

Distribution, threats and conservation of the White-collared Kite (*Leptodon forbesi*, Accipitridae), the most threatened raptor in the Neotropics

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Abstract. The White-collared Kite (*Leptodon forbesi*) is an endemic and threatened raptor of the Brazilian Atlantic Forest. Here we present the known records of the species, describe the vegetation types where it was found and show Ecological Niche Models generated using Maxent algorithm. Most of the presence data were recorded in open ombrophilous forest and seasonal semideciduous forest in the states of Alagoas and Pernambuco. Maxent model had a good performance ($AUC = 0.982 \pm 0.004$ SD), showing higher suitability for the species from Paraíba to Alagoas states. Maxent average model revealed a distribution range of 20,344 km² and an area of occupancy of 1,636.89 km². The most suitable areas for the species are those near watercourses and streams. We suggest the creation of protected areas, including private ones, and possible restoration actions to connect the most suitable forest fragments, along with the captive breeding, as the most appropriate strategies for the conservation of the White-collared Kite.

Key-Words. Raptors; Atlantic Forest; Brazil; Biogeography; Niche modeling.

INTRODUCTION

The White-collared Kite *Leptodon forbesi* (Swann, 1922; Fig. 1) is a diurnal raptor endemic to the Atlantic Forest of northeastern Brazil. It occurs in the states of Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, in the Pernambuco Center of Endemism, with a handful of records in Sergipe and northern Bahia (Dénes *et al.*, 2011; Pereira *et al.*, 2014; IUCN, 2016; Leite *et al.*, 2017; WikiAves, 2018). Until the beginning of the first decade of the 21st century almost nothing was known about *L. forbesi* and several authors, due the lack of specimens or even sight records, doubted the validity of the species. However, in the past ten years the literature on *L. forbesi*'s biology, taxonomy and ecology has significantly grown, and its specific status is no longer a question (Dénes *et al.*, 2011; Seipke *et al.*, 2011).

Leptodon forbesi is considered endangered both by international (IUCN, 2016) and national red lists (Brasil, 2014). Although *L. forbesi* was found in quite disturbed habitats, massive deforestation in the Atlantic Forest of northeastern Brazil and consequent habitat loss of habitat are the main threats for this species (IUCN, 2018). The extinction of many elements in this region is occurring now due the existing time lag between deforestation and extinction of endemic and threatened birds (Brooks & Balmford, 1996; Brooks *et al.*, 1999), as noticed for the birds (Pereira *et al.*, 2014). Ultimately, *L. forbesi* has been recorded sporadically even in urban forests of state capitals such as João Pessoa and Maceió, in NE Brazil (Pereira *et al.*, 2014), but no evidence of breeding activities was observed in these places.

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Figure 1. Adult of White-collared Kite (*Leptodon forbesi*). Photo: Yuri Raia.

Here we use Ecological Niche Models (ENM henceforth) to evaluate the environmental variables influencing *L. forbesi* distribution and the extent of the areas climatically suitable for the species. Information on habitat suitability presented here has the potential to inform future conservation actions for the maintenance of *L. forbesi* preferential habitat (see Thorn *et al.*, 2008; Marco-Júnior & Siqueira, 2009; Wu *et al.*, 2012; Giorgi *et al.*, 2014).

MATERIAL AND METHODS

We compiled all available records of *L. forbesi* published in the literature (Pereira *et al.*, 2006; Roda & Pereira, 2006; Dénes *et al.*, 2011; Seipke *et al.*, 2011; Del Hoyo *et al.*, 2014; Pereira *et al.*, 2014), those found in websites where the identity of the species could be verified (WikiAves, 2018), and our personal records. These presence data were recorded on five types of Atlantic Forest vegetation in NE Brazil: open ombrophilous forest, dense ombrophilous forest, ecological tension zone, seasonal semideciduous forest, and pioneer formation (IBGE, 2004). The maximum altitude in this region is 1,100 m (Tabarelli & Santos, 2004), the average annual temperature is between 24 and 26°C, with annual rainfall reaching about 2,000 mm in some areas (Nimer, 1977; IBGE, 1985). It is the most threatened area of the Neotropics (Pereira *et al.*, 2014) or even in the Americas, which is considered a hotspot within another hotspot.

We compiled 41 records of *L. forbesi* (Table 1), visiting all areas except those in Bahia and Rio Grande do Norte for validation (see below). To diminish sampling bias (see Brown, 2014), sampling data were rarefied by spatially filtering locality data by 1 km radius input Euclidian distance using SDMtoolbox v1.1b (Brown, 2014). This technique reduced occurrence data to a single point within ~ 7 km², based on the species' home range, resulting in 31 independent records.

Twenty-one environmental variables (19 climatic and 2 topographic) were tested as potential predictors for ENMs. The climatic variables were obtained from the Worldclim bioclimatic database (Hijmans *et al.*, 2005) and the topographic variables (elevation and declivity) were derived from the Shuttle Radar Topography Mission – SRTM (Jarvis *et al.*, 2008). All the environmental variables are available for Brazil in ASCII grid format, World Geodetic System 1984 (WGS-84), and 30 arc-seconds resolution (~ 1 km) (Amaral *et al.*, 2013).

To avoid overparameterization with redundant variables, we removed the strongly correlated ones (Dormann *et al.*, 2007). Therefore, variables with high correlation ($r > 0.7$) were eliminated, and a subset of 10 uncorrelated environmental variables was selected: mean diurnal range – bio 2, temperature seasonality – bio 4 (mean of monthly (max temp – min temp)), mean temperature of wettest quarter – bio 8, precipitation of driest month – bio 14, precipitation seasonality – bio 15 (coefficient of variation), precipitation of wettest quarter – bio 16, precipitation of warmest quarter – bio 18, precipitation of coldest quarter – bio 19, elevation, and declivity. For details on climatic variables see Hijmans *et al.* (2005).

The R Package 'dismo' (version 1.1-4) was used to apply the maximum entropy algorithm (Maxent – version 3.3.3k – Hijmans *et al.*, 2017). This algorithm uses environmental variables that are relevant to the species and presence-only data to calculate the probability of presence, making good predictions or inferences even with incomplete available data (Phillips *et al.*, 2006). Following Phillips *et al.* (2006), the model was generated by 10 bootstrapping randomly the presence records into training (75% of the records) and test (25% of the records).

The Receiver Operating Characteristics (ROC) was analyzed to evaluate the model performance, comparing to random prediction (Baldwin, 2009). The significance of the ROC plot is quantified using the Area Under the Curve (henceforth AUC) (Fielding & Bell, 1997). AUC provides a single measure of the model's performance, regardless of any threshold rule (Phillips *et al.*, 2006). Models with $AUC \geq 0.5$ are able to predict the species presence better than by chance, but only models with $AUC \geq 0.75$ are considered potentially useful for species distribution modeling (Elith, 2002).

A *p-value* test was used to evaluate the significance of the average model, where $p \leq 0.05$ was considered better than a random prediction (Pearson *et al.*, 2007). The maximum training sensitivity plus specificity logistic threshold was applied for binary classification in ArcGis 10.2. If the probability value was equal or greater than this

Table 1. Localities, geographical coordinates (WGS 84), vegetation types and the sources records where *Leptodon forbesi* was recorded from 1987 to 2019.

Locality	Municipality/State	Longitude	Latitude	VegetationType	Source
REBIO Guaribas	Mamanguape, Rio Tinto/PB	-6.716667	-35.183333	SSF/ETZ	Glauco Pereira (<i>pers. obs.</i> , 2013)
RPPN Fazenda Pacatuba	Sapé/PB	-7.037222	-35.159444	SSF	Frederico Sonntag (<i>pers. com.</i> , 2015)
RPPN Engenho Gargaú	Santa Rita/PB	-7.020833	-34.958889	SSF	Pereira <i>et al.</i> (2014)
APP Mata do Buraquinho	João Pessoa/PB	-7.148611	-34.861667	ETZ	Pereira <i>et al.</i> (2014)
Fazenda Cidade Viva	Conde/PB	-7.222500	-34.921389	ETZ	Pereira <i>et al.</i> (2014)
PE Mata do Pau Ferro	Areia/PB	-6.968333	-35.745833	OOF	Caio Brito and Nailson Junior (<i>pers. com.</i> , 2015)
Mata do Estado	São Vicente Férrer/PE	-7.619444	-35.511111	ETZ	Pereira <i>et al.</i> (2014)
Engenho Água Azul	Timbaúba/PE	-7.609167	-35.405000	SSF	Collar <i>et al.</i> (2000); Pereira <i>et al.</i> (2014)
Mata de Aldeia	Abreu e Lima, Camaragibe, Pau D'alto/PE	-7.904444	-35.056389	OOF	Pereira <i>et al.</i> (2014)
ESEC Caetés	Paulista/PE	-7.927500	-34.931111	OOF	Pereira <i>et al.</i> (2014)
PE de Dois Irmãos	Recife/PE	-8.000833	-34.945278	OOF	Glauco Pereira (<i>pers. obs.</i> , 2015)
Mata do Benedito/Engenho Jussará	Gravatá/PE	-8.293889	-35.589167	SSF	Pereira <i>et al.</i> (2014)
Sítio do Contente	Gravatá/PE	-8.266667	-35.543611	SSF	Pereira <i>et al.</i> (2014)
Engenho Brejão	Bonito/PE	-8.548611	-35.729722	SSF/ETZ	Pereira <i>et al.</i> (2014)
Mata da Cutia/Leão	Sirinhaém/PE	-8.541944	-35.170556	DOF	Seipke <i>et al.</i> (2011)
Mata das Cobras	Sirinhaém/PE	-8.553611	-35.147222	DOF	Seipke <i>et al.</i> (2011)
Mata do Dêra/Tauá	Sirinhaém/PE	-8.571389	-35.170833	DOF	Seipke <i>et al.</i> (2011)
Mata de Xanguá/Usina Trapiche	Rio Formoso/PE	-8.629444	-35.186667	DOF	Pereira <i>et al.</i> (2014)
Engenho Cachoeira Linda	Barreiros/PE	-8.821111	-35.315550	DOF	Pereira <i>et al.</i> (2006), Seipke <i>et al.</i> (2011)
Engenho Roncadorzinho	Barreiros/PE	-8.811667	-35.296111	DOF	Glauco Pereira (<i>pers. obs.</i> , 2009)
RPPN Eco Fazenda Morim/Mata do Cristóvão	São José da Coroa Grande/PE	-8.878056	-35.218889	DOF	Pereira <i>et al.</i> (2014)
RPPN Frei Caneca/RPPN Pedra D'Anta	Jaqueira/Lagoa dos Gatos/PE	-8.716944	-35.843611	SSF/OOF	Stephen Jones (<i>pers. com.</i> , 2013)
Engenho Gigante/Usina Una Álcool	Maraial/PE	-8.794167	-35.773889	OOF	Glauco Pereira (<i>pers. obs.</i> , 2009)
Mata da Cunha/Fazenda Soberana	São Benedito do Sul/PE	-8.852500	-35.905000	OOF	Glauco Pereira (<i>pers. obs.</i> , 2009)
Engenho Coimbra/Usina Serra Grande	Ibateguara/AL	-9.003889	-35.845556	OOF	Seipke <i>et al.</i> (2011)
Mata do Espinho/Usina Serra Grande	São José da Laje/AL	-8.950556	-36.019444	SSF	Seipke <i>et al.</i> (2011)
Mata da Cachoeira/Usina Serra Grande	São José da Laje/AL	-8.941944	-36.058889	SSF	Seipke <i>et al.</i> (2011)
Mata da Capiana	São José da Laje/AL	-8.941111	-36.001389	SSF	Seipke <i>et al.</i> (2011)
Mata do Pinto/Usina Serra Grande	São José da Laje/AL	-8.980000	-36.105556	SSF	Seipke <i>et al.</i> (2011)
RPPN Boa Sorte	Murici/AL	-9.191944	-35.932778	OOF	Seipke <i>et al.</i> (2011)
ESEC Murici	Murici, Messias/AL	-9.205556	-35.870556	OOF	Teixeira <i>et al.</i> (1987); Seipke <i>et al.</i> (2011)
Usina Santo Antônio	Passo de Camaragibe/AL	-9.221667	-35.526944	OOF	Glauco Pereira (<i>pers. obs.</i> , 2013)
Fazenda Cachoeira	Pindoba/AL	-9.477778	-36.347778	OOF	Pereira <i>et al.</i> (2014)
Mata do Cedro	Rio Largo/AL	-9.522500	-35.913056	OOF	Glauco Pereira (<i>pers. obs.</i> , 2013)
Parque Municipal de Maceió	Maceió/AL	-9.612500	-35.762500	OOF	Pereira <i>et al.</i> (2014)
Fazenda Varrela	São Miguel dos Campos/AL	-9.710000	-36.007500	OOF	Pereira <i>et al.</i> (2006); Seipke <i>et al.</i> (2011)
Lagoa do Roteiro	Roteiro/AL	-9.822222	-35.993611	OOF	Seipke <i>et al.</i> (2011)
RPPN Madeiras	Junqueiro/AL	-9.865556	-36.333056	SSF	Pereira <i>et al.</i> (2014)
Mata do Capiatã/Usina Coruripe	Coruripe/AL	-10.008056	-36.282500	SSF	Pereira <i>et al.</i> (2014)
Mata do Crasto/APA do Litoral Sul	Santa Luzia do Itanhhy/SE	-11.367222	-37.417222	SSF	Pereira <i>et al.</i> (2014)

States: AL = Alagoas, PB = Paraíba, PE = Pernambuco, and SE = Sergipe. Protected areas: APP = Permanent Protection Area; ESEC = Ecological Station; PE = State Park; REBIO = Biological Reserve; APA = Environmental Protection Area, and RPPN = Private Reserve of Natural Heritage. Vegetation types: OOF = open ombrophilous forest; DOF = dense ombrophilous forest; ETZ = ecological tension zone, and SSF = seasonal semideciduous forest.

threshold value, it was classified as suitable for *L. forbesi*, otherwise unsuitable (Trisurat & Duengkae, 2011). These approaches (sensitivity-specificity) are widely used and have great accuracy (Liu *et al.*, 2005). Finally, it was performed a heuristic estimate of the variables relative contribution to the model.

Following IUCN (2001) we estimated the potential suitable area by measuring the extent of occurrence, and calculating the area of occupancy. In the case of *L. forbesi* only fragments larger than 1 km² were considered (the smallest area where the species was recorded). We also excluded the records from Sergipe and Bahia from the analysis, and more studies must be conducted at these sites to confirm the existence of populations. These re-

ords may refer to vagrant individuals, as correctly stated by Leite *et al.* (2017).

Finally, ArcGIS 10.2 was used to overlap the species' habitat suitability map with the maps of Atlantic Forest fragments and Brazilian Protected Areas (SNUC, 2004; Fundação SOS Mata Atlântica, 2015).

RESULTS

Current records of *L. forbesi* (82.5%) are concentrated in the Brazilian states of Pernambuco and Alagoas, with isolated records in Sergipe, Paraíba, Rio Grande do Norte, and Bahia. Observations of the species in Open

Table 2. Distribution of the records of *Leptodon forbesi* in different vegetation types.

Vegetation type	Number of records	%
OOF	15	37.5
DOF	7	17.5
SSF	12	30
ETZ	3	7.5
SSF/ETZ	2	5
SSF/OOF	1	2.5
Total	40	100

Vegetation types: OOF = open ombrophilous forest; DOF = dense ombrophilous forest; ETZ = ecological tension zone, and SSF = seasonal semideciduous forest.

ombrophilous forest and seasonal semideciduous forest accounted for 77.5% of the total number of records (Table 2).

The ENM showed higher suitability for the species from the coastal region of north Paraíba to center-east Alagoas, spreading westward between the states of Pernambuco and Alagoas. There are also few isolated suitable areas further west in Paraíba and in the coastal regions of Sergipe and Rio Grande do Norte (Figs. 2a and 2b).

The average model was considered statistically significant ($p < 0.01$) and had a good performance identifying suitable areas for the species ($AUC = 0.982 \pm 0.004$ SD). The maximum training sensitivity plus specificity logistic threshold was 0.1691, and the training omission was 0.0133.

The environmental variable that most contributed to the ENM was the precipitation of coldest quarter (bio 19), with 70.6% relative contribution, followed by declivity (6.3%), mean temperature of wettest quarter (bio 8; 5.5%), and precipitation of wettest quarter (bio 16; 4.6%). The ranges with better probability of presence of *L. forbesi* for these variables were respectively > 600 mm for bio 19, between 2 and 20% of declivity, about 20°C for bio 8 and > 900 mm for bio 16 (Fig. 3).

The suitable area estimated for *L. forbesi* is 20,344 km² (Fig. 2b). Within this suitable area, 3,118.59 km² are classified as forest fragments, but only 1,636.89 km² might be considered as occupancy area (suitable fragments larger than 1 km²) (Fig. 2c) and scarce 241 km² are currently under legal protection.

DISCUSSION

Areas of high suitability for *L. forbesi* are located on humid coastal region and in dry transition zone, locally known as *agreste*. This subregion of the Atlantic Forest has the highest density of threatened bird taxa in the Neotropics, with three recently extinct endemic species plus one extinct in the wild (Roda et al., 2011; Pereira et al., 2014). Our results show that there are some forest patches with environmental suitability in Sergipe, and Dénes et al. (2011) and Leite et al. (2017) suggested that individuals might wander southwards,

reaching to northern Bahia state. An individual was recorded recently in Sergipe, at Serra da Itabaiana (Silva & Lima, 2016), an area climatically suitable for the species according to our model. Another recent record in the south of Rio Grande do Norte (Gurgel, 2016) may be the result of the dispersion of some individuals to the north, because in this state there is almost no area with suitability for the species. In this case, these individuals must be monitored and the vagrancy of individuals searching for rarer suitable territories should be investigated.

According to our model, suitable areas for *L. forbesi* extend predominantly over seasonal and ombrophilous forests. These forests are wetter than other vegetation types in the region and are located mostly in Pernambuco and Alagoas (IBGE, 2004). These states harbor much of the ombrophilous and seasonal forests, and the rains are intense mainly from the central coast of Pernambuco to the north coast of Alagoas (see Moura et al., 2007) where *L. forbesi* finds favorable habitats, especially near streams or rivers in the forests (see Pereira et al., 2006), being similar with its congener *Leptodon cayanensis* (Thiollay, 1994; Ferguson-Lees & Christie, 2001). This may explain why the rainfall is the main environmental feature contributing for our ENM.

The species area of occupancy is very small compared to its extension of occurrence, especially when considering only the fragments larger than 1 km². Most of these forest patches do not provide undisturbed, stable habitat for *L. forbesi* populations, given that only 15% of these patches are legally protected areas. Even with some resilience, the records in small forest fragments and within cities may be masking the real situation of the species.

Most of the forest patches inhabited by *L. forbesi* are located in private properties embed in plantations of sugar cane (Bensusan, 2006; Uchôa-Neto & Tabarelli, 2003). These forests, with variable sizes, are highly fragmented and certainly will not be converted into National Parks or other public protected areas. For these unique forest remnants and its endemic and threatened animals and plants we suggest public policies to promote the creation of private protected areas, known as Private Reserves of Natural Heritage (Reservas Particulares do Patrimônio Natural, RPPNs in Portuguese). RPPNs play an important role in the conservation of endemic and threatened birds in the Atlantic Forest (Oliveira et al., 2010), and the maintenance of the Pernambuco Center of Endemism biodiversity could be granted with the creation of RPPNs in forest fragments. Specifically in the case of *L. forbesi*, the importance of the connection of these fragments rest on the necessity of ecological corridors (Bennett, 2003), which would ensure gene flow and evolutionary processes' maintenance in a regional scale (Campanili & Prochnow, 2006).

Forest patches with high suitability for the species such as Murici Ecological Station, Private Reserve of Frei Caneca, Santa Justina, Serra Grande and Trapiche Mills must be prioritized in conservation actions and efforts.

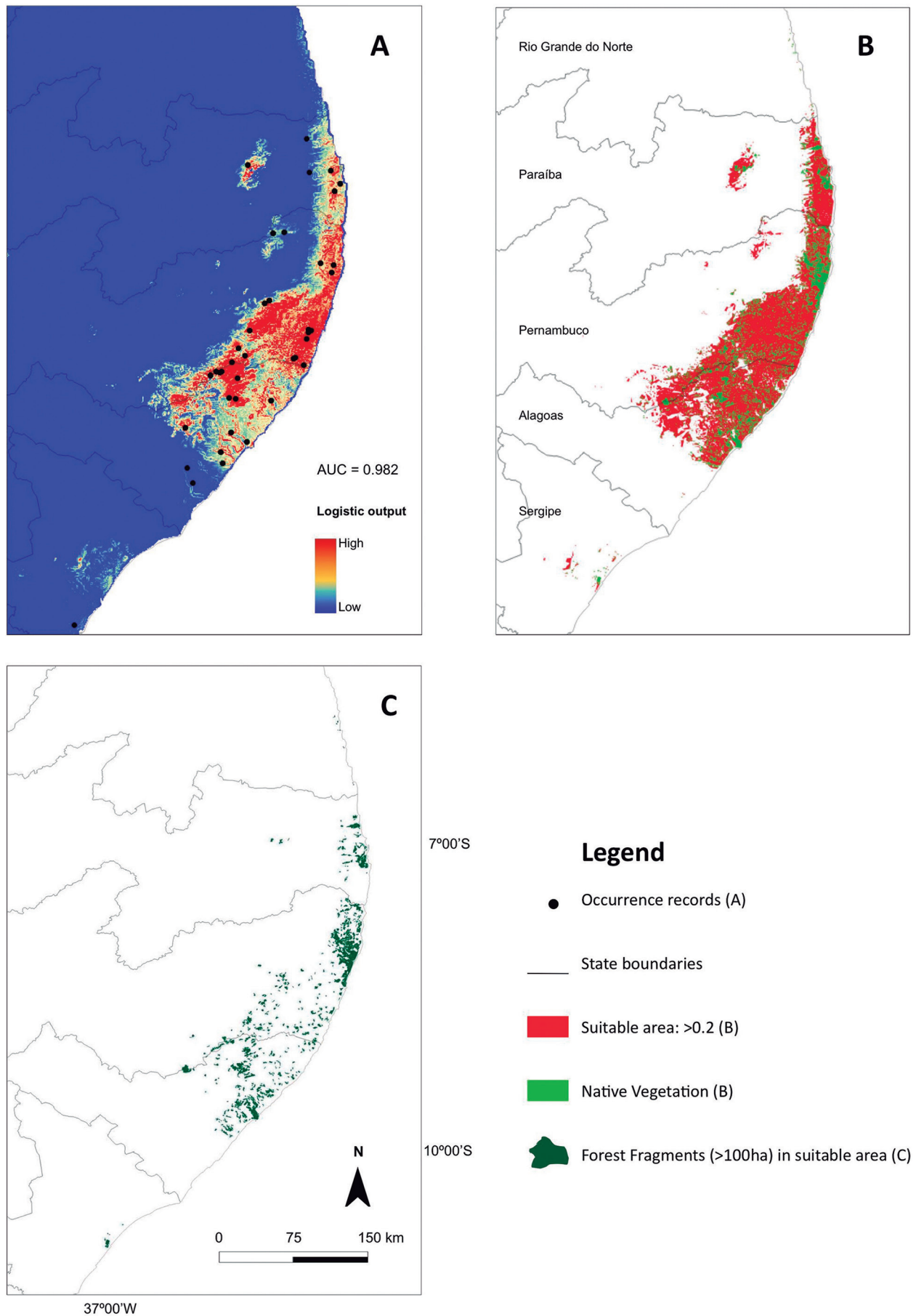


Figure 2. (A) Potential distribution maps of *Leptodon forbesi* continuous model (probability of presence from 0 to 1: warmer colors show areas with better environmental conditions based on the species occurrence records (black points)); (B) Binary model: suitable areas in red color (probability of presence ≥ 0.2) and forest fragments in gray color (probability of presence < 0.35); (C) Forest fragments > 100 ha in suitable area, adopted here as distribution area of *Leptodon forbesi*.

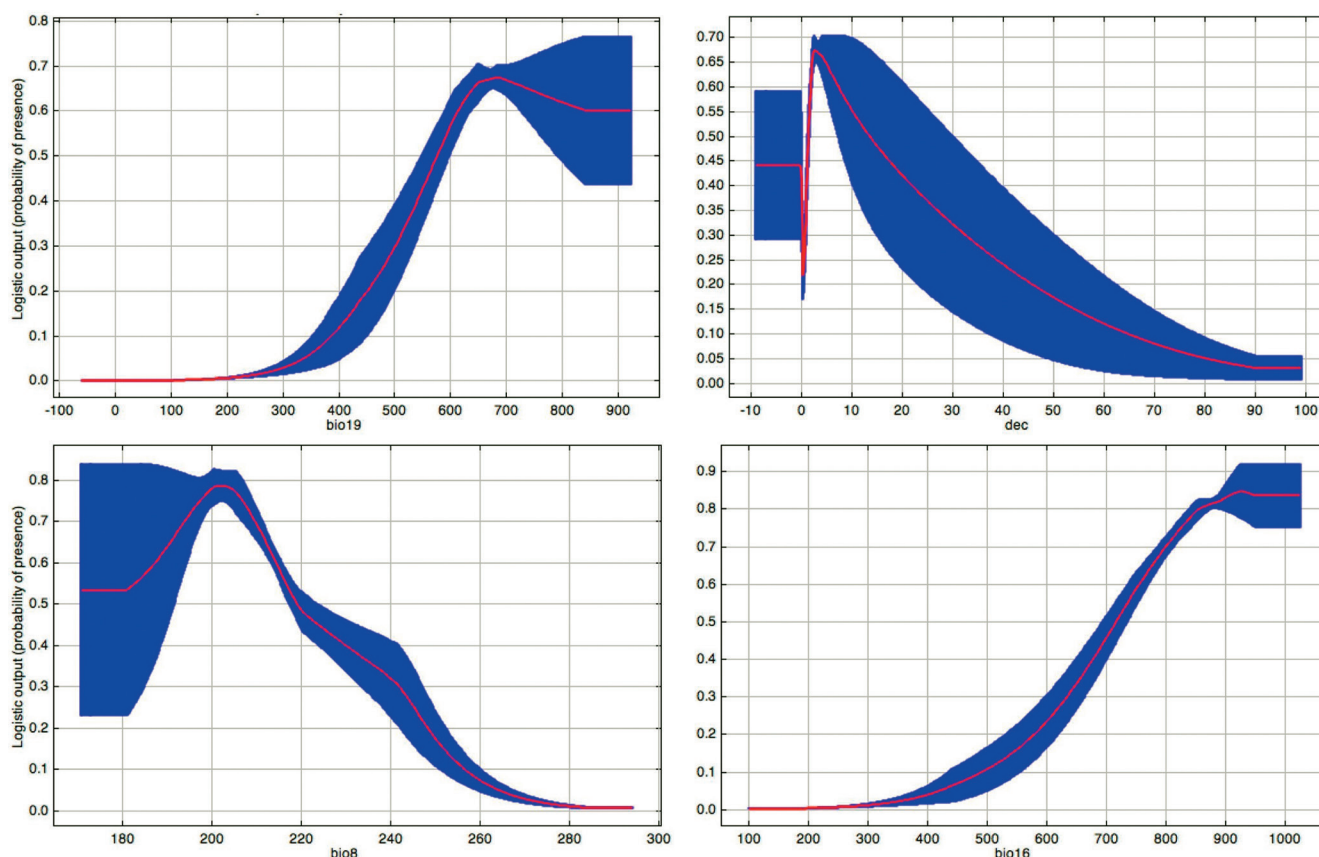


Figure 3. Response curves of the four predictor variables that most contributed to the model of *Leptodon forbesi*. Precipitation of coldest quarter (bio 19) (mm), declivity (dec) (%), mean temperature of wettest quarter (bio 8) ($^{\circ}\text{C} \times 10$), and precipitation of wettest quarter (bio 16) (mm).

These protected areas could serve as the core of an ecological corridor, as suggested by Tabarelli *et al.* (2006). Moreover, captive breeding is also recommended as a part of a strategy of *ex-situ* conservation, as individuals of the congener *Leptodon cayanensis* has been kept successfully in captivity in some Brazilian zoos, and the expertise can be used in benefit of the *L. forbesi*.

We call for conservation action plans, sounding the alarm for the necessity of innovative and dare measures to stop the ongoing extinction process faced in Pernambuco Center of Endemism (Teixeira, 1986; Coimbra-Filho & Câmara, 1996; Pereira *et al.*, 2014).

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