bahia coastal forests, 4) Bahia interior forests, 5) Caatinga, 6) Cerrado, 7) Pernambuco interior forests, 8) southern Atlantic mangroves, and 9) campos rupestres montane savanna (Olson *et al.*, 2001). We established the habitat use for each species through the inspection of the ecoregions of the municipal district where the snakes were collected.

Data collection

The species occurrence records were based on the following herpetological collections: (1) The Natural History Museum, London, UK (NHM); (2) Coleção Herpetológica Alphonse Richard Hoge, Instituto Butantan, São Paulo, SP (IB); (3) Coleção Herpetológica do Museu de Zoologia da Universidade de São Paulo, São Paulo, SP (MZUSP); (4) Museu Nacional, Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ (MNRJ); (5)

Coleção Científica Instituto Vital Brazil, Niterói, RJ (IVB); (6) Coleção Herpetológica do Museu de Zoologia da Universidade de Brasília, Brasília, DF (CHUNB); (7) Museu de Zoologia da Universidade Estadual de Santa Cruz, Ilhéus, BA (MZUESC); (8) Coleção Zoológica Gregório Bondar, Comissão Executiva do Plano da Lavoura Cacaueira (CEPLAC), Ilhéus, BA (CZGB); (9) Coleção Científica de Animais Peçonhentos e Herpetologia da Universidade Estadual de Feira de Santana, Feira de Santana, BA (CCAPHUEFS); and (10) Coleção de Répteis do Museus de História Natural da Universidade Federal da Bahia, Salvador, BA (MHNUFBA); as well as the following specific bibliography: Wücherer, 1861; Günther, 1862; Wücherer, 1863; Vanzolini *et al.*, 1980; Franco *et al.*, 1998; Argôlo, 2004; Argôlo, 2005; Dias & Rocha, 2005; Lugli & Juncá, 2008, Marques *et al.*, 2012; Freitas *et al.*, 2012; Freitas, 2014; Marques *et al.*, 2016; Freitas *et al.*, 2016a; Freitas *et al.*, 2016b; Freitas *et al*., 2018; Freitas *et al.*, 2019. We included only records identified at the species level. Finally, we added data from the Voucher Book of the Núcleo de Ofiologia e Animais Peçonhentos da Bahia (NOAP/UFBA), which comprises all snakes that are collected or delivered by the population to the NOAP, as well as those with geographic coordinate and documented photography provided by herpetologists (B. Hamdan, D. Pinto-Coelho, R. Abreu, M. Soeiro, and T. Filadelfo). We adopted this procedure since most species of this family (e.g. *B. constrictor, Eunectes murinus, C. hortullanus* and *Epicrates cenchria*) are of easy taxonomic determination.

Distribution maps

We drew the distribution maps using the shapefile of ecoregions provided by Olson *et al.* (2001). The geographic coordinates were obtained in gazetteer (CidVil), scientific publications, or based on direct observation through GPS. All maps were built in software Arcgis version 10.1.

Taxonomic nomenclature and species identification

Taxonomic nomenclature follows Costa & Bérnils (2018), although *Boa constrictor* has been only identified to the species level. The identification of the specimens followed Peters & Orejas-Miranda (1970) for genus *Boa*, Henderson

(1997) for genus *Corallus*, Passos & Fernandes (2008) for genus *Epicrates,* and Dirksen & Böhme (2005) for genus *Eunectes*.

RESULTS

We analysed 1,385 records of specimens of the Boidae family, registered between the years of 1861 and 2019, inhabiting eight of the nine ecoregions of the state of Bahia. We found records of all the six species of the Boidae family occupying the ecoregion Bahia interior forest. On the other hand, there were no records of the Boidae species for the ecoregion Southern Atlantic mangroves (Table I). The records covered 142 municipalities, including protected areas, such as Parque das Dunas (Salvador), the Parque Nacional da Chapada Diamantina (central Bahia) and Parque Estadual Serra do Conduru (southern Bahia). All species were registered in extreme priority areas for conservation, such as in the municipalities of Caetité and Jequié, in the Caatinga ecoregion; Barreiras and São Desidério, in the Cerrado ecoregion; and Ilhéus and Valença, in the Bahia coastal forest ecoregion (Appendix I).

Boa constrictor (Fig. 1a). We compiled records of 652 specimens occurring in eight ecoregions and 80 municipal districts (Fig. 2) (Appendix I). Individuals of *Boa constrictor* were recorded in altitudes ranging from 4 m in the district of Prado, south of Bahia, up to 1,011 m in Morro do Chapéu, an extreme priority area for conservation, in the Chapada Diamantina (Fig. 3). This species is relatively common in areas of great human settlement such as the state capital, Salvador, and the surrounding metropolitan region (Appendix I).

Corallus hortulanus (Fig. 1b). We compiled records of 369 specimens in six ecoregions (Fig. 2) and 60 municipal districts in Bahia (Appendix I). The species inhabit mostly Bahia coastal forest ecoregion and were recorded in altitudes ranging from 4 m in Canavieiras, the southern coastline of the state, up to 923 m in Vitoria da Conquista, in the southeast of Bahia (Fig. 4).

Eunectes murinus (Fig. 1c). We compiled records of 102 specimens in four ecoregions (Fig. 2) and 17 municipal districts in Bahia (Appendix I). The species predominantly inhabits the lowland coastline region of Bahia, with most

records in Bahia coastal forests, usually in altitudes around sea level (Fig. 5). The records in the Atlantic dry forests regions are lower frequency, such as wetland regions (APA Marimbus-Iraquara / Parque Nacional da Chapada Diamantina) in the municipality of Lençóis, with an average altitude of 350 m.

Epicrates cenchria (Fig. 1d). We compiled records of 174 specimens in four ecoregions (Fig. 2) and 39 districts in Bahia (Appendix I). The species inhabit mostly Bahia coastal forest ecoregion and were recorded in altitudes ranging from 4 m in Canavieiras, up to 726 m in Boa Nova (Fig. 6).

Epicrates assisi (Fig. 1e). We compiled records of 83 specimens in five ecoregions (Fig. 2) and 42 districts in Bahia (Appendix I). *Epicrates assisi* inhabits more open and dry areas and occurs in altitudes ranging from 32 m in Mata de São João, up to 983 m in Mucugê, in the Chapada Diamantina (Fig. 7).

Epicrates crassus (Fig. 1f). We compiled records of seven specimens in three ecoregions (Fig. 2) and five districts in Bahia (Appendix I). The records indicate that this species inhabits more open and dry areas, from 452 m in Barreiras, up to 760 m in Poções, both in western region of Bahia state (Fig. 8), including extreme priority areas for conservation.

Table I: Richness and composition of snakes from the Boidae family recorded for the state of Bahia and their different ecoregions of occurrence. ACR = Atlantic Coastal Restingas; ADF = Atlantic Dry Forests; BCF = Bahia Coastal Forests; BIF = Bahia Interior Forests; Ca = Caatinga; Ce = Cerrado; PIF = Pernambuco Interior Forests; SAM = Southern Atlantic Mangroves; CRMS = Campos Rupestres Montane Savanna (Olson *et al.,* 2001).

Taxon	Ecoregions								
Species	ACR	ADF	BCF	BIF	Ca	Ce	PIF	SAM	CRMS
Boa constrictor Linnaeus 1758	X	X	X	X	X	X	X		X
Corallus hortulanus Linnaeus 1758	X	X	X	X	X	X			
Eunectes murinus Linnaeus 1758	X	X	X	X					
Epicrates assisi Machado, 1944		X	X	X	X	X			X
Epicrates cenchria Linnaeus 1758	X		X	X					
Epicrates crassus Cope, 1862		X		X		X			
Total	4	5	5	6	3	4	1	0	2

Figure 1 a-f. Snakes of the Boidae family in the state of Bahia, Brazil. a. *Boa constrictor*; b. *Corallus hortulanus*; c. *Eunectes murinus*; d. *Epicrates cenchria*; e. *Epicrates assisi*; f. *Epicrates crassus*. Photos: a. Rafael Abreu; b and c. Breno Hamdan; d. Carlos Cintra; e. Thiago Filadelfo; and f. Marco Freitas.

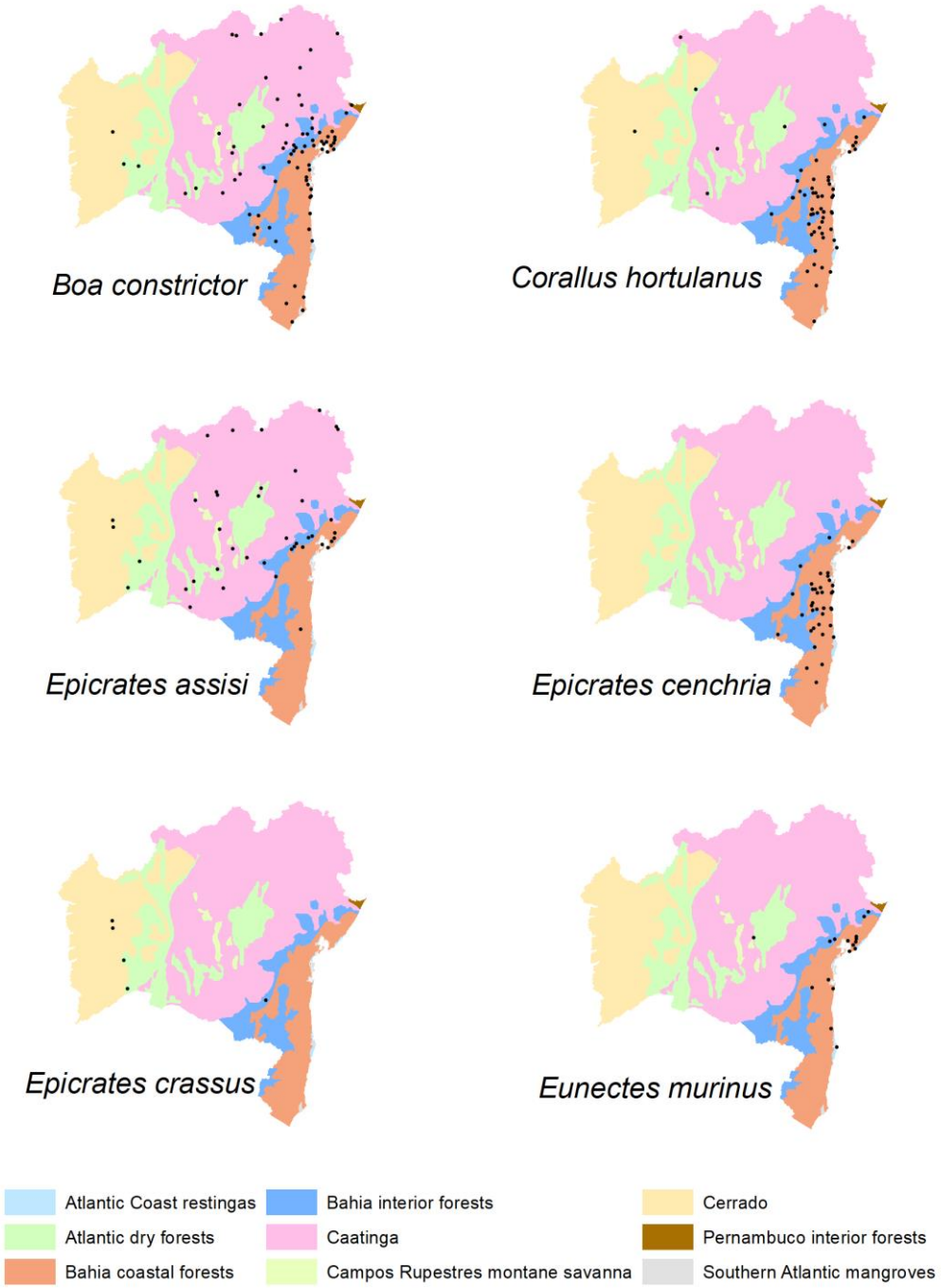

Figure 2. Distribution map of Boidae snakes across different ecoregions in the state of Bahia, Brazil.

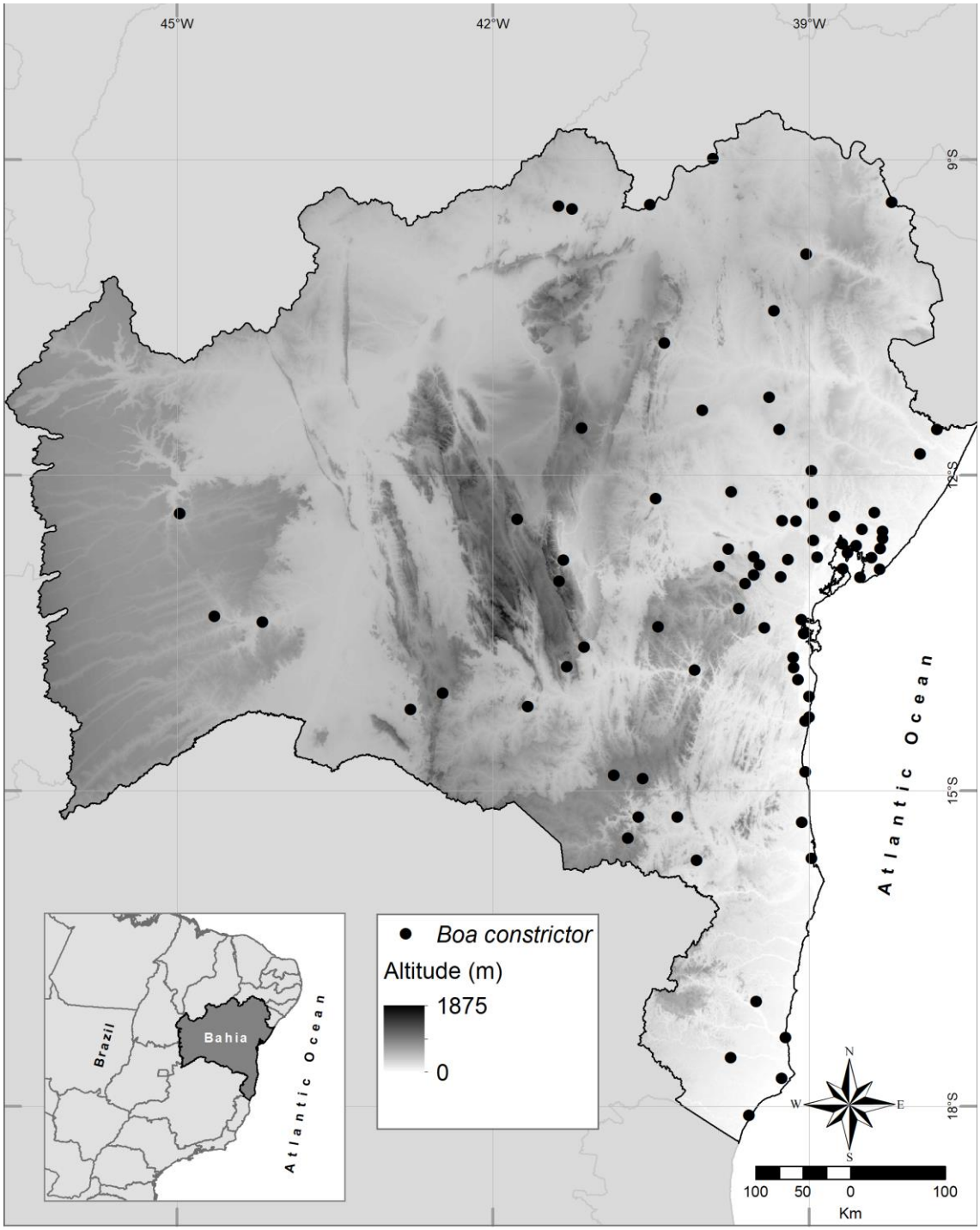

Figure 3. Geographic distribution records for *Boa constrictor* in the state of Bahia, Brazil.

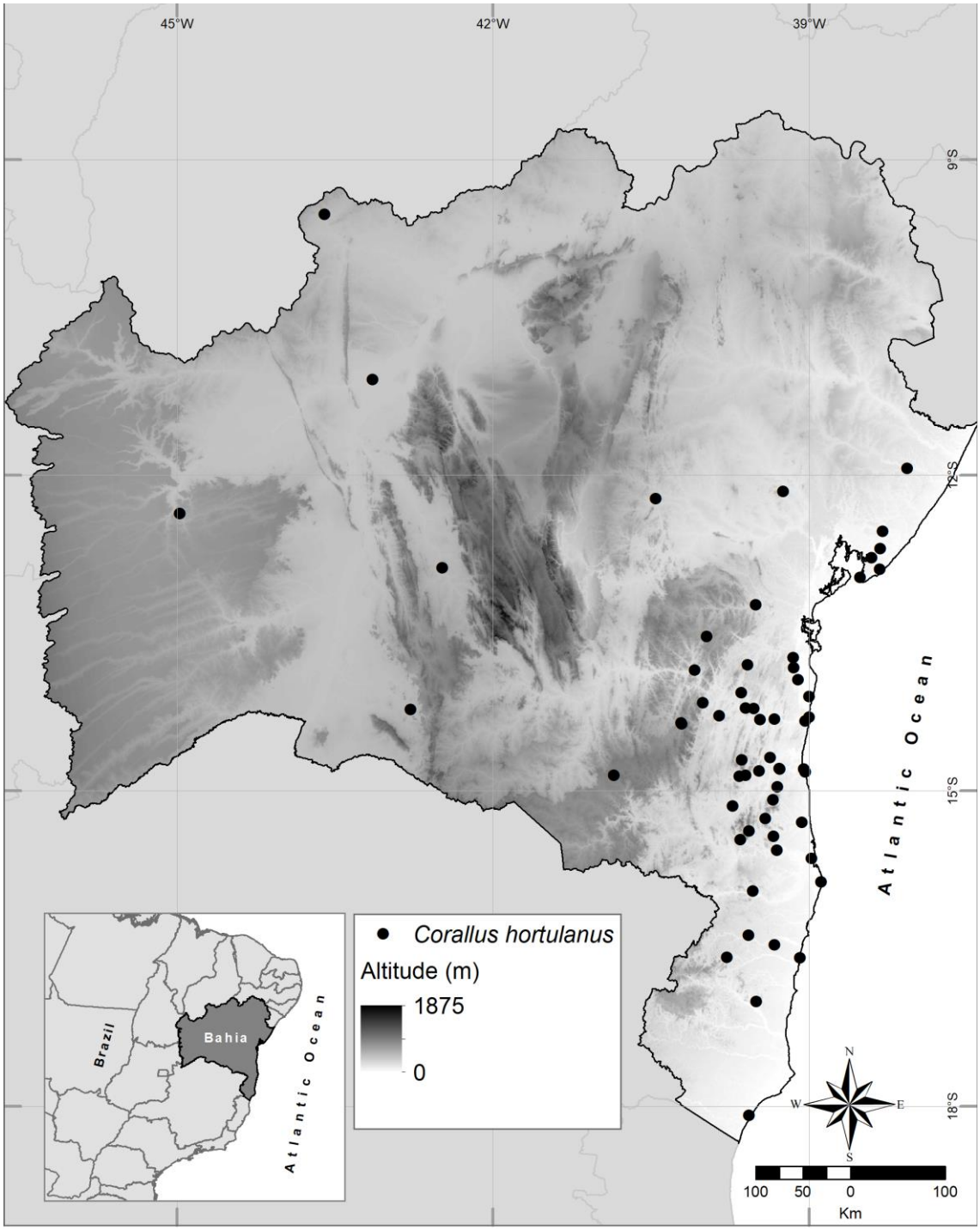

Figure 4. Geographic distribution records for *Corallus hortulanus* in the state of Bahia, Brazil.

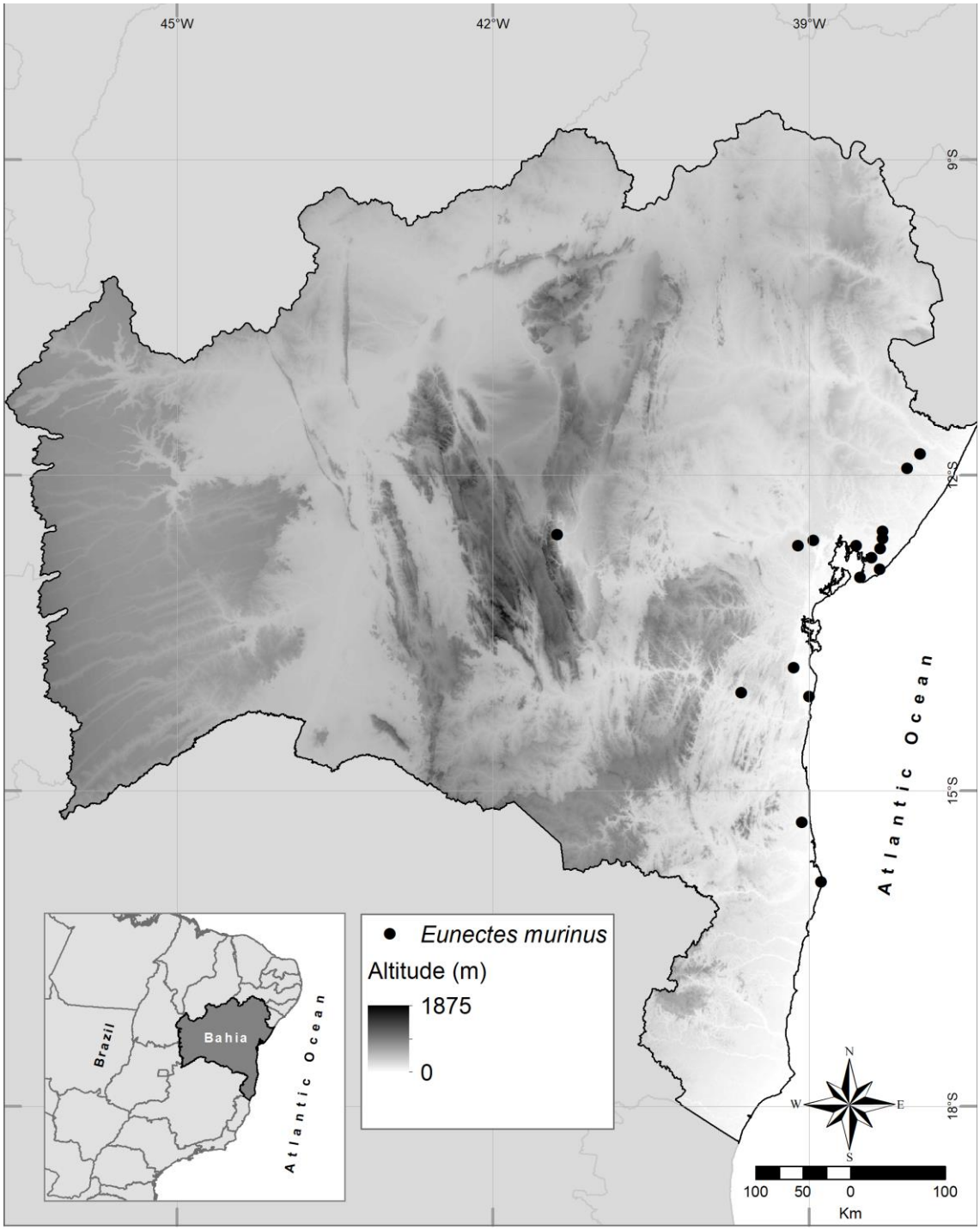

Figure 5. Geographic distribution records for *Eunectes murinus* in the state of Bahia, Brazil.

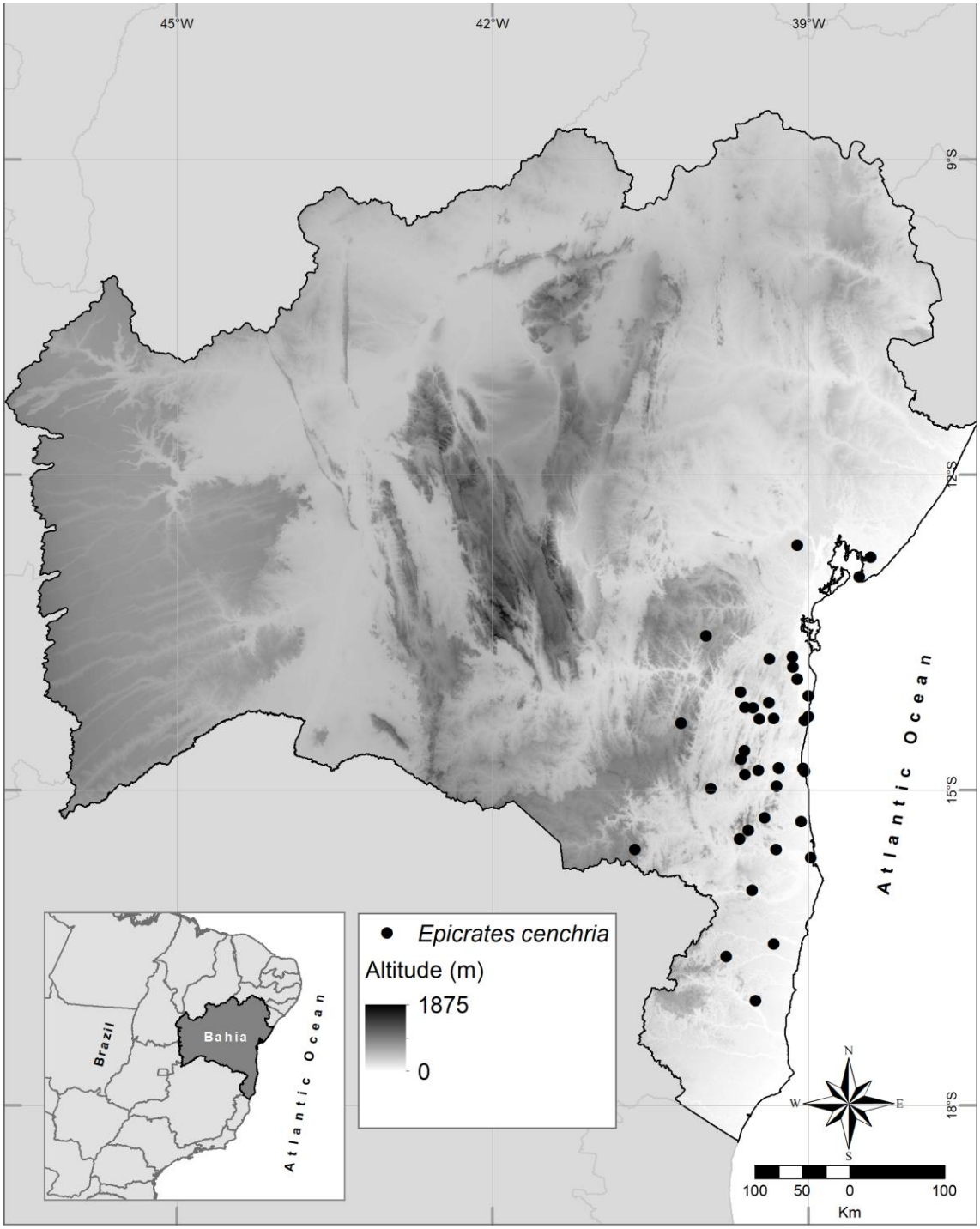

Figure 6. Geographic distribution records for *Epicrates cenchria* in the state of Bahia, Brazil.

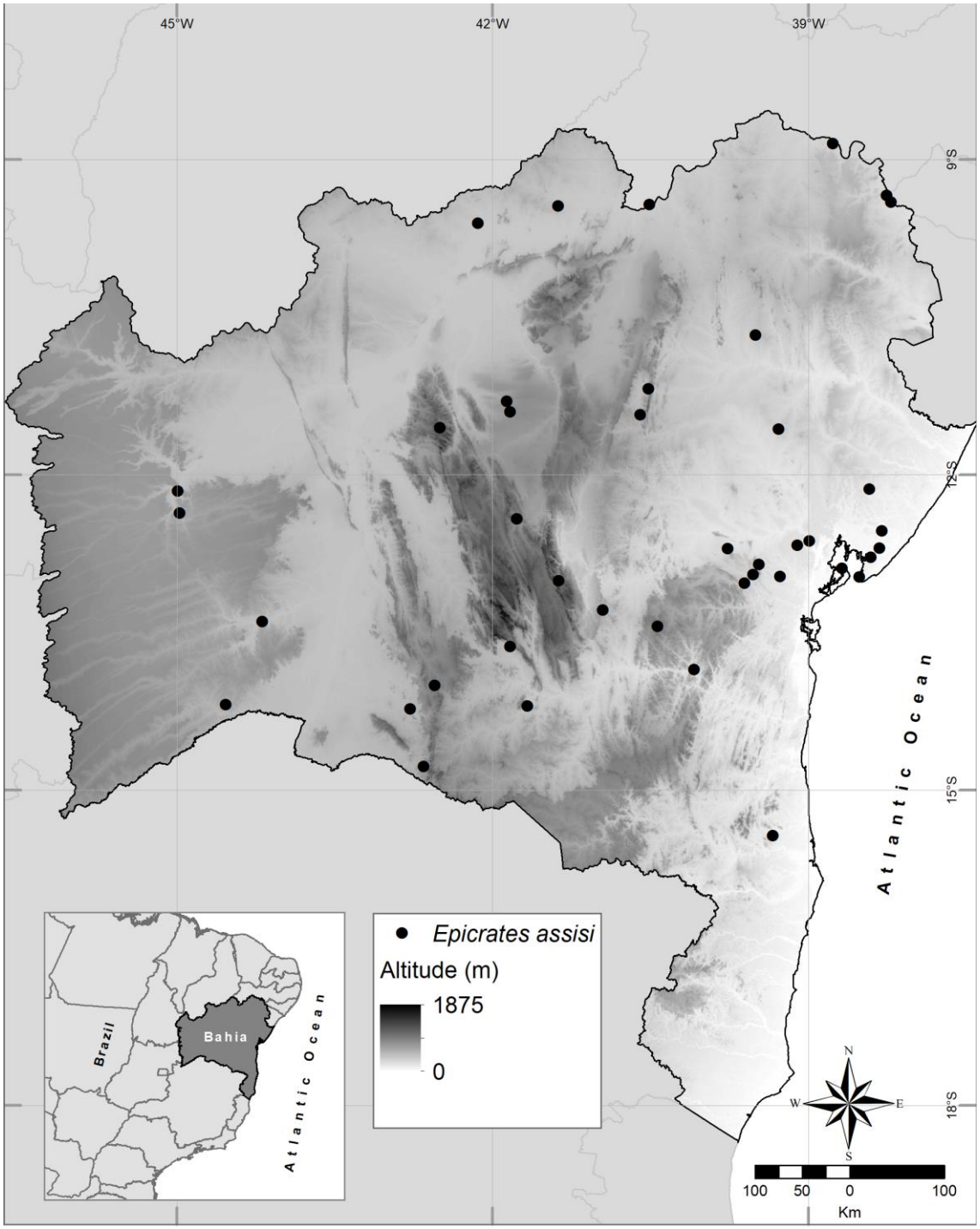

Figure 7. Geographic distribution records for *Epicrates assisi* in the state of Bahia, Brazil.

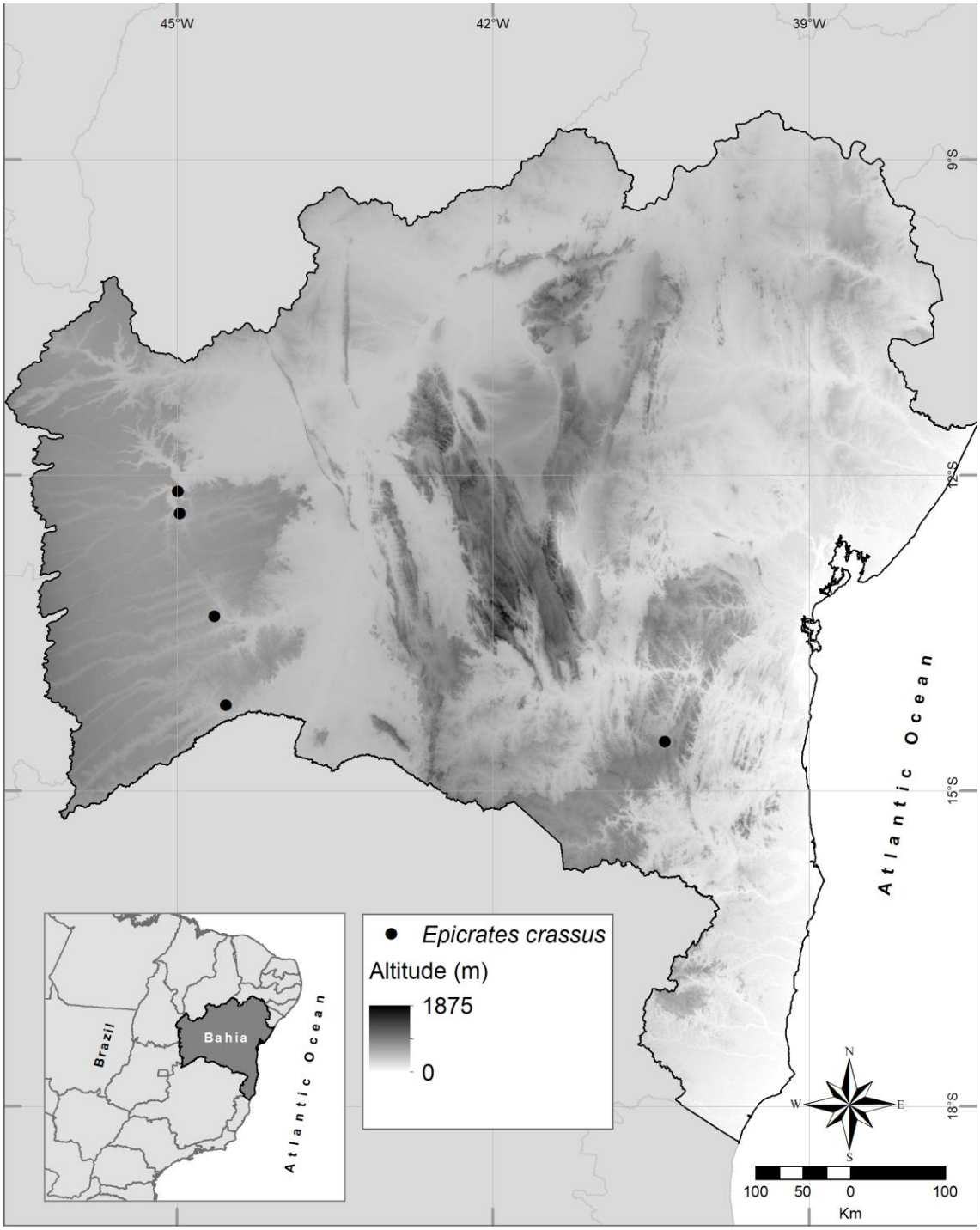

Figure 8. Geographic distribution records for *Epicrates crassus* in the state of Bahia, Brazil.

Among the three species of the genus *Epicrates*, *E. assisi* and *E. crassus* occur syntopically in the municipality of Barreiras, western Bahia, whereas *E. assisi* and *E. cenchria* in the municipality of Santa Luzia, southern Bahia, and Simões Filho, metropolitan region of Salvador. Other syntopic finds are highlighted in Appendix I.

DISCUSSION

We reported a widespread distribution of Boidae snakes in the state of Bahia, inhabiting eight of the nine ecoregions that cover the state, in altitudes ranging from sea level to 1,011 m. The first occurrences of the boas recorded in Bahia were reported by Wücherer (1861; 1863) with *Epicrates cenchria, Boa constrictor* and *Eunectes murinus*.

Boa constrictor had the highest number of records, being commonly found in anthropized areas, probably for being a generalist (Vanzolini *et al.*, 1980; Sawaya *et al.*, 2008; Bernarde *et al*., 2012; Marques *et al.*, 2017). Wücherer (1863) reported that *B. constrictor* used to be common in Salvador, Bahia during the 19th century. This species is still commonly recorded in the Salvador region, indicating its adaptability to man-made habitat (*e.g.* Marques *et al.*, 2017; Freitas, 2014). According to Guedes *et al*. (2014) it is present in all portions of the Caatinga, with the absence of records for the central regions of the state (*e.g.* municipalities of Jacobina, Seabra, Mundo Novo, Iramaia, Boninal, and Barra do Mendes) probably due to lack of sampling. Our data compilation indicated that *B. constrictor* occurs in the municipality of Seabra, an area with extreme priority for conservation (WWF, 2017).

Corallus hortulanus occurs in Atlantic forest, Amazon, Cerrado, Pantanal, Caatinga, and Restinga (Henderson, 1997; Strüssmann & Sazima, 1993; Martins & Oliveira, 1998; Argôlo, 2004; Sawaya *et al.*, 2008; Marques *et al.*, 2012; Guedes *et al.*, 2014). It was first recorded in the Salvador region only by Wücherer (1861; 1863). The species rediscovery occurred 150 years later by Marques *et al.* (2012), in the district of Lauro de Freitas, metropolitan region of

Salvador. Although it is an arboreal species, *C. hortulanus* seems to inhabit phytophysiognomies of the Caatinga, where small, thorny trees that shed their leaves seasonally are predominant (Guedes *et al.,* 2014).

Eunectes murinus is widely distributed along the Atlantic forest, Amazon, and Pantanal, being dependent on aquatic regions and have a good ability to adapt to areas of human settlement (Cunha & Nascimento, 1993; Strüssmann & Sazima 1993; Martins & Oliveira, 1998; Argôlo, 2004; Duarte, 2012). The area of occurrence in the Caatinga is adjacent to coastal areas with high humidity (Guedes *et al.*, 2014). Wücherer (1863) reports *E. murinus* as very common around the city of Salvador.

Most of the *E. murinus* records are in the coastal region of Bahia, with a low sampling margin in the southeast, probably due to adaptation to inhabit aquatic environments, which is not often found in the districts investigated (Argôlo, 2004). In the Atlantic Forest of northern Bahia, this species was found in habitats of wetland vegetation only (Marques *et al.*, 2017). The urban growth, the decrease and fragmentation of forest areas in the cities, and the embankments and pollution of many water bodies are probably the main factors responsible for any present or future threat (Tinôco, 2011; Puorto, 2012).

Herein we did not find *E. munirus* at high altitudes, in agreement with other regions along its whole geographic distribution. We suggest that accurate studies assess whether the absence of records in higher altitude areas is a possible physiological restriction of the species or geological environment or both (see McCain, 2010). The closest place at high altitude we reported was in APA Marimbus-Iraquara (Lugli & Juncá, 2008), a floodplain in Parque Nacional da Chapada Diamantina at 350 m above sea level.

We found species of *Epicrates* distributed from humid forests to Caatinga. *Epicrates cenchria* inhabits the Amazon and Atlantic Forest from Alagoas to Rio de Janeiro (Vanzolini *et al.,* 1980; Cunha & Nascimento, 1993; Guedes *et al*., 2014). The species seems to be more vulnerable due to their inability to bear high temperatures in open formations (Franco, 2003; Rodrigues, 2005). We mainly found records of *E. cenchria* in wet areas, such as

Bahia coastal forest, in concordance with Passos & Fernandes (2008). However, unlike the findings of Passos & Fernandes (2008), that indicated only sympatry, our data reported syntopy between *E. cenchria* and *E. assisi*, at the southern limit of distribution of *E. assisi*, in the district of Santa Luzia, Bahia coastal forest ecoregion.

Epicrates assisi is considered an endemic species of the Caatinga biome (Guedes *et al.*, 2014), occurring from Piauí to Bahia (Peters & Orejas-Miranda, 1970; Passos & Fernandes, 2008). As a consequence of the advance of deforestation in the Caatinga biome, especially due to cattle raising, agriculture, dams, and mining, an extra pressure is expected, may forcing the species to migrate to new habitats (Leal *et al.*, 2005; Guedes *et al.,* 2014). Furthermore, the presence of patches of Cerrado near the north coast of Bahia allows *E. assisi* to occur near or in the border of atlantic forest areas (Freitas, 2014).

Epicrates crassus is typical from Cerrado biome (Passos & Fernandes, 2008) and the low number of records we found precludes further discussion. There is one possible zone of syntopy for *E. assisi* and *E. crassus* in the west of Bahia (Passos & Fernandes, 2008), which constitute one ecotone between the Cerrado and Caatinga biomes (Ab'Saber, 1977). Our results also showed syntopy in the municipality of Barreiras, Cerrado ecoregion in western Bahia.

FINAL CONSIDERATIONS

Ecoregions are an important tool for use in conservation, as they allow agreement or incompatibility in the patterns of richness and endemism of the analyzed taxa (Olson *et al.,* 2001). Likewise, knowing the ranges of altitudinal distribution of species allows us to know how environmental factors limit the distribution of organisms (McCain, 2010). In general, the low number of Boidae specimens housed in the scientific collections, because of its large size and storage difficult, precludes deeper discussions on geographic and altitudinal distribution. The lack of information may hinder research on ecological processes of environmental occupation.

The acquisition of a few specimens for deposit in scientific collections would hardly contribute to species extinction (Rocha *et al.*, 2014). However, it is important to highlight that extinctions in both aquatic and terrestrial systems occur more frequently in large-bodied organisms, as boid snakes, in part because body size correlates positively with home range size and negatively with reproductive rate and population size (Woodward *et al.*, 2005).

In order to fill sampling gaps, we suggest fieldwork expeditions in the central and western regions of the state of Bahia, which include most of the areas with extreme priority for conservation. We also indicate that environmental consultants strive to publish lists of species from environmental impact studies as a way of increasing knowledge of species distribution, especially due to the difficulty in making financial resources available for extensive fauna inventories.

This research provides an update on the geographical distribution of all species from the Boidae in the state of Bahia, based on data collected for over 150 years. Moreover, we provide important data for future biogeography studies and conservation planning to the landscape.

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