Potential distribution of the endangered endemic lizard *Liolaemus lutzae* Mertens, 1938 (Liolaemidae): are there other suitable areas for a geographically restricted species?

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Abstract

In this study we attempted to access further information on the geographical distribution of the endangered lizard *Liolaemus lutzae*, estimating its potential distribution through the maximum entropy algorithm. For this purpose, we related its points of occurrence with matrices of environmental variables. After examining the correlation between environmental matrices, we selected 10 for model construction. The main variables influencing the current geographic distribution of *L. lutzae* were the diurnal temperature range and altitude. The species endemism seemed to be a consequence of a reduction of the original distribution area. Alternatively, the resulting model may reflect the geographic distribution of an ancestral lineage, since the model selected areas of occurrence of the two other species of *Liolaemus* from Brazil (*L. arambarensis* and *L. occipitalis*), all living in sand dune habitats and having psamophilic habits. Due to the high loss rate of habitat occupied by the species, the conservation and recovery of the remaining areas affected by human actions is essential.

Keywords: lizards, coastal environment, ecological modeling, biogeography, maximum entropy.

Distribuição potencial do lagarto endêmico e ameaçado *Liolaemus lutzae* Mertens, 1938 (Liolaemidae): existem outras áreas favoráveis a uma espécie geograficamente restrita?

Resumo

No presente estudo buscamos acessar informações adicionais acerca da distribuição geográfica do lagarto *Liolaemus lutzae*, estimando sua distribuição potencial através do algoritmo de máxima entropia. Para tanto, relacionamos os pontos de ocorrência da espécie com matrizes de variáveis ambientais. Após análise da correlação entre as matrizes ambientais, selecionamos 10 variáveis não correlacionadas para a construção do modelo. As principais variáveis que influenciam a distribuição geográfica atual de *L. lutzae* foram a amplitude média diurna de temperatura e a altitude. O endemismo atual da espécie parece ser consequência da redução da área de ocorrência original. Alternativamente, o modelo resultante pode refletir a distribuição geográfica de uma linhagem ancestral, devido à seleção das áreas de ocorrência das outras espécies de *Liolaemus* com registro no Brasil (*L. arambarensis* e *L. occipitalis*), todas vivendo em ambientes de dunas arenosas e possuindo hábitos psamófilos. Considerando a grande taxa de perda do habitat ocupado pela espécie, torna-se imprescindível a conservação dos remanescentes e a recuperação de áreas afetadas pelas ações humanas.

Palavras-chave: lagartos, ambiente litorâneo, modelagem ecológica, biogeografia, entropia máxima.

1. Introduction

Ecological modelling may be used to estimate the potential geographical distribution of species based on environmental attributes that are related to the elements necessary to allow the occurrence and distribution of a particular organism (Peterson, 2001; Guisan and Thuiller, 2005; Giovanelli et al., 2010). Different techniques for characterising the geographical distribution of species relate the occurrence records of species with environmental data, and have been widely applied in different geographical scales (Guisan and Thuiller, 2005; Phillips et al., 2006;

338

Braz. J. Biol., 2014, vol. 74, no. 2, p. 338-348

Pearson et al., 2007). Applicability of such techniques include easier detection of unknown distribution areas for a species having few distributional records (Bourg et al., 2005), potential impacts of environmental changes on organisms (e.g., Rocha et al., 2009a; Sinervo et al., 2010), the support when planning conservation policies (e.g., Araújo and Williams, 2000) and to preview potential expansion in distribution of invasive alien species (e.g., Thuiller et al., 2005; Rödder et al., 2008). Species distribution modelling is commonly based substantially on climatic variables that have strong association with broad-scale geographic patterns of species richness (Hawkins et al., 2003; Buckley and Jetz, 2007). Distribution maps generated by these techniques are widely accepted among the scientific community and are increasingly being used in a range of research fields (Franklin, 2010). On the other hand, range maps generated by distribution modelling are expected to overpredict the distributional limits of species, predicting presence where it is known to be truly absent (errors of commission). This occurs because many modelling methods are unable to evaluate absences generated by evolutionary history of species, dispersal limitations, and biotic interactions with other species (Graham and Hijmans, 2006; Pineda and Lobo, 2009).

The genus *Liolaemus* Wiegmann, 1834 comprises more than 220 species distributed throughout South America and is known to have the greatest climatic, latitudinal and altitudinal (from sea level to over 5000 m) distributions among lizards. However, only three species, all of them sand-dwellings (Etheridge, 2000), are presently known to occur in Brazil: *L. arambarensis* Verrastro, Veronese, Bujes and Dias-Filho, 2003 and *L. occipitalis* Boulenger, 1885, both from coastal sandy habitats from southern Brazil, and *Liolaemus lutzae* Mertens, 1938, endemic to

the restinga habitats of Rio de Janeiro State, southeastern Brazil (Rocha et al., 2005). *Liolaemus lutzae* is a small sand-dwelling lizard (51-80 mm snout-vent length when adult; Rocha, 1992). Its distribution is markedly narrow and comprises from Restinga da Marambaia (23°04'S, 43°52'W) to Cabo Frio (22°51'S, 41°59'W), inserted in the Atlantic Rainforest domain (for details on 'restinga' environment, see Araujo and Henriques, 1984; Suguio and Tessler, 1984; Pereira and Araújo, 2000). In these areas, *L. lutzae* is mainly found in a thin strip of approximately 50 to 100 m wide of beach vegetation (Vanzolini and Ab'Saber, 1968; Rocha, 1991; Rocha et al., 2009a) where males and females share the relatively small area of habitat for their ecological tasks such as thermoregulation (Rocha, 1995), space use (Rocha, 1999) and feeding activities (Rocha, 1989). This species is currently considered to be threatened with extinction even in State level (Governmental Decree from 5 june 1998; Bergallo et al., 1998), as in federal level (Brasil, 2003) and global level (IUCN, 2012), as result of the intensive and extensive destruction of restinga habitats (Rocha et al., 2007).

In the present study, we evaluated whether *Liolaemus lutzae*, currently restricted to restinga areas in the state of Rio de Janeiro, would have the potential to occur in other areas of Brazil, and which bioclimatic variables would have greater influence on the limits of its distribution.

2. Material and Methods

We used the occurrence records of *Liolaemus lutzae* from Rocha et al. (2009a) (Table 1, Figure 1), excluding the population from Praia das Neves (state of Espírito Santo), due to this population resulting from an experimental introduction in the area and not within the original species distribution (see Soares and Araújo, 2008).

Table 1. Localities, municipalities and coordinates with records of *Liolaemus lutzae* used for potential distribution modelling. Modified from Rocha et al. (2009a).

Locality	Municipality	Latitude	Longitude
Marambaia	Rio de Janeiro	–23.049428	–43669862
Grumari	Rio de Janeiro	–23.047663	–43.524308
Recreio	Rio de Janeiro	–23.025117	–43.457655
Barra da Tijuca	Rio de Janeiro	–23.009023	–43.348214
Itaipuaçu	Maricá	–22.968892	–42.984173
Barra de Maricá	Maricá	–22.955000	–36.773300
Ponta Negra	Maricá	–22.954224	–42.718822
Jaconé	Maricá	–22.940619	–42.668623
Barra Nova	Saquarema	–22.932321	–42.570410
Itaúna/Jacarepiá	Saquarema	–22.933310	–42.448806
Pernambuca	Araruama	–22.936438	–42.315934
Massambaba	Araruama	–22.938342	–42.283379
Figueiras	Araruama	–22.944425	–42.172768
Praia Grande	Arraial do Cabo	–22.959874	–42.047290
Praia do Foguete	Cabo Frio	–22.938023	–42.039307
Praia do Forte	Cabo Frio	–22.890757	–42.025346
Praia das Conchas	Cabo Frio	–22.872014	–41.983188
Praia do Peró	Cabo Frio	–22.847097	–41.988340

Braz. J. Biol., 2014, vol. 74, no. 2, p. 338-348

339
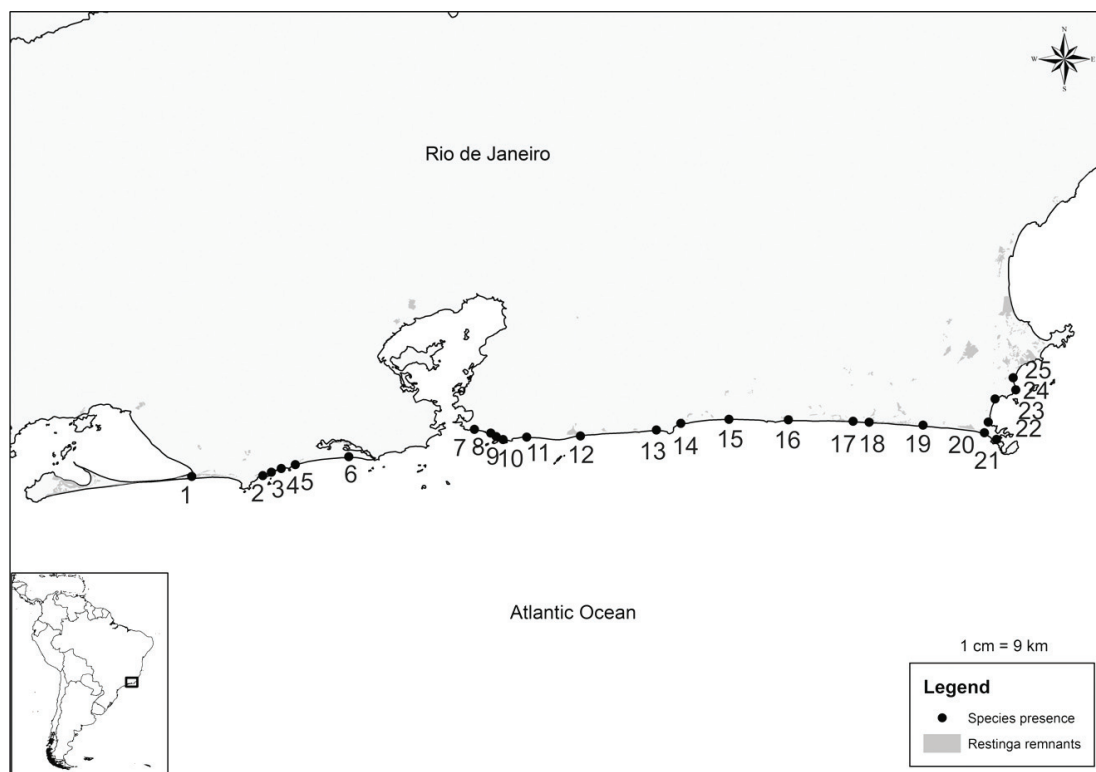
Figure 1. Records of occurrence of the lizard *Liolaemus lutzae*, endemic to the state of Rio de Janeiro, Brasil. Grey areas represent the remnants of restinga habitats according to the "SOS Mata Atlântica Organization". 1. Marambaia, 2. Grumari, 3. Prainha, 4. Macumba, 5. Recreio, 6. Barra da Tijuca, 7-10. Piratininga, Camboinhas, Itaipu e Itacoatiara, 11. Itaipuaçu, 12. Barra de Maricá, 13. Ponta Negra, 14. Jaconé, 15. Barra Nova, 16. Itaúna/Jacarepiá, 17. Pernambuca, 18. Massambaba, 19. Figueiras, 20. Praia Grande, 21. Praia dos Anjos, 22. Praia do Foguete, 23. Praia do Forte, 24. Praia das Conchas, 25. Praia do Peró. Modified from Rocha et al. (2009a).

To create the potential distribution model, we used the software MaxEnt 3.2.3. Despite the availability of different methods for potential distribution modelling, some studies have shown the Maximum Entropy as one of the best performing algorithms (e.g., Elith et al., 2006; Costa et al., 2010; Giovanelli et al., 2010). The model is estimated from data of presence, and generates pseudo-absence data for the calibration (Pawar et al., 2007). The maximum entropy algorithm assumes the less biased solution in the evaluation of an unknown probability of distribution, maximising its entropy (Pawar et al., 2007). The algorithm differs from the others (e.g., genetic algorithms, artificial neural networks) by building a probability distribution, while the others produce a probability for each point (see Pawar et al., 2007; Elith et al., 2011). Despite its sensibility to sampling bias, Maxent comparatively showed a better performance when sampling involve poor number of points (Costa et al., 2010).

We used 20 bioclimatic variables provided by WorldClim. org (Hijmans et al., 2005), with resolution of 30 arcseconds: annual mean temperature (bio 1); mean diurnal temperature range (bio 2); isothermality (bio 3); temperature seasonality (bio 4); maximum temperature of warmest month (bio 5);

minimum temperature of coldest month (bio 6); temperature annual range (bio 7); mean temperature of wettest quarter (bio 8); mean temperature of driest quarter (bio 9); mean temperature of warmest quarter (bio 10); mean temperature of coldest quarter (bio 11); annual precipitation (bio 12); precipitation of wettest month (bio 13); precipitation of driest month (bio 14); precipitation seasonality (bio 15); precipitation of wettest quarter (bio 16); precipitation of driest quarter (bio 17); precipitation of warmest quarter (bio 18); precipitation of coldest quarter (bio 19); and altitude. Temperature data was expressed in °C, precipitation in mm and altitude in meters above sea level - ASL. All matrices were than appraised in South America range. To construct the model, we used the default threshold of convergence (10^{-5}) and the maximum number of data randomization (500 iterations). For manipulation of matrices and the construction of resulting maps, we used the software ArcGIS 9.3 (ESRI, 2008).

We performed a multivariate correlation test among occurrence points and all environmental variables to avoid collinearity in the model, using R (www.r-project.org). Variables with high correlation (up to 75%) were excluded from the analysis. The Jacknife test was performed to

evaluate which variables would be more important to the model regarding the amount of information, from two processes: the first rebuilt the model adding one variable at time; the second removes each variable. To validate and interpret the model, usually it is preferable the distinction of suitable and non-suitable areas, though the establishment of a cumulative threshold for the resulting model (presence prediction) (Pearson et al., 2007). A threshold must be defined by the user (parameter *E*), and consists into the amount of error associated to the presence localities dataset (see Peterson et al., 2008). However, due to the reduced geographic distribution and the well-studied populations (periodically monitored; see Rocha, 1992; Rocha and Bergallo, 1992; Rocha et al., 2009a, b), we evaluated the resulting model based in the pattern discrimination statistics (area under the curve on receiver operating characteristics; AUC and ROC, respectively). These statistics provide the evaluation that the model correctly classifies a point of actual presence and a point of true absence (Phillips et al. 2006). Values of AUC vary between zero and one, according to the proportion of hits and errors: from zero to 0.5 the discrimination is at random, and higher values indicate more hits (Elith et al., 2006). Values up to 0.75 are considered sufficiently discriminatory (Elith et al., 2006). To evaluate the importance of each environmental variable used for modelling, we used the Jacknife test, which estimates the amount of information retained by each variable in its absence and in its presence (see García, 2006).
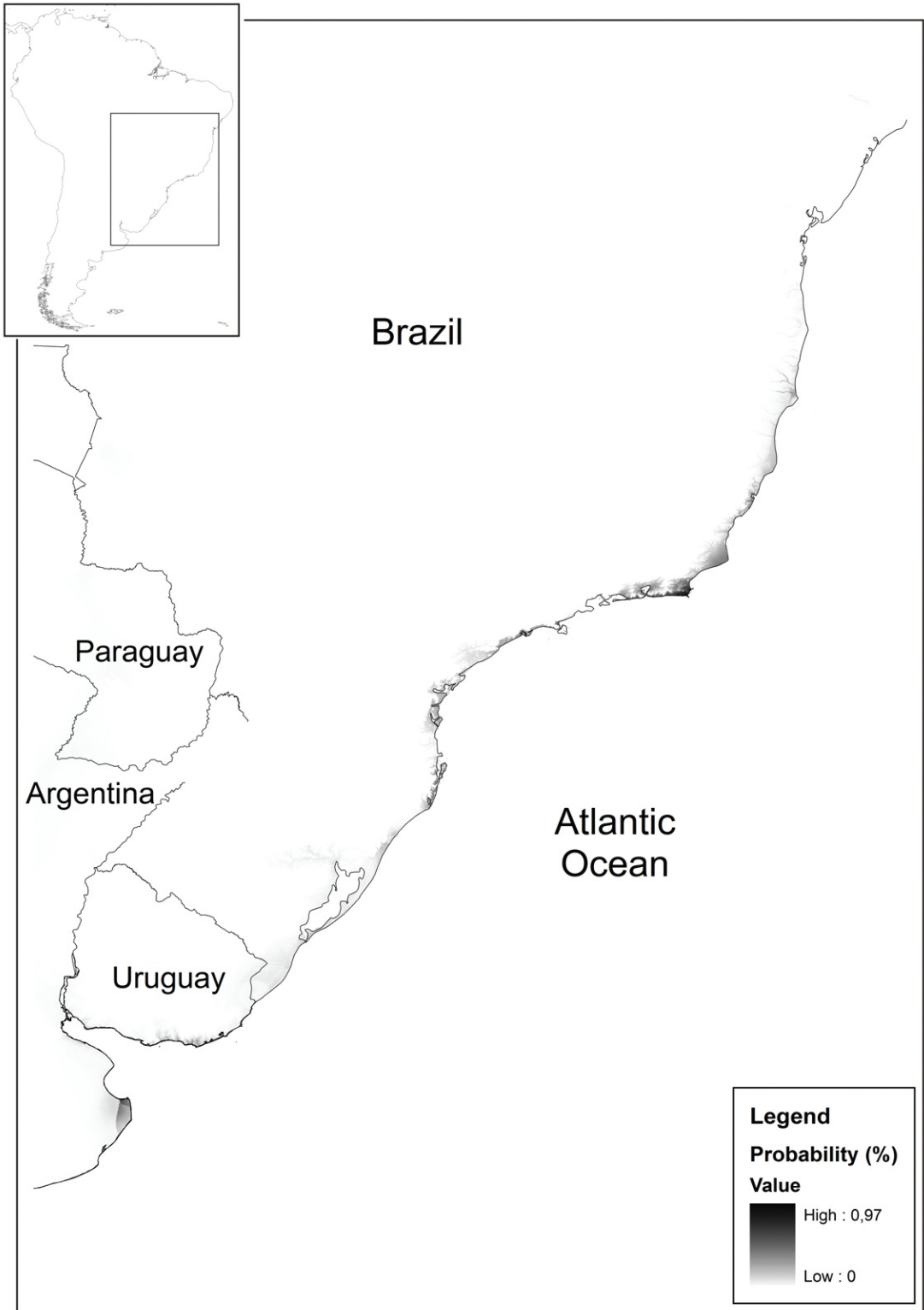
3. Results

We considered 10 environmental variables in the final analysis, considered best applied among those non-correlated, for constructing the potential distribution model for *Liolaemus lutzae*: mean diurnal temperature range (bio 2); isothermality (bio 3); maximum temperature of warmest month (bio 5); mean temperature of driest quarter (bio 9); precipitation seasonality (bio 15); precipitation of wettest quarter (bio 16); precipitation of driest quarter (bio 17); precipitation of warmest quarter (bio 18); precipitation of coldest quarter (bio 19); and altitude.

The model identified as the most important environmental influencing the occurrence of *L. lutzae* the diurnal temperature range (41.1% of contribution), precipitation of coldest quarter (17.7%), altitude (17.2%), maximum temperature of warmest month (11.28%), isothermality (8.9%), and precipitation seasonality (3.1%). The estimation of the potential distribution suggested that this species was more likely to occur largely at sites located in coastal sand dune areas of Brazil (Figures 2-6). When compared to other species from *L. wiegmannii* group, the model for *L. lutzae* suggests a potential distribution in areas of currently occurrence of *L. occipitalis*, *L. arambaraensis*, *L. wiegmanni*, and *L. multimaculatus* (Figure 6). The model suggested altitude as the variable that provided the highest information gain when used in isolation, therefore holding the most useful information by itself. When the variables were removed one at a time, the diurnal temperature range

decreased the gain when omitted, and therefore, retained the greatest amount of information that was absent in the other variables. AUC value for the model validation was considered satisfactory ($AUC_{model} = 0.974 \pm 0.023$).

4. Discussion

The resulting potential distribution model of *Liolaemus lutzae* differs in part from the known distribution of the species (see Rocha et al., 2009a), with the current distribution being a sub-set of the area to which the species could potentially spread. Based on the model, we observe that there were sites with potential for occurrence of populations in different areas on the coast of Brazil, not only in the state of Rio de Janeiro. Probably, the environments in which the species could potentially occur have similar general environmental characteristics. Interestingly, validating the model, no inland area was predicted but instead, only areas in coastal region. This coincide to the specialized ecological requirements of the species, including thermal biology and psamophilic habits. In the state of Rio de Janeiro, beyond the northern boundary of the known distribution of *L. lutzae*, the areas with potential for occurrence of the model included restinga habitats of Jurubatiba and Grussaí. However, outside the territory of Rio de Janeiro state, both northwards and southwards, the probability of occurrence decreased considerably due to the adjustment of the model to it's distribution records. Besides those areas where the three cogeneric species live, the areas with a potential for occurrence of *L. lutzae* indicated by the model interestingly corresponded in part to the geographic distribution of the related lizard *Tropidurus torquatus* (see Rodrigues, 1987), including the restinga habitats of Jurubatiba and Grussaí. In all areas of presence of *L. lutzae*, *T. torquatus* occur sympatrically suggesting that they share similar ecological requirements. Despite the Doce River region having been recognised as an area of endemism, and potential barrier limiting taxa distributions (see Rocha, 2000; Carnaval and Moritz, 2008; Carnaval et al., 2009; Silva et al., 2012), *T. torquatus* manages to overcome this area. For *L. lutzae*, due to its limited occurrence to the narrow strip of beach areas with herbaceous vegetation, it is possible that this species could never have been able to overcome the Doce River. It is still unclear the reasons to why *L. lutzae* does not occur in restinga areas northwards of its northern known distribution in Rio de Janeiro state. Further detailed studies on limiting/favouring variables affecting the occurrence of this species are still needed, especially at the microhabitat and habitat scale, including sand granulation and/or dominant winds. Areas with the greatest potential for occurrence in the southern region (states of Santa Catarina and Rio Grande do Sul) correspond to the distribution of its Brazilian congeners (*L. occipitalis* and *L. arambarensis*), and could be reflecting the historical distribution of a common ancestor with *L. arambarensis* and *L. occipitalis*. The divergence between *L. lutzae* and *L. occipitalis* was previously estimated at about 4,000 years ago (Vanzolini and Ab'Saber, 1968); however,

Braz. J. Biol., 2014, vol. 74, no. 2, p. 338-348

341

Figure 2. Map of the resulting potential distribution of *Liolaemus lutzae* (Squamata, Liolaemidae) in Brazil.

342

Braz. J. Biol., 2014, vol. 74, no. 2, p. 338-348
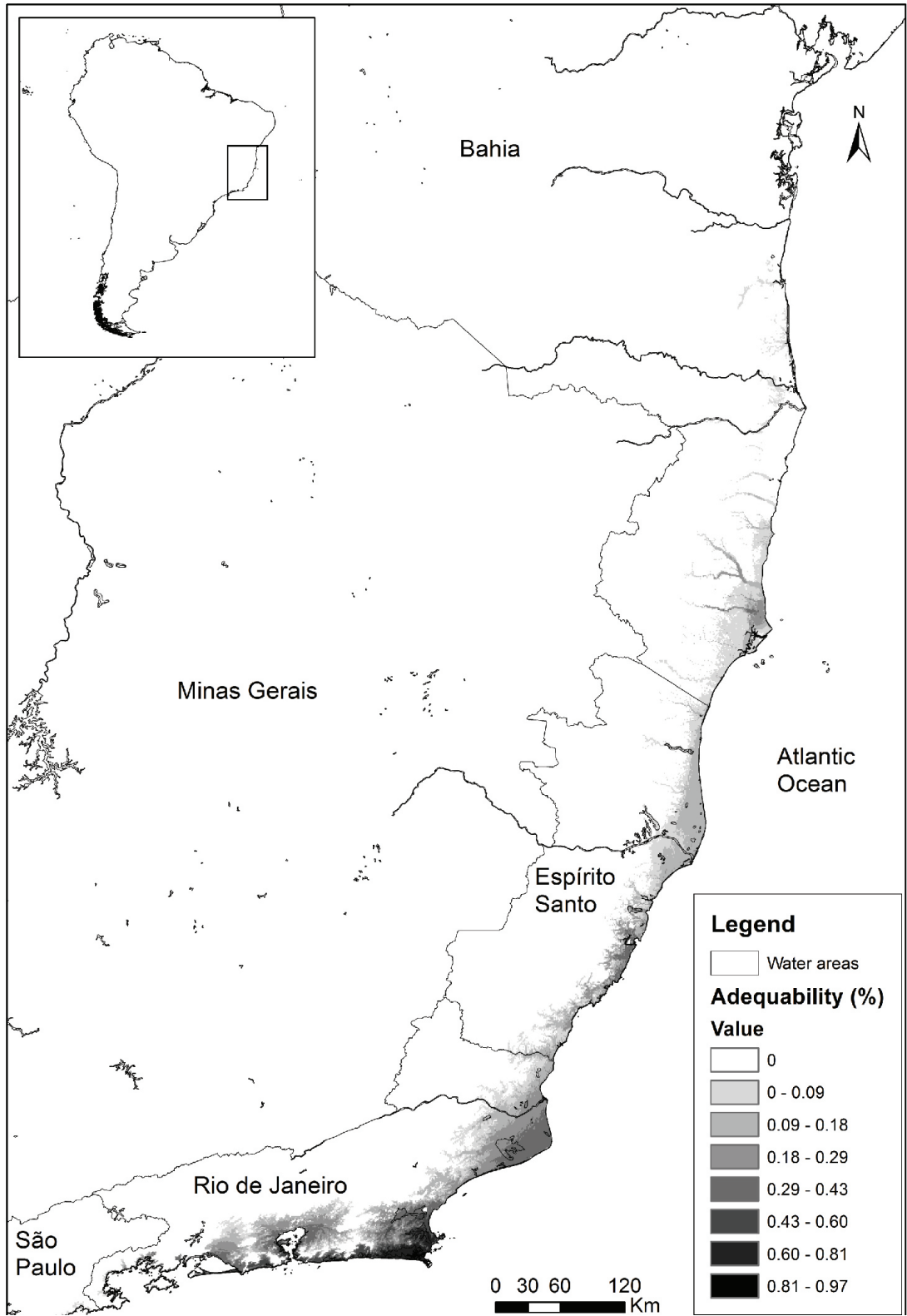
Figure 3. Map of the resulting potential distribution of *Liolaemus lutzae* (Squamata, Liolaemidae) in the northern portion of known geographic distribution for the species (Rio de Janeiro, Espírito Santo and southern Bahia).
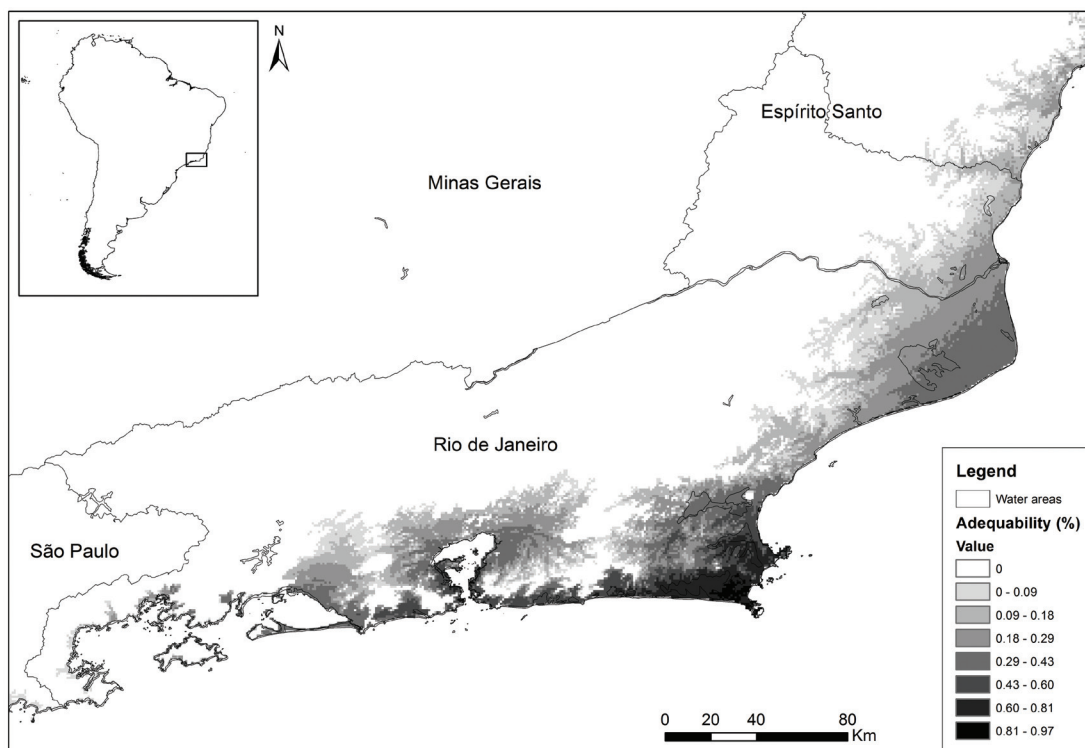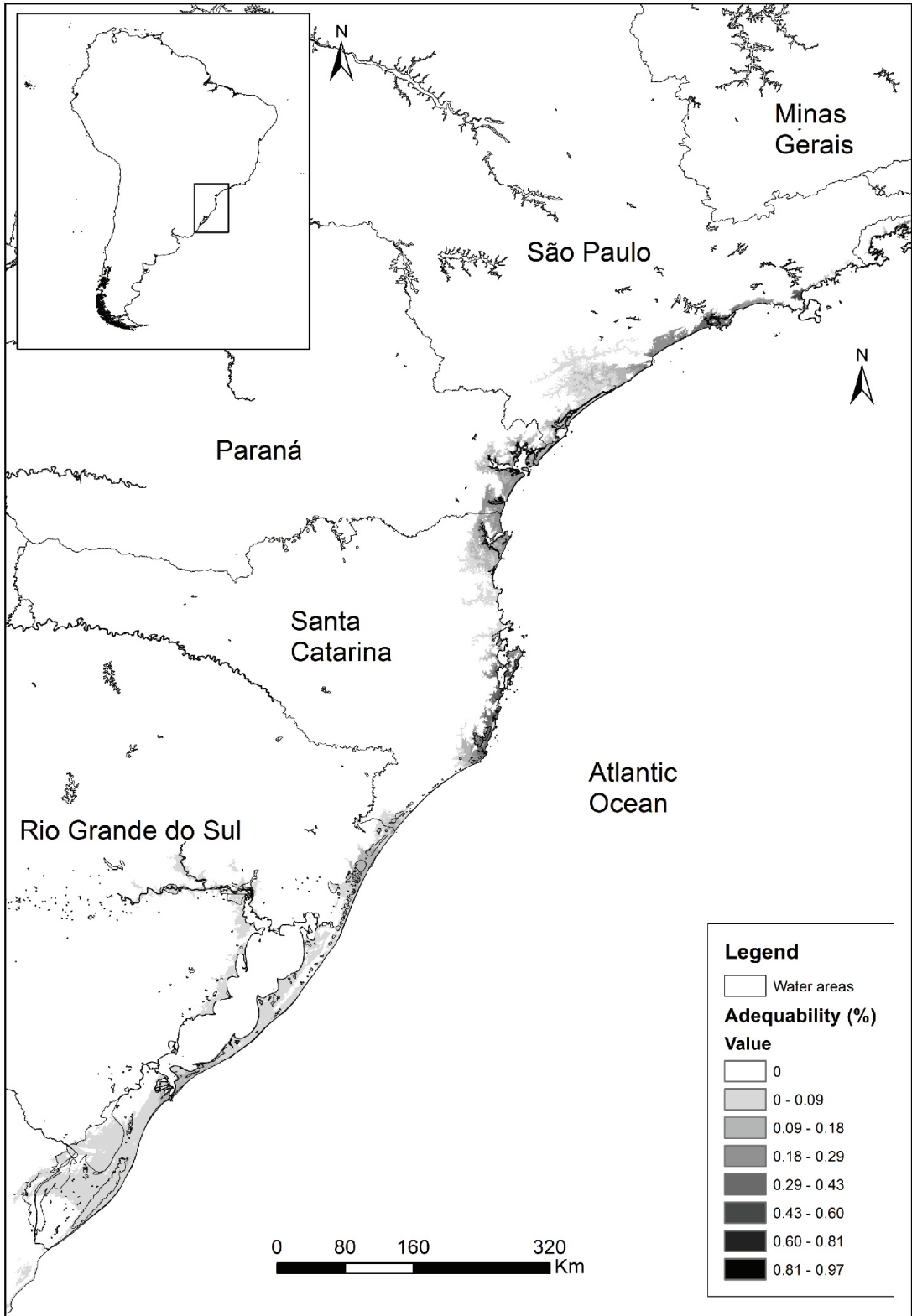
Figure 4. Resulting potential distribution of *Liolaemus lutzae* (Squamata, Liolaemidae) in the currently geographic distribution for the species (Rio de Janeiro). 1. Jurubatiba, 2. Grussaí.

the divergence among *L. arambaraensis* and the other two species has not yet been estimated. Suitable areas in southern São Paulo for the occupation by the species *Liolaemus* has been already hypothesised (Vanzolini and Ab'Saber, 1968), and these areas were also indicated by our model. Species from *L. wiegmannii* group are currently well distributed in subtropical zone, mainly between 24°S and 40°S (see Avila et al., 2009). The east portion of this area (which includes Brazilian territory) suffered markedly modifications on topography and climate along time, as well as intense tectonic activity (Ribeiro, 2006). Together with the Antarctic cold front during late Quaternary, the region of the currently southern portion of the Atlantic Rainforest was not suitable for a forest on various periods (see Behling, 2002). The opened-vegetation habitat in subtropical region of South America may have provided the appropriate habitat for species diversification of *L. wiegmannii* group. On the southeastern and southern coast of Brazil, where the species of *Liolaemus* currently occur, the 24°S corresponds to middle Paraná region, previously recognised as an endemism area (see Cracraft, 1985; Silva et al., 2012). Based on vegetation modelling using palynological data, Carnaval and Moritz (2008) predicted the occurrence of forest in a longitudinal stripe, which could act as a barrier for organisms restricted to more opened environments. *Liolaemus lutzae* is the only species from this group that exceeds this latitudinal constraint (see Avila et al., 2009),

suggesting a probably more ancient distribution from the south to at least up to the Doce River, potentially benefitting from a more open vegetation and from transgressions and regressions of the sea, followed by differentiation due to vicariance. Consequently, the divergence between *L. lutzae* and *L. occipitalis* may potentially be more ancient than the hypothesis of Vanzolini and Ab'Saber (1968).

The area with the greatest values for probability of occurrence of *L. lutzae* is adjusted to the currently known geographic distribution. This result was expected, since the maximum entropy algorithm is biased by concentration of points (see Costa et al., 2010). However, the model validation values were considered satisfactory. Further validation to the model can be provided by the low prediction value to the location of Praia das Neves as an presently area of occurrence of the species, since there was no previous occurrence of native populations previously to the deliberate intentional introduction of a set of individuals in the area which established a successfully population (see Soares and Araújo, 2008). Apparently, the large Paraiba do Sul River, which divides the states of Rio de Janeiro and Espírito Santo, may constitute an effective geographic barrier, although currently the northern known population of *L. lutzae* is located in Cabo Frio (Rocha, 1986; Rocha et al., 2009a).

The potential distribution of *L. lutzae* suggests that its occurrence would be possible in other areas of the

344

Braz. J. Biol., 2014, vol. 74, no. 2, p. 338-348

Figure 5. Map of the resulting potential distribution of *Liolaemus lutzae* (Squamata, Liolaemidae) in the southeastern-southern portion of known geographic distribution for the species (São Paulo, Paraná, Santa Catarina and Rio Grande do Sul).
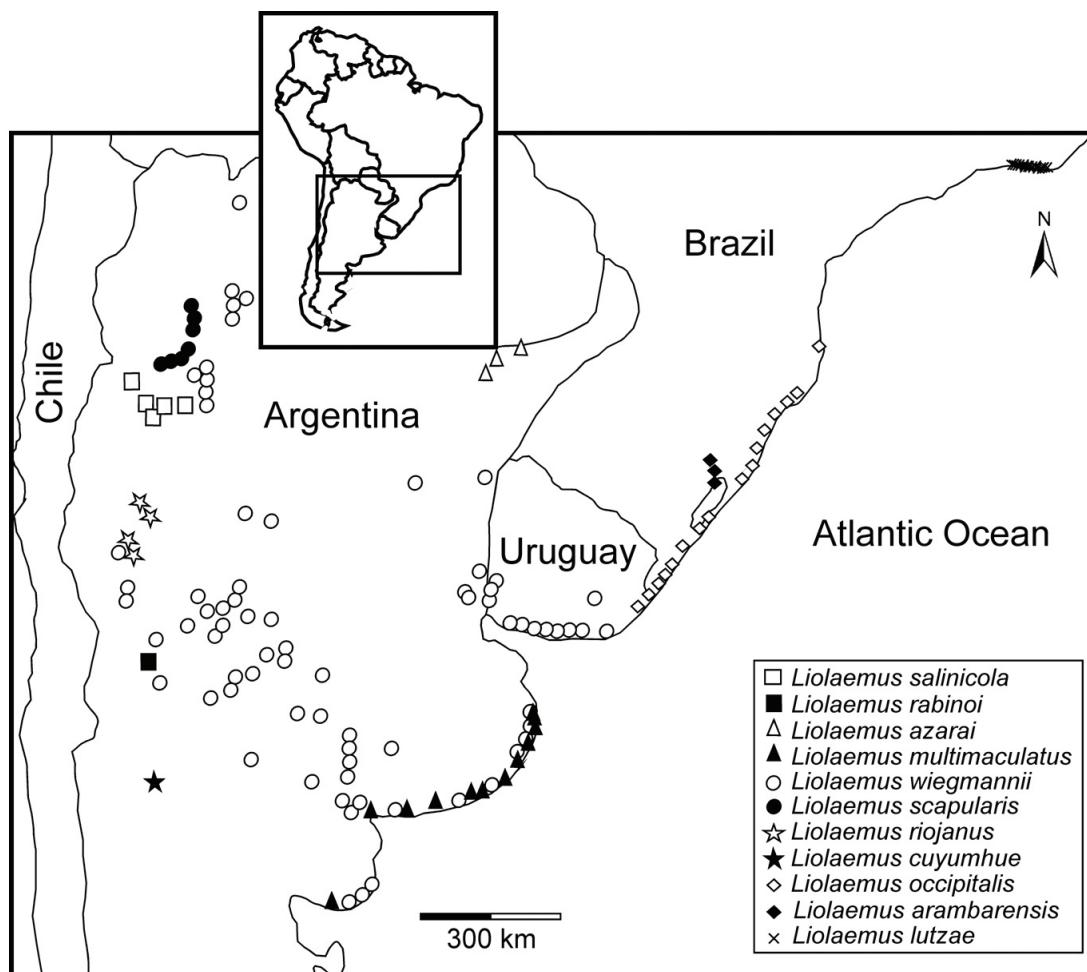
Figure 6. Distribution of the species of *Liolaemus wiegmannii* group. Modified from Avila et al. (2009).

Brazilian coast, considering the variables selected for this study. However, these areas are mainly located at southern coastal areas of Brazil. It is likely that *L. lutzae* had a greater geographic distribution historically, and that its extensive former coastal distribution area successively decreased, partly due to the sea transgressions which have suppressed extensive areas of restinga habitats along the states of Paraná, São Paulo and in the southern portion of Rio de Janeiro state.

Also, it is important to consider the human actions which can have started even during pre-colonisation and that have intensively increased throughout the last five centuries since colonisation. The elimination of some current populations (see Rocha and Bergallo, 1992; Rocha et al., 2009a) and the potential recovery when correct policies for the conservation of the species (Rocha et al., 2009b) are adopted suggest this. Alternatively, it may suggest a larger geographic distribution of an ancient lineage of the genus *Liolaemus* on the coast of Brazil. The conservation of restinga environments in the state of Rio de Janeiro is imperative, for the maintenance of the species, now restricted to small areas that strongly suffer ongoing human impacts.

346

Braz. J. Biol., 2014, vol. 74, no. 2, p. 338-348

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Braz. J. Biol., 2014, vol. 74, no. 2, p. 338-348

347

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348

Braz. J. Biol., 2014, vol. 74, no. 2, p. 338-348