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Short Note

Potential geographic distribution of *Myotis ruber* (Chiroptera, Vespertilionidae), a threatened Neotropical bat species

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Myotis ruber (E. Geoffroy 1806) is an endangered species under the category of Vulnerable according to the Brazilian Institute of Environment and Renewable Natural Resources – IBAMA (Machado et al. 2005), and under the category of Near Threatened at global level according to IUCN (2009). It is distributed across southeastern Brazil, Argentina, Uruguay, and Paraguay (Barquez et al. 1999, López-González et al. 2001, Reis et al. 2007, Achaval et al. 2008). The biology and ecology of this species are not well known (Wilson 2007), and the most common data regarding this species are geographic records about its distribution (Miretzki 2003, Sbragia and Pessôa 2007, Weber et al. 2007, Vieira et al. 2008).

Thus, the goal of this study is to provide a general distribution map of *Myotis ruber* using methods of distribution modeling to predict the potential geographic distribution and the main variables associated with its distribution. This will be useful to decide on conservation planning for the species, by predicting regions where it could be common or rare.

Occurrence records were obtained only from the literature review, because all distribution data about this species are interesting to the scientific community (Appendix 2). These data were utilized to predict the geographic distribution based on 14 environmental and topographic variables: annual precipitation, precipitation seasonality (coefficient of variation), precipitation of warmest quarter, precipitation of coldest quarter, annual mean temperature, temperature seasonality (coefficient of variation), maximum temperature of the warmest period, minimum temperature of the coldest period, mean temperature of the wettest quarter, mean temperature of the driest quarter, elevation (meters above sea level), normalized difference vegetation index (NDVI), aspect and slope. All variables were derived from the WorldClim interpolated map database (Hijmans et al. 2005) and reduced to a grid resolution of 0.0417° for the analysis. A distribution model was performed in Maxent 3.2.1 software (Steven Phillips, AT&T Labs – Research, NJ, USA) (Phillips et al. 2006). This software estimates the distribution from a model of occurrence probability, in which we considered only the distribution at a 75% level of the area to be suitable for *Myotis ruber*. Maxent only includes presence data, and excludes absence data.

The model sensitivity is defined as the proportion of true presences in relation to the overall presences predicted by the model, whereas the model specificity is the proportion of true absences in relation to the overall absences predicted by the model. It is worth mentioning that the ROC (receiver operating characteristic) is obtained using the relation between the sensitivity and the specificity, resulting in a minimum threshold probability. The area under the curve (AUC) is obtained from the integration of the ROC curve and it evaluates the ability of the model to predict the species distribution correctly. The AUC varies from 0 to 1, where values near to 1 indicate high performance to the model, and values below 0.5 indicate low performance (Dudík et al. 2004, Allouche et al. 2006).

Most records of *Myotis ruber* were from the Atlantic Forest. The records outside of the Atlantic Forest, mainly in Pampa and Chaco, were associated with riparian forests, and were indeed near or in transitional areas linking to the Atlantic Forest (Figure 1). In addition, this species is presumably associated with forests, particularly those forests of southern Brazil near the coast and some upland forests, and riparian forests along the Uruguay River.

Recently, *Myotis ruber* was recorded in Caatinga (Sbragia and Pessôa 2007) and in elevational swamps in northeastern Brazil (Sousa et al. 2004), and these are the most northward records for this species. The sampling area in the Caatinga comprises the semi-humid forests of the Chapada Diamantina, under direct influence of the Atlantic Forest. In addition, this area has been suggested as the northern limit for several bird species of the Atlantic Forest (Parrini et al. 1999). Sbragia and Pessôa (2007) suggested this might be the northern limit of distribution of *M. ruber*, but the record of Sousa et al. (2004) is located still farther northward. As well as the

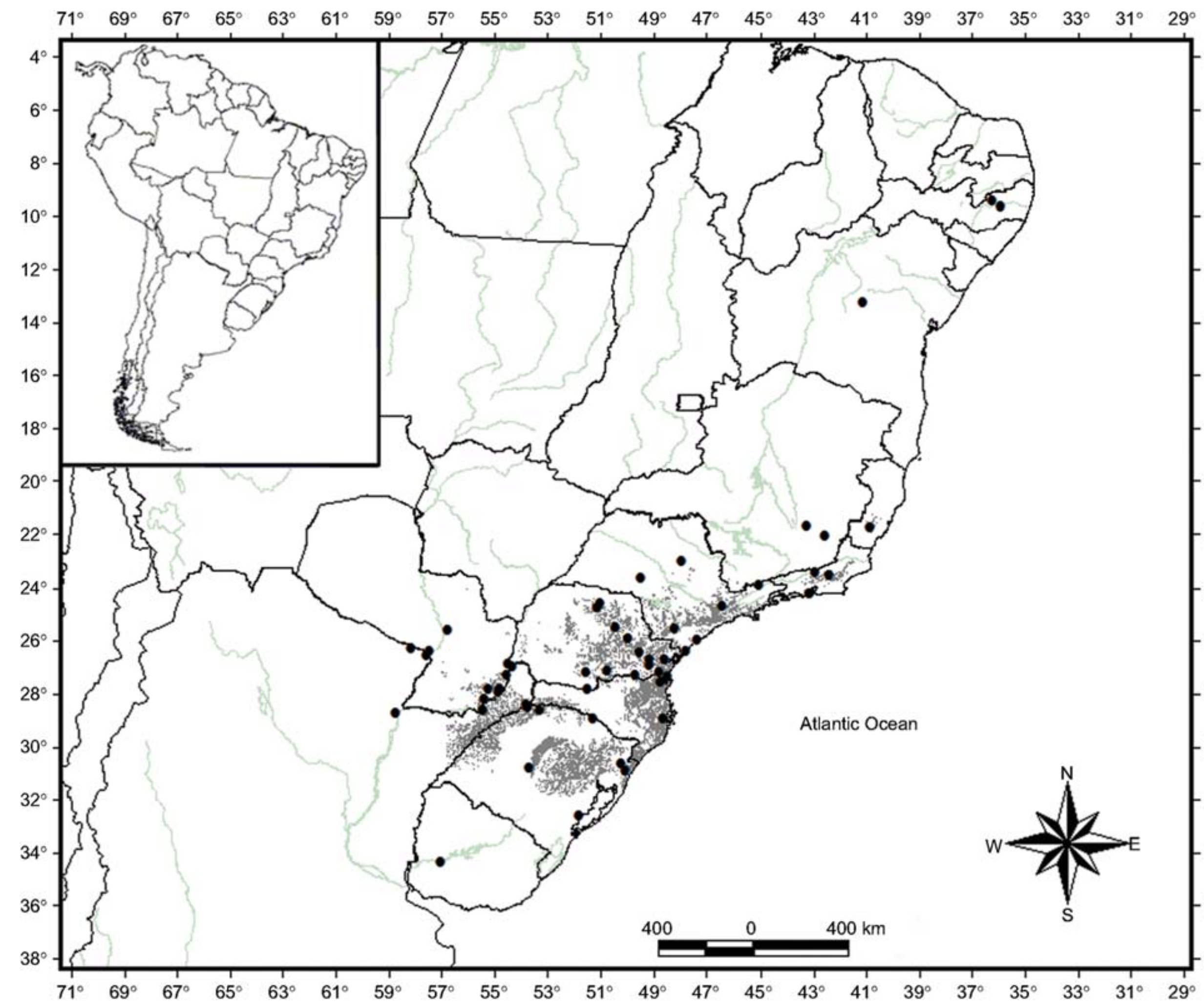

Figure 1 Records from the literature and potential geographic distribution (Maxent software) of *M. ruber*, a Neotropical bat species. Main rivers in gray (see geographic coordinates in Appendix 1).

record of Sbragia and Pessôa (2007), the record of Sousa et al. (2004) in elevational swamps is also located in area influenced by the Atlantic Forest. These isolated areas have higher annual rainfall and humidity than areas around the Caatinga (Tabarelli and Santos 2004). All records strongly suggest that this species occurs in humid woodland habitats, being rare in isolated patches when outside the southern Atlantic Forest.

According to Moratelli (2008), *Myotis ruber* is restricted to high altitudes between 8°S and 23°S, and in low altitudes between 25°S and 31°S. However, most of the records in the Atlantic Forest are in higher elevations throughout its distribution, and the southern boundary of its range should be increased to 33°S, according to the record of López-González et al. (2001) in Uruguay. Moreover, Achaval et al. (2008) pointed out that *M. ruber* occurs in Artigas and Paysandu Departments in Uruguay, but without providing the exact points for these records. The known records of *M. ruber* outside of the Atlantic Forest are in low elevations, such as in eastern Paraguay, northeastern Argentina, Uruguay and southern Brazil. Thus, elevation is not important for the potential geographic distribution of *M. ruber* (Table 1). Finally, although with a wide distribution, it is worth mentioning that *M. ruber* did not exhibit geographic variation in

Table 1 Percent contribution of each variable in the potential geographic distribution of *M. ruber*.

Variable	Percent contribution
Temperature seasonality (C of V)	35.9
Precipitation of warmest quarter	22.9
Annual mean temperature	13.1
Min temperature of coldest period	6.5
Precipitation of coldest quarter	6.3
Annual precipitation	4.7
Mean temperature of wettest quarter	3.9
Aspect	2.3
Mean temperature of driest quarter	1.5
Max temperature of warmest period	0.7
NDVI	0.7
Slope	0.6
Elevation	0.6
Precipitation seasonality (C of V)	0.2

body size or color (La Val 1973, López-González et al. 2001, Moratelli 2008).

The model generated presents a value AUC=0.991, indicating that the model performed well. Temperature seasonality, precipitation of warmest quarter, and annual mean temperature, respectively, were the main variables that influenced the potential geographic distribution of *Myotis ruber* (Table 1). This means that regions with a combination of marked seasonality in temperature, and high precipitation during a given period of the year, and that also present high annual temperature, are more suitable for *M. ruber* populations. In fact, these characteristics predominate in the southern Atlantic Forest. Except for areas of upland cold grasslands in southern Brazil where *M. ruber* is not expected to occur, the eastern coastal regions and the western riparian regions of Uruguay and Paraná rivers match with the estimated species distribution and the associated characteristics of high seasonality, heavy rainfall and high temperature.

Therefore, the potential geographic distribution included several areas of Atlantic Forest, confirming the association of *Myotis ruber* with this vegetation (Figure 1). The Uruguay River can act as corridors for dispersal of populations of this bat species, connecting populations from west to east, that are isolated with the upland grasslands which are common in southern Brazil. By contrast, populations of *M. ruber* appear to be common and connected at the eastern Brazilian coast, diminishing and becoming rarer northward in the Atlantic Forest, because in that region they probably depend on seasonal humid habitats normally found at high elevations (Sousa et al. 2004).

An interesting fact was that the model included patches of the Atlantic Forest in Espírito Santo state in southeastern Brazil. When we ran the Maxent for the first time, we did not include the record of Vieira et al. (2008) from the Espírito Santo state, but the record assigned by these authors coincided with the potential area predicted posteriorly using Maxent. This confirms the credibility of this software to estimate species potential geographic distribution. Later, the model generated with the record of Vieira et al. (2008) did not differ from the first model.

However, the potential distribution generated did not include some bordering known locations in Paraguay and Uruguay (Figure 1). Because the modeled distribution is the probability that a random specimen occurs in a given cell based on environmental variables (Dudík et al. 2004), the records not included in the potential distribution of *Myotis ruber* can be derived from small areas within a cell with different features from the whole cell. Hence, the average of the environmental variables might confound the suitable areas for the species in such cases. Thus, we do not believe that those populations are isolated, but they are rather connected by Atlantic Forest patches or by related formations. For the apparently isolated records of *M. ruber* in elevational swamps of northeastern Brazil, Costa (2003) argues that forest-dweller small mammals are also found in similarly elevated swamps surrounded by Caatinga dry forests in Ceará and Bahia states. This suggests that these mesic areas in Caatinga, supporting populations of forest species, were connected with the Atlantic Forest in the recent past (Vivo 1997). Currently, we believed that populations of *M. ruber* in its northern distribution is poorly connected, occurring mainly in humid forest patches and with different dynamics to the southern populations. Based on our distribution model for this species, perhaps more conservationist attention should be given for northern populations, where the species should be rarer.

Although this species is primarily associated with forests, the conservation status of the Atlantic Forest and riparian forests in southern South America is alarming in the face of the actual existence and persistence of *Myotis ruber*. This species was found in mature forests, forests in early succession stages, forest edges and urban forests (Reis et al. 2002, Weber et al. 2007), but this varied information could lead to a confounding knowledge of the preferred habitat of the species. Therefore, the existence of humid forests is the first factor for occurrence of *M. ruber* according to our results, so that the conservation of woodland patches will be very important to the persistence of this species over time, because it is a near threatened species (Machado et al. 2005, IUCN 2009). We highlight the poor level of conservation of riparian forests along the upper Uruguay River (M.E. Graipel, personal communication), a region where *M. ruber* is expected to occur, and that connects eastern and western populations in its southern distribution. By our simulated map of distribution of *M. ruber*, we think that several populations are being conserved in biological reserves along the Atlantic Forest, but many of them could be isolated by deforestation. We should also consider this species as rare throughout its distribution (López-González 2005). Therefore, it would be interesting to know the dispersal capacity of *M. ruber* to cross isolated forest patches, or examine the molecular differentiation of distinct populations, to better understand the gene flow along its distribution. Moreover, we suggest that every distribution map of a species should include the model of potential distribution plus the empirical records, and respective biological interpretation of such areas of occurrence, because natural areas are vanishing and these will be more logistically viable in terms of time and funds.

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Appendix 1

Localities where specimens of *Myotis ruber* were collected, with respective geographic coordinates and sources.

Argentina

1. Arroyo Oveja Negra, Misiones. 27°08′S, 53°54′W. (Mares et al. 1995).

2. Parque Nacional Iguazú, Iguazú, Misiones. 25°41′S, 54°27′W. (Barquez et al. 1999).
3. Corrientes, Corrientes. 27°28′S, 58°50′W. (Barquez et al. 1999).
4. Parque Nacional Rio Pilcomayo, Formosa. 25°00′S, 58°15′W. (Barquez et al. 1999).
5. Santa Ana, Candelária, Misiones. 27°22′S, 55°34′W. (Chebez and Massoia 1996).
6. Puerto Esperanza, Iguazú, Misiones. 26°01′S, 54°39′W. (Chebez and Massoia 1996).

Brazil

1. Parque Ecológico Municipal Professor João Vasconcelos Sobrinho, Caruaru, Pernambuco. 08°21′S, 36°01′W. (Sousa et al. 2004).
2. Brejo Madre de Deus, Pernambuco. 08°08′S, 36°22′W. (Sousa et al. 2004).
3. Bonito, Bahia. 11°58′S, 41°15′W. (Sbragia and Pessôa 2008).
4. Parque Estadual Pedra Azul, Domingos Martins, Espírito Santo. 20°25′S, 41°00′W. (Vieira et al. 2008).
5. Mariana, Minas Gerais. 20°22′S, 43°24′W. (Vieira 1942).
6. Viçosa, Minas Gerais. 20°45′S, 42°42′W. (López-González et al. 2001).
7. Nova Friburgo, Rio de Janeiro. 22°16′S, 42°31′W. (Vieira 1942).
8. Parque Nacional da Tijuca, Rio de Janeiro. 22°57′S, 43°17′W. (Esberárd 2003).
9. Parque Nacional da Serra dos Órgãos, Rio de Janeiro. 22°08′S, 43°03′W. (Moratelli and Peracchi 2007).
10. Estação Ecológica de Caetetus, Gália/Alvinlândia, São Paulo. 22°22′S, 49°37′W. (Pedro et al. 2001).
11. Piquete, São Paulo. 22°36′S, 45°10′W. (Vieira 1955).
12. Iguape, São Paulo. 24°42′S, 47°33′W. (Vieira 1955).
13. Américo Brasiliense, São Paulo. 21°43′S, 48°06′W. (Species Link 2008).
14. Parque Estadual da Ilha do Cardoso, São Paulo. 28°08′S, 47°57′W. (Alves 2008).
15. Parque Estadual Intervales, Ribeirão Grande, São Paulo. 24°16′S, 48°24′W. (Passos et al. 2003).
16. Parque Estadual da Cantareira, São Paulo. 23°24′S, 46°35′W. (Bertola et al. 2005).
17. Fazenda Iguaçu, Faxinal do Céu, Paraná. 25°56′S, 51°41′W. (Persson and Lorini 1990).
18. Fazenda Monte Alegre, Telêmaco Borba, Paraná. 24°12′S, 50°33′W. (Reis et al. 1999).
19. Parque Estadual Mata dos Godoy, Londrina, Paraná. 23°27′S, 51°16′W. (Reis and Muller 1995).
20. Parque Municipal Arthur Thomas, Londrina, Paraná. 23°18′S, 51°09′W. (Reis et al. 2003).
21. Rio Negro, Paraná. 26°01′S, 49°48′W. (Miretzki 2003).
22. Serra do Araçatuba, Guaratuba, Paraná. 25°54′S, 48°55′W. (Miretzki 2003).
23. Três Córregos, Campo Largo, Paraná. 25°12′S, 49°38′W. (Miretzki 2003).
24. Curitiba, Paraná. 25°25′S, 49°16′W. (Margarido and Braga 2004).
25. Fazenda Durgo, São Mateus do Sul, Paraná. 25°52′S, 50°52′W. (Margarido and Braga 2004).
26. Reserva Natural do Cachoeira, Antonina, Paraná. 25°25′S, 48°42′W. (Margarido and Braga 2004).
27. Parque Estadual de Caxambu, Castro, Paraná. 24°40′S, 50°04′W. (Margarido and Braga 2004).
28. Parque Nacional do Iguaçu, Foz do Iguaçu, Paraná. 25°36′S, 54°35′W. (Sekiama et al. 2001).
29. Campos de Palmas, Palmas, Paraná. 26°34′S, 51°36′W. (Miranda et al. 2008).
30. Fazenda Gralha Azul, Fazenda Rio Grande, Paraná. 25°39′S, 49°16′W. (Graciolli and Bianconi 2007).
31. RPPN de Volta Velha, Itapoá, Santa Catarina. 26°04′S, 48°37′W. (Sipinski and Reis 1995).
32. Joinville, Santa Catarina. 26°18′S, 48°50′W. (Cherem et al. 2004).
33. Santo Amaro da Imperatriz, Santa Catarina. 27°41′S, 48°46′W. (Cherem et al. 2004).
34. São Lourenço do Sul, Rio Grande do Sul. 31°21′S, 51°58′W. (Vieira 1955).
35. Parque Estadual do Turvo, Derrubadas, Rio Grande do Sul. 27°15′S, 53°51′W. (Wallauer and Albuquerque 1986).
36. São Francisco de Paula, Rio Grande do Sul. 29°24′S, 50°22′W. (Pacheco and Freitas 2003).
37. Maquiné, Rio Grande do Sul. 29°39′S, 50°12′W. (Pacheco and Freitas 2003).
38. Barracão, Rio Grande do Sul. 27°41′S, 51°26′W. (Pacheco and Freitas 2003).
39. Itaara, Rio Grande do Sul. 29°32′S, 53°47′W. (Weber et al. 2007).
40. Vila Faguense, Frederico Wesphalen, Rio Grande do Sul. 27°22′S, 53°25′W. (Bernardi et al. 2009).

Paraguay

1. Sapucay, Departamento de Paraguari. 24°20′S, 56°55′W. (La Val 1973).
2. Salto Tembey, Departamento de Itapua. 26°38′S, 54°57′W. (López-González 1998).
3. Arroyo Pirayu-i, Departamento de Itapua. 26°51′S, 55°14′W. (López-González 1998).
4. Arroyo Pirapo, Departamento de Itapua. 25°58′S, 56°09′W. (López-González 1998).
5. San Rafael, Departamento de Itapua. 27°07′S, 56°22′W. (López-González 1998).
6. Vila Hayes, Departamento de Presidente Hayes. (Baud and Menu 1993).

Uruguay

1. Arroyo Grande, Flores. 33°07′S, 57°08′W. (López-González et al. 2001).

Appendix 2

References compiled to elaborate the map (Figure 1) of geographic distribution of *Myotis ruber*.

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