Arquivos do Museu Nacional, Rio de Janeiro, v.65, n.2, p.217-223, abr./jun.2007
ISSN 0365-4508

POTENTIAL GEOGRAPHIC DISTRIBUTION OF THE CORALSNAKE *MICRURUS DECORATUS* JAN, 1858 (SERPENTES, ELAPIDAE) IN THE ATLANTIC RAIN FOREST OF BRAZIL [1]

(With 2 figures)

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ABSTRACT: The coralsnake *Micrurus decoratus* is restricted to the Atlantic Rain Forest from southeastern Brazil and data on its geographic distribution and natural history are poorly known. In this paper, we modeled its geographic range using the GARP program. Map was generated by combining the 20 best models and predicted the occurrence of *Micrurus decoratus* in the Atlantic Rain Forest, indicating the importance of this biome for the preservation of this species. Our study showed that ecological niche modeling might be an important computational tool to supplement traditional field studies in herpetology, allowing the identification of areas to be protected, and for the formulation of specific public policies for threatened species.

Key words: Serpentes. Elapidae. *Micrurus decoratus*. Atlantic Rain Forest. Genetic algorithm.

RESUMO: Distribuição geográfica potencial da cobra coral *Micrurus decoratus* Jan, 1858 (Serpentes, Elapidae) na Floresta Atlântica do Brasil.

A cobra coral *Micrurus decoratus* é uma espécie restrita à Mata Atlântica do Sudeste do Brasil e dados quanto a sua distribuição geográfica e história natural são pouco conhecidos. Neste trabalho, a distribuição geográfica dessa espécie foi modelada utilizando-se o programa de modelagem GARP. Foi gerado um mapa de predição de ocorrência de *M. decoratus* na Mata Atlântica por meio da combinação dos 20 melhores modelos resultantes da modelagem, indicando a importância desse bioma para a preservação da espécie. Este estudo mostrou que a modelagem do nicho ecológico pode representar importante ferramenta computacional para suplementar estudos de campo em herpetologia, permitindo a identificação de áreas prioritárias para conservação e formulação de políticas públicas específicas para espécies ameaçadas.

Palavras-chave: Serpentes. Elapidae. *Micrurus decoratus*. Floresta Atlântica. Algoritmo genético.

INTRODUCTION

The New World elapid coralsnakes comprise more than 124 taxa (species and subspecies) divided into three genera: *Leptomicrurus* Schmidt, 1937 (three species), *Micruroides* Schmidt, 1928 (one species), and *Micrurus* Wagler, 1824 (more than fifty species) (Silva & Sites, 2001). The neotropical genus *Micrurus* is possibly the most distinctive group among the whole elapid radiation due to their bright color pattern (Roze, 1996; Silva & Sites, 2001; Marques, 2002). However, data on natural history, ecology, and geographic distribution are restricted to a few species (Marques, 2002). Moreover, studies addressing the status and conservation of coralsnakes do not exist (Campbell & Lamar, 2004).

Micrurus decoratus Jan, 1858 is restricted to the Atlantic Rain Forest of southeastern Brazil (Campbell & Lamar, 2004) and its geographic distribution and natural history are poorly known. Many studies addressing the geographic distribution of *M. decoratus* have shown large areas of Atlantic Rain Forest from southern, southeastern, and northeastern Brazil as a potential place for the occurrence of this species (Amaral, 1929; Prado, 1945; Roze, 1967; Lema & Azevedo, 1969; Lema *et*

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al., 1984). In general, geographic ranges have been estimated subjectively and mapped using information from specimens' records, and most authors do not agree about the distribution of this species. AMARAL (1929) proposed the widest range for *M. decoratus*, including states from northeastern and central Brazil. However, there are no available records for these regions and indeed the author does not provide any specimens that could confirm this wide distribution. PRADO (1945) and ROZE (1967) suggested that this taxon ranges from the State of Rio de Janeiro up to the south of Santa Catarina. LEMA *et al.* (1984) expanded the geographic distribution of *M. decoratus* beyond Serra do Mar based in one specimen collected in São Leopoldo, Rio Grande do Sul State (MCN 2769) from the extinct Instituto Pinheiros S.A. (São Paulo State). We examined the specimen MCN 2769 and confirmed that it is a *M. decoratus* specimen, but probably the locality was in error (Thales de Lema, Pontifícia Universidade Católica do Rio Grande do Sul, pers.comm.). Once more, no specimen was collected and deposited as a museum voucher to support these extremely large distributions, and there are no later records for the Rio Grande do Sul State.

However, no studies have considered information on geographic ranges combined with data on biotic and abiotic factors. This combination allows a more accurate estimate of the potential extent of occurrence of a certain species (ANACLETO *et al.*, 2006; GUISAN & ZIMMERMANN, 2000). Development of such geographic range estimates were favored by the recent availability of detailed climatological data and ecological information on some taxa, as well as by the development of optimization and modeling algorithms and programs that create range models with reasonable abilities of prediction. The use of these niche modeling tools allows a better understanding of regional biodiversity patterns and, consequently, improves the implementation of many conservation actions, such as the selection of priority areas and biodiversity corridors (ANACLETO *et al.*, 2006).

The present study aimed to estimate the potential geographic ranges of *Micrurus decoratus*, a taxon that occurs in one of the biodiversity hotspots of the World (MYERS *et al.*, 2000).

MATERIAL AND METHODS

Several methods have been adopted for the creation of these models, such as multivariate statistics (AUSTIN & MEYERS, 1996; CORSI *et al.*, 1999), multiple logistic regression, discriminant analysis, and artificial intelligence based on genetic algorithms (STOCKWELL, 1999). Among the many available methods, the Genetic Algorithm for Rule-Set Production (GARP) has been considered a particularly robust and efficient optimization technique (STOCKWELL & PETERSON, 2002), which allows the prediction of geographic ranges for species in poorly sampled or unknown regions (PETERSON *et al.*, 2004).

The program GARP (http://biodi.sdcs.edu) is a genetic algorithm developed by STOCKWELL & NOBLE (1991), combining analytical abilities of several individual methods, such as BIOCLIM and logistic regression (PETERSON, 2001), optimized on a set of rules. GARP tries to find non-random relationships between data of species occurrence and environmental variables at recorded sites, producing models of the species' potential geographic ranges (STOCKWELL & NOBLE, 1991). Among the numerous interpretations of ecological niche (GRINNELL, 1917; ELTON, 1927; HUTCHINSON, 1965), the concept of fundamental niche is used in GARP modeling. According to this concept, a niche might be defined as a set of ecological and environmental conditions in which the species is able to survive. It might be represented by a multidimensional space, when the species is not restricted through competition with others (HUTCHINSON, 1965).

GARP works with sets of rules of logic inference that indicate the presence or absence of a species in a region (STOCKWELL & NOBLE, 1991). Specifically, half of the data is randomly selected for the development of the rules (training data), whereas the other half is used to evaluate the accuracy of the rules (test data). An algorithm is applied to the training rules to evaluate the accuracy of the model, according to the two errors likely to occur in estimation: omission (when an area of occurrence of the species is not predicted) and commission (when the prediction includes an area not occupied by the species). Omission is considered intrinsic when accuracy is evaluated from the training data, or extrinsic, when testing data are used (ANDERSON *et al.,* 2003). Each half is then sampled with 1250 substitutions, generating data of presence and absence (pseudo-absence) for a given locality. These presence-absence data are related to the environmental variables, generating a set of rules that define these associations by a process of self-evaluation according to a zero omission error. These rules are then modified and re-evaluated using the same criterion, generating an evolution of the rules that will tend to maximize the relationship between occurrence and a given set of environmental conditions. Thus, the program can run for a previously defined number of iterations, allowing model improvement. It can also stop when the addition of new rules has no appreciable effect on the accuracy measure (convergence), i.e., the difference between the current and the previous rule-set. The final rule-set, or ecological-niche model, is then projected onto a digital map.

We used the above procedures to model the geographic range of *M. decoratus* in Southeastern Brazil. We obtained 42 occurrence points (Fig.1) from all museums vouchers available from the following scientific collections: Instituto Butantan, São Paulo (SP); Museu de Zoologia da Universidade de São Paulo, São Paulo (SP); Instituto Vital Brasil, Niterói (RJ); Museu Nacional, Rio de Janeiro (RJ), and Museu de História Natural Capão da Imbuia, Curitiba (PR) (see the list of specimens in Appendix). Two of us (LCT and NJS) personally confirmed the taxonomic identification of all specimens included in our database.

In the optimization, we ran GARP 200 times, with 2000 iterations at each run, setting the convergence limit to 0.001, a 0% extrinsic omission error and 10% commission error. The environmental variables used were six climatic variables – annual mean temperature, temperature seasonality (coefficient of variation), mean temperature of driest quarter, annual precipitation, precipitation seasonality (coefficient of variation) and precipitation of warmest quarter –, derived from the WORDCLIM (http://www.worldclim.org/), and three topographic variables – altitude, aspect and slope –, derived from the Hydro-1K global digital elevation model (http://edcdaac.usgs.gov/gtopo30/hydro/). All variables were reduced to a grid resolution of 0.0417 degrees for the analysis.

We selected the 20 best models (i.e., the best subset) generated for the species and imported them into a GIS platform (ArcView). Models in the best-subset were summed and mapped, allowing a visual inspection of regions with high level of model overlap, which presumably represents the regions with higher chance of species' occurrence. We used a map with five classes representing the number of models (0,

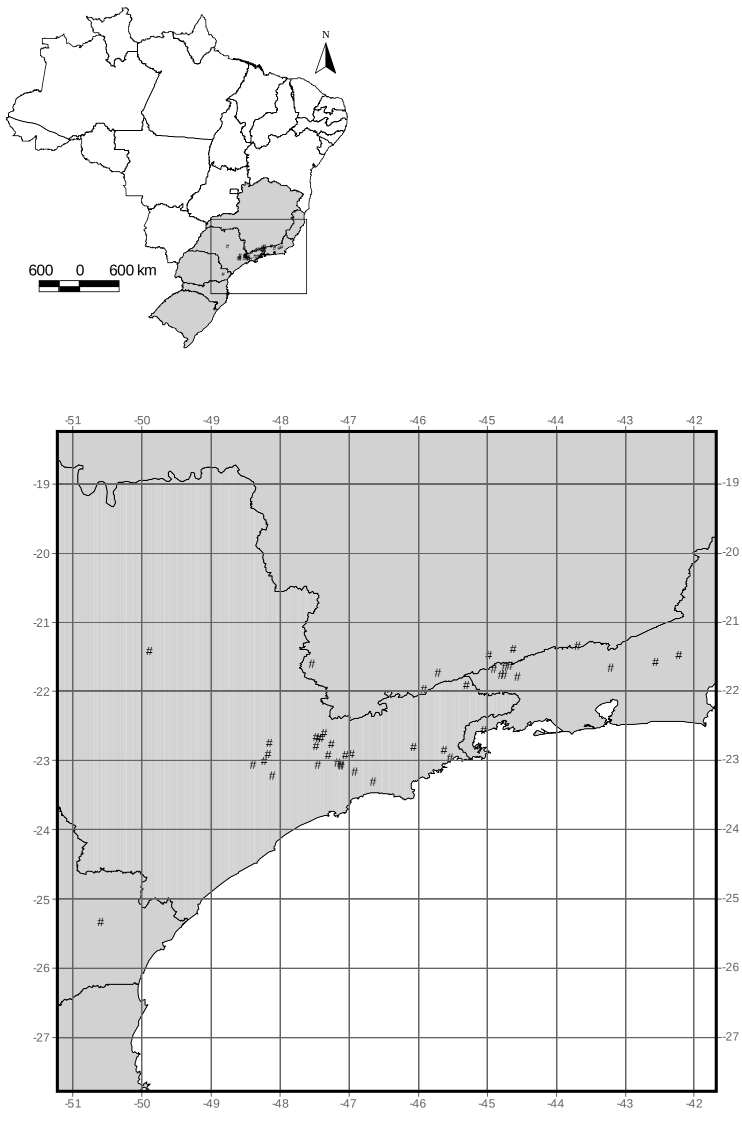

Fig.1- Distribution of 42 sites of occurrence of *Micrurus decoratus* used to model geographic range using GARP.

1-5, 6-10, 11-15 and 16-20) to estimate the species' geographic range. The predictive performance of GARP was evaluated with AUC (the area under the receiver operating characteristic curve) statistic (see ALLOUCHE *et al.*, 2006; ELITH *et al.*, 2006). AUC has been used extensively in evaluating species' distribution models, and measures the ability of a model to discriminate between sites where a species is present vs. those where it is absent. A score lower than 0.5 indicates that a model has no discriminatory ability, whereas a score tending to 1 indicates that presences and absences are perfectly discriminated (ELITH *et al.*, 2006).

RESULTS

The GARP model based on the 42 data points from museum specimens is shown in figure 2. The AUC statistic was 0.99, indicating a very good predictive performance of GARP. Considering occurrence based on records only, the geographic range of the species was primarily concentrated along the mountains of the states of São Paulo, Rio de Janeiro, and Minas Gerais in the southeastern Brazil, including regions of the Serra do Mar, Serra da Mantiqueira, and Serra de Paranapiacaba. Annual mean temperature of the records of *M. decoratus* ranged from 14° to 23°C and altitude ranged from 457 to 1,643 meters. The best subset of models to estimate the potential distribution of *M. decoratus* was given apparently by the overlap of 16-20 models. Areas where GARP predicted highest overlap of presences in the models are predominantly in the immediate vicinity of the museum specimens records, although moderate to high levels of probability (6 to 15 models) are also defined in areas where *M. decoratus* has not been previously collected (e.g., the species is predicted in the northern part of State of Paraná, southeastern Santa Catarina, and southeastern Minas Gerais). Sets with a lower number of models (1 to 5) included sites where the probability of occurrence is low, including areas in the states of Rio Grande do Sul and Santa Catarina, in extreme southern Brazil.

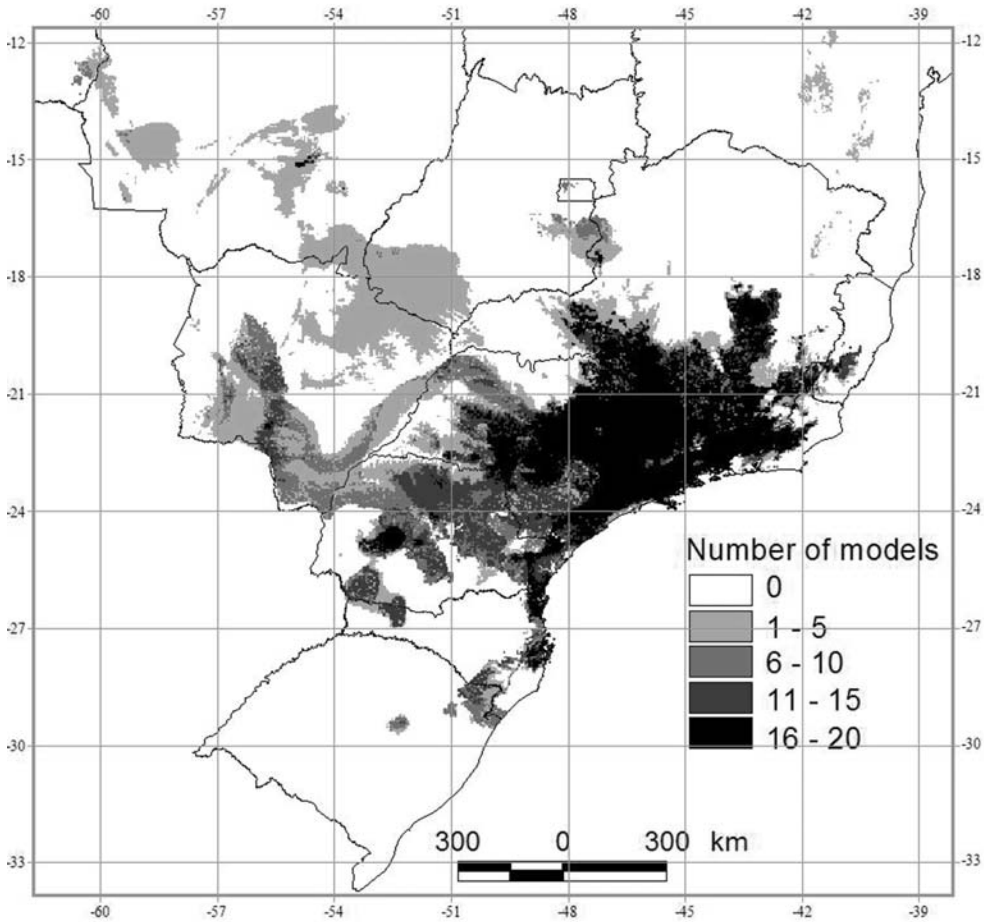

Fig.2- Model of the potential distribution of *Micrurus decoratus* according to GARP. The scale of colors (black to white) represents the number of overlapping models predicting the occurrence of species (see Material and Methods for details).

DISCUSSION

Modeling techniques of geographic distribution have been widely used to predict species distribution (Filipe *et al.*, 2004) and pinpointing areas where appropriate environmental conditions exist to sustain species whose habitat is threatened (Chefaoui *et al.*, 2005). In many instances, there are only crude descriptions of the extent of occurrence of the species, not infrequently dealing with geopolitical (countries, states, provinces or municipalities) units. On the other hand, niche modeling approach, based on occurrence records, is more accurate to generate maps of potential distribution of species.

The predicted range of *M. decoratus* was concentrated in southeastern region, reflecting the reduced and clustered distribution of occurrence records. Considering the statistical properties of GARP, we believe that the reduced number of occurrence points is not a problem and will not qualitatively affect our conclusions, since previous methodological papers using GARP showed that the procedure works relatively well even with a low number of points (10-20) (Peterson *et al.*, 2002).

Recently, Campbell & Lamar (2004) presented a map with a continuous range from southern Minas Gerais to northeastern Rio Grande do Sul, based on literature records. The range predicted for *M. decoratus* does not corroborate the geographic distribution proposed by Campbell & Lamar (2004) and reinforces that this species has a more restricted range than cited in the literature. In respect of the several studies that suggested a broad distribution of *M. decoratus* in southern Brazil (Prado, 1945; Roze, 1967; Lema *et al.*, 1984), the GARP prediction shows a more restricted distribution of suitable areas in these regions.

On the other hand, GARP prediction power in the present study may be limited for the variables included on modeling. *Micrurus decoratus* needs forested areas to survive and we include no variables of vegetation in the model of species distribution. This may be particularly important to explain the reduction of GARP prediction power along Atlantic Rain Forest. However, climatic and topographic variables used here can be useful surrogates for vegetation variation pattern. Perhaps more refined studies with specific purposes (i.e., reserve design in regional or local spatial scales) would incorporate these variables and information on habitat fragmentation to improve model performance and, more importantly, allow better scientific basis for practical conservation decisions.

Although the GARP output does not allow to evaluate which variables are more important to determinate *M. decoratus*' occurrence, the distribution of the records suggests that altitude can hold an important role to determine the geographic distribution of this species. Also, it is important to consider that non-climatic processes and evolutionary factors may also drive the geographic distribution of species, and they are currently not included in most studies using niche-based models. These factors generate patterns of non-equilibrium between species and climate (*sensu* Araújo & Pearson, 2005) and reduce the predictive ability of these models. However, it is difficult to incorporate these stochastic and contingential factors in species' distribution models, and further studies are still required to avoid these problems. Thus, although our GARP model had a very high statistical performance according to AUC, it is not possible to rule out, for example, that the distribution of *M.decoratus* is a bit more restricted than mapped here by dispersal limitations not included in our model.

Also, *M. decoratus* is endemic from Atlantic Rain Forest (Campbell & Lamar, 2004) and the current fragmentation of this biome can bring about habitat loss and extinction of this species. The high number of models that predicts the occurrence of this species along the mountains reinforces the importance of preserving reserves along the Serra do Mar and Serra da Mantiqueira, such as Parque Nacional do Itatiaia, Parque Nacional da Serra da Bocaina, and Parque Nacional da Serra dos Órgãos.

Finally, our study showed that ecological niche modeling might be an important computational tool to supplement traditional field studies in herpetology. It can be used to identify areas to be protected or recovered and for the formulation of public policies specific for threatened species. In addition to predicting the geographic ranges of a certain species, this analysis allows highlighting the importance of the Atlantic Rain Forest as a hotspot that urgently needs political and management actions to effectively protect this species.

ACKNOWLEDGMENTS

Our research program in macroecology, evolutionary ecology and species distribution modeling has been continuously supported by many grants and fellowships from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq). We also thank Francisco Luís Franco (Instituto Butantan), Hussam Zaher (Museu de Zoologia da Universidade de São Paulo), Aníbal Melgarejo (Instituto Vital Brasil), Ronaldo Fernandes (Museu Nacional), and Julio César de Moura Leite (Museu de História Natural Capão da Imbuia), for access to record data.

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APPENDIX

LIST OF SPECIMENS

Minas Gerais: IB 6476 (♂), Rio Preto; IB 31573 (♂), Retiro Centro d'Oeste.

Rio de Janeiro: IB 1233 (♂), Itatiaia; IB 17327 (♀), Parque Nacional do Itatiaia (Resende); IB 17328 (♂), Parque Nacional do Itatiaia (Itamonte); IB 17329 (♀), Parque Nacional do Itatiaia (Bocaina de Minas); IVB 0078 (♂), Nova Friburgo; IVB 0079 (♀), Petrópolis; IVB 0080 (♀), Teresópolis.

São Paulo: IB 1456 (♂), Pindamonhangaba; IB 6330 (♂), Cascata; IB 5676 (♀), Campo Limpo; IB 7295 (♂), Perequê; IB 18263 (♂), Queluz; IB 21113 (♂), Piedade; IB 23233 (♂), Jundiaí; IB 25002 (♂), Rio Grande da Serra; IB 25219 (♂), Estação Ecológica da Boracéia; IB 34164 (♀), Bananal; IB 42561 (♀), Ribeirão Pires; IB 42331 (♀), Bertioga; IB 42693 (♂), Jarinú; IB 43222 (♂), Várzea Paulista; IB 43745 (♀), Cajamar; IB 44187 (♂), São Roque; IB 44648 (♂), Cunha; IB 47647 (♂), Moji das Cruzes; IB 49611 (♀), Cabreúva; IB 9488 (?), Suzano; IB 51356 (♀), Ibiúna; IB 53077 (♂), Paraibuna; IB 54274 (♂), Juquitiba; IB 61107 (♂), Mairiporã; IB 62062 (♀), Moji Mirim; IB 64300 (♂), Itapecerica da Serra; IB 66479 (♀), Mauá; IB 66669 (♀), Campos Novos da Cunha; MZUSP 0066 (♂), Piquete; MZUSP 4593 (♀), São José do Barreiro (Serra da Bocaina); MZUSP 4830 (♀), Boracéia; MZUSP 10575 (♀), Serra da Bocaina (Fazenda do Bonito).

Paraná: MHNCI 5895 (♀), Piraquara, Mananciais da Serra.