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Implementing new northernmost records to modelling the distribution of *Hypsiboas caingua* (Anura: Hylidae) in South America

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Abstract

New northwestern records of the striped treefrog *Hypsiboas caingua* (Carrizo, 1991 "1990") are presented for Brazil, extending its known geographic distribution approximately 115 km northward (linear distance) of the previous northernmost record of the species. In all new localities, individuals of *H. caingua* were only found in calling activity under temperatures below 18ºC. The species appears to be associated with Atlantic Forest, although it had already been recorded in Cerrado. Although the scientific literature data suggests that *H. caingua* presents discontinuous geographical distribution, three methods of distribution modelling based on climatic data show that the species' distribution is continuous. The gap in the distribution may be related to the lack of field surveys in the regions that connect these populations, especially in colder periods. Nevertheless, factors other than climate might also be responsible for the current distribution of *H. caingua*, since the species was absent in well-surveyed sites situated between the areas of modeled distribution. Therefore, further studies on natural history, populations' genetic structure, and geographic distribution models implementing factors other than climate will be important to elucidate some ecological and evolutionary aspects of the distribution of *H. caingua* in South America.

Keywords: Central-Southern Brazil, Cerrado, striped treefrog, species distribution modelling (SDM), low temperatures.

Uso de novos registros ao norte para a modelagem de distribuição de *Hypsiboas caingua* (Anura: Hylidae) na América do Sul

Resumo

Novos registros da perereca *Hypsiboas caingua* (Carrizo, 1991 "1990") são apresentados para o noroeste do Brasil, ampliando sua distribuição geográfica em aproximadamente 115 km ao norte (distância linear) em relação ao registro anterior setentrional da espécie. Em todas as novas localidades, indivíduos de *H. caingua* foram apenas encontrados vocalizando sob temperaturas abaixo de 18 ºC. A espécie aparenta estar associada com a Mata Atlântica, embora já tenha sido registrada no Cerrado. Apesar de dados da literatura científica sugerirem que *H. caingua* apresente distribuição geográfica descontínua, os três métodos de modelagem de distribuição, baseados em dados climáticos demonstram que a distribuição da espécie é contínua. A lacuna na distribuição pode estar relacionada à ausência de levantamentos de campo nas regiões que conectam essas populações, principalmente em períodos frios. Contudo, outros fatores além do climático também podem ser responsáveis pela atual distribuição de *H. caingua*, visto a ausência da espécie em locais bem amostrados situados entre as áreas de distribuição modeladas. Portanto, mais estudos sobre a história natural, genética de populações e modelos de distribuição geográfica que abordem outros fatores além do clima, serão importantes para elucidar alguns aspectos ecológicos e evolucionários da distribuição de *H. caingua* na América do Sul.

Palavras-chave: Centro-Sul do Brasil, Cerrado, striped treefrog, modelagem de distribuição de espécie (SDM), baixas temperaturas.

1. Introduction

Hypsiboas (Hyla) caingua is a recently revalidated species (with 30 other species) included in the *H. pulchellus* group (Faivovich et al., 2005). This species is relatively small size (mean total length 33.7 mm), thin legs, and underdeveloped adhesive disks. The dorsal color pattern varies from whitish to brown with three thin longitudinal lines, and a dark lateral stripe from the snout to the posterior surfaces of the flanks, where it is replaced by a dark color. The posterior part of the thighs is whitish with dark blotches (Carrizo, 1990).

The current distribution of *H. caingua* encompasses the provinces of Misiones (type locality) and Corrientes, northeastern Argentina (Carrizo, 1990; Garcia et al., 2007a), and adjacent areas in southeastern Paraguay (Brusquetti and Lavilla, 2006). In addition, there are isolated populations in Brazil located in the states of São Paulo (Melo et al., 2007; Condez et al., 2009; Toledo and Haddad, 2009; Brassaloti et al., 2010; Araujo and Almeida-Santos, 2011; Maffei et al., 2011), Rio Grande do Sul (Garcia et al., 2007b; Lema and Martins, 2011) and Mato Grosso do Sul (municipalities of Tacuru and Naviraí: Aoki et al., 2010). Herein, we provide new records of *H. caingua* from Mato Grosso do Sul state, Brazil, representing the northernmost records of the species in South America. In addition, we present an overview map of its current geographical distribution, and determine potential areas of occurrence using species distribution modelling (SDM) methodologies.

2. Material and Methods

Throughout herpetofaunal surveys in Mato Grosso do Sul, we recorded nine new points of occurrence for *H. caingua* (Table 1), and collected four males as voucher specimens, deposited in the Coleção Zoológica da Universidade Federal de Mato Grosso do Sul (ZUFMS), Campo Grande, Mato Grosso do Sul, Brazil (ZUFMS-AMP2503, ZUFMS-AMP2504, ZUFMS-AMP2505, ZUFMS-AMP2506 - permission of IBAMA: 011/2010 and process no. 02014.000112/2011-06; permits: 013/2010, process no. 02014.000111/2011-53). Point occurrence data obtained from our new records and literature (Appendix 1) were used to generate potential distribution areas using three SDM methodologies, which are widely used in the literature (e.g., Giovanelli et al., 2010; Terribile et al., 2010; Vasconcelos et al., 2012). BIOCLIM characterizes sites that are located within the environmental hyperspace occupied by a species, in which the potential climatic domain is the multidimensional envelope that encompasses all recorded locations of the species (Nix, 1986). OM-GARP is a version of GARP (Anderson et al., 2003) implemented in openModeller 1.1.0 software (Muñoz et al., 2011), which uses a genetic algorithm to select a set of rules that best predicts the species' distributions (Stockwell and Peters, 1999). Support Vector Machines (SVM) are a class of non-probabilistic statistical pattern recognition that estimate the boundary of the set from which a collection of observations is drawn, minimizing errors of empirical classifications and maximizing the geometric boundaries (De Marco-Junior and Siqueira, 2009; Giovanelli et al., 2010). The environmental variables used to model species distributions were taken from the WorldClim database (Hijmans et al., 2005) and selected to describe general climatic trends (i.e. mean values), variation in temperature and precipitation over time, and potential physiological limits for amphibians (Nix, 1986): annual mean temperature, temperature seasonality, minimum temperature of the coldest month, temperature annual range, annual precipitation, precipitation seasonality, and precipitation of the warmest quarter (10 km spatial resolution). The SDM of each model was evaluated by the receiver operating characteristic (ROC) curve, whose area under the curve (AUC) ranges from 0.5 (random prediction) to 1 (sufficiently discriminatory prediction) (Elith and Burgman, 2002). Finally, two consensus maps were generated in openModeller 1.1.0 (Muñoz et al., 2011) in order to consider, based on the three SDM methodologies, the most probable occurrence area for *H. caingua* in South America. The first consensus map considered a probability of 50% of occurrence considering all SDM methods, while the second map considered a more restrictive threshold of 70%. All SDM methods were performed in openModeller 1.1.0 (Muñoz et al., 2011).

Table 1. Characterizations of point data occurrence of *Hypsiboas caingua* in Mato Grosso do Sul state, Brazil. The localities' sequence corresponds to north-south direction ("Datum WGS 84").

Municipality	Coordinates (lat., long.)	Environment	Temperature (ºC)
Nova Alvorada do Sul	21°34'41"S; 54°13'56"W	Swamp areas	12
Rio Brilhante	21°51'08"S; 54°00'54"W	Permanent ponds	18
Bela Vista	22°01'53"S; 55°52'33"W	Swamp areas	16
Angélica	22°03'46"S; 53°47'53"W	Permanent ponds	17
Ponta Porã	22°16'56"S; 55°07'07"W	Swamp areas	15
Fátima do Sul	22°18'59"S; 54°35'15"W	Swamp areas	16
Ivinhema	22°25'58"S; 53°53'58"W	Permanent ponds	18
Vicentina	22°29'04"S; 54°23'31"W	Swamp areas	18
Amambaí	22°59'39"S; 54°55'55"W	Permanent ponds	18

3. Results

The record of *H. caingua* in Nova Alvorada do Sul municipality, Brazil, expands its distribution to approximately 115 km (linear distance) northward (previously northernmost record was between Gália and Alvilândia municipalities, São Paulo - 22°24'11" S; 49°42'05" W – Brassaloti et al., 2010) and reaches into the Cerrado phytogeographic domain of Mato Grosso do Sul state, Brazil (Figure 1).

In all new localities, individuals of *H. caingua* were only found in calling activity under temperatures below 18ºC (Table 1). Each male was observed in calling activity over shrubs and aquatic vegetation, perched in branches and leaves varying from 20 cm to one meter height.

Considering the current extent of distribution of *H. caingua* in South America and specifically in Brazil (Figure 1A and 1B, respectively), all SDM methods show reasonable congruence with the current species' distribution (Figure 2A, 2B and 2C). Among the three methods, BIOCLIM provided the smallest predicted occurrence area, SVM provides the largest, and OM-GARP an intermediary foreseen occurrence area (Figure 2). Both consensus maps (Figure 2D and 2E) show high probability of occurrence of *H. caingua* in the Cerrado and Atlantic Forest, which includes all extent of occurrence of the current species' distribution, but higher probabilities of occurrence mostly include the western region of Paraná state, south of Mato Grosso do Sul state, southeastern Paraguay, and Misiones Province in Argentina (Figure 2D and 2E).

4. Discussion

The record of *H. caingua* in the municipality of Nova Alvorada do Sul, Brazil, is the northernmost record of *H. caingua* in South America. Furthermore, this record extends the known distribution of *H. caingua* in 155 km (linear distance) northward from the nearest occurrence in Mato Grosso do Sul state, recorded in the municipality of Naviraí (Aoki et al., 2010). Despite the limited knowledge about the biology and ecology of *H. caingua* (e.g., Melo et al., 2007; Kolenc et al., 2008; Brassaloti et al., 2010), the species appears to be predominantly associated with the Atlantic Forest domain in the São Paulo state (Araújo et al., 2009; Condez et al., 2009; Rossa-Feres et al., 2011). However, the species had already been recorded in open area formations in São Paulo state, i.e. Cerrado (Melo et al., 2007; Araujo and Almeida-Santos, 2011; Valdujo, 2011), but its record in Nova Alvorada do Sul and Bela Vista are the first reports of this species in the Cerrado of Mato Grosso do Sul state, Brazil. Besides, *H. caingua* also occurs in the mixed ombrophilous forest in the brazilian southern states, open natural fields in Argentina (provinces of Misiones and Corrientes) and in

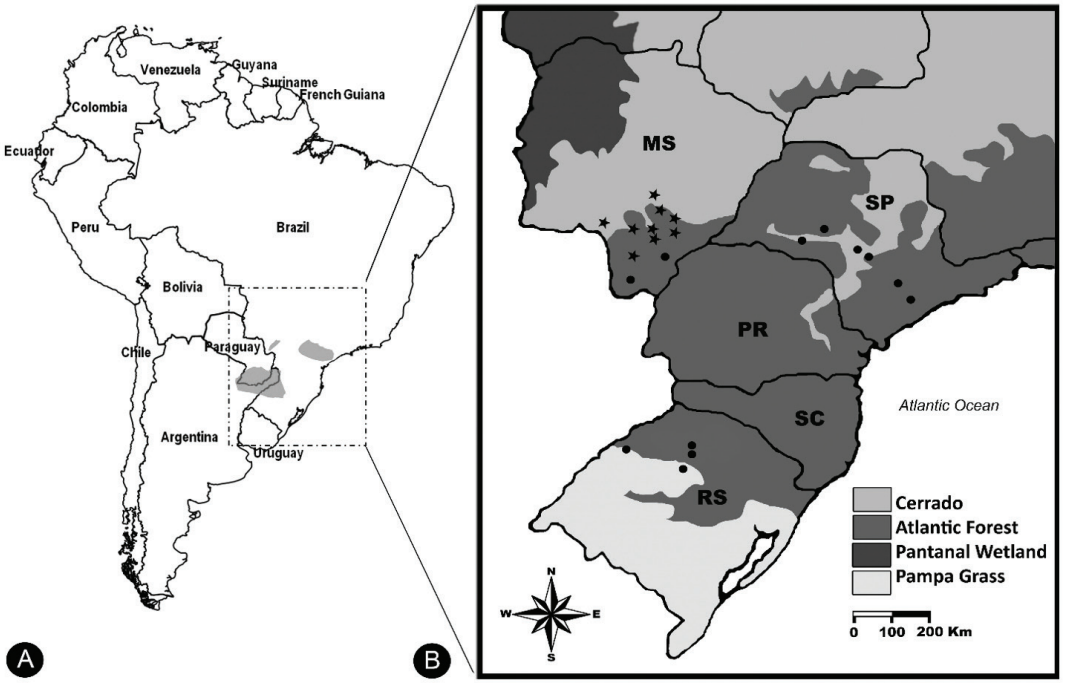

Figure 1. (A) Known geographical distribution of *H. caingua* in South America (modified from Scott et al. (2004)); (B) and the reported occurrence of the species in central-southern Brazil (Acronym of the states – MS: Mato Grosso do Sul; SP: São Paulo; RS: Rio Grande do Sul; PR: Paraná and SC: Santa Catarina) (circles - Garcia et al., 2007b; Melo et al., 2007; Condez et al., 2009; Toledo and Haddad, 2009; Aoki et al., 2010; Brassaloti et al., 2010; Araujo and Almeida-Santos, 2011; Maffei et al., 2011). Stars represent the news records in Mato Grosso do Sul state Brazil. Brazilian phytogeographic domains accordingly to IBGE (2011).

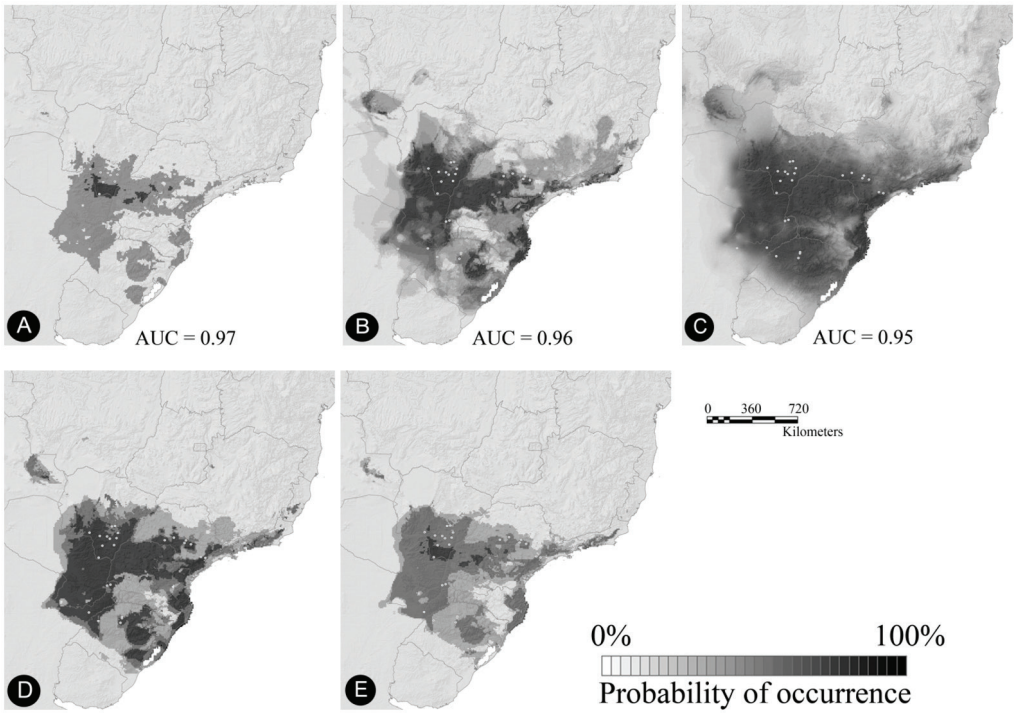

Figure 2. Predicted occurrence areas for *Hypsiboas caingua*: (A) BIOCLIM prediction, (B) OM-GARP prediction, (C) SVM prediction, (D) Consensus map considering a threshold of 50%, and (E) consensus map considering a threshold of 70%. AUC = Area Under the Curve for model validation (see Methods). White dots represent the 26 occurrence records used in the modeling process (see Appendix 1).

the humid chaco ecoregion of Argentina and Paraguay (Garcia et al. 2007a).

Considering the new records, males of *H. caingua* were only found in calling activities under low temperatures, which reinforces the hypothesis of adaptation to low temperatures (Melo et al., 2007). Even though the species may congregate for breeding throughout the year, with decrease in abundance on nights with temperatures below 15°C (Brassaloti et al., 2010), we recorded calling activities at even lower temperatures in Nova Alvorada do Sul (~8-15°C). All males were calling perched over shrubs and aquatic vegetation, in agreement with Jim (1980), but Melo et al., (2007) also found males calling on the floor.

The current distribution of *H. caingua*, also considering our records, clearly shows discontinuity with a gap among the isolated populations in Paraguay, Argentina, Rio Grande do Sul state (Brazil), and the most occurrence points in São Paulo and Mato Grosso do Sul states, Brazil. The three SDM methods pointed out that the most probable occurrence areas represent the current records in Brazil (states of Mato Grosso do Sul, São Paulo, and Rio Grande do Sul), southeastern Paraguay and Misiones Province in Argentina. However, all SDM maps showed continuity on the occurrence of *H. caingua*, except for the low probability of occurrence area between the states of Rio Grande do Sul and central Paraná (southern Brazil). It intuitively suggests that the current gap on the distribution (western and north-western regions of São Paulo and Paraná states, respectively) is because of the lack of anurans surveys in these regions, mainly in cold periods, as reported herein. Nevertheless, SDM methodologies, as they were performed herein, are not able to predict absences caused by other factors than climate (e.g. biotic interactions and evolutionary history). Rather, SDM methods consequently provided only those suitable areas where *H. caingua* would be able to occupy. Then, other factors than climate might be also responsible in the current distribution of *H. caingua*, since well surveyed sites between the current records, which have higher probabilities of occurrence according to the species distribution modelling, have no occurrence record for this species (e.g., Bernarde and Machado, 2001; Vasconcelos and Rossa-Feres, 2008; Serafim et al., 2008; Santos et al., 2009; Armstrong and Conte, 2010; Conte et al., 2010; Forlani et al., 2010; Silva and Rossa-Feres, 2011; Sabbag and Zina, 2011). We believe that further studies on natural history, populations' genetic structure and geographic distribution models implementing other factors than climate will be important to elucidate some ecological and evolutionary aspects of the distribution of *H. caingua* in South America.

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Appendix 1. Geographical coordinate and municipality of known literature occurrence and new records of *H. caingua* used to generate the potential distribution areas by the three SDM methodologies. Acronym of the states – MS: Mato Grosso do Sul; SP: São Paulo; RS: Rio Grande do Sul. The localities' sequence corresponds to north-south direction ("Datum WGS 84").

Municipality (State)	Coordinates (lat., long.)	Reference
Nova Alvorada do Sul, MS	21°34'41"S; 54°13'56"W	Present study
Rio Brilhante, MS	21°51'08"S; 54°00'54"W	Present study
Bela Vista, MS	22°01'53"S; 55°52'33"W	Present study
Angélica, MS	22°03'46"S; 53°47'53"W	Present study
Ponta Porã, MS	22°16'56"S; 55°07'07"W	Present study
Fátima do Sul, MS	22°18'59"S; 54°35'15"W	Present study
Between Gália and Alvilândia, SP	22°24'11"S; 49°42'05"W	Brassaloti et al. (2010)
Ivinhema, MS	22°25'58"S; 53°53'58"W	Present study
Vicentina, MS	22°29'04"S; 54°23'31"W	Present study
Assis, SP	22°35'44"S; 50°21'55"W	Araujo and Almeida-Santos (2011)
Lençóis Paulista, SP	22°47'44"S; 48°55'27"W	Maffei et al. (2011)
Botucatu, SP	22°53'09"S; 48°26'42"W	Melo et al. (2007)
Naviraí, MS	22°56'43"S; 54°04'39"W	Aoki et al. (2010)
Amambaí, MS	22°59'39"S; 54°55'55"W	Present study
Pilar do Sul, SP	23°48'47"S; 47°42'59"W	Toledo and Haddad (2009)
Tacuru, MS	23°52'01"S; 55°12'37"W	Aoki et al. (2010)
Between Tapiraí and Piedade, SP	23°53'20"S; 47°23'20"W	Condez et al. (2009)
Iguazú, Misiones	25°50'53"S; 54°20'48"W	Carrizo (1990)
Puerto Bemberg, Misiones	25°55'10"S; 54°35'07"W	Carrizo (1990)
Posada, Misiones	27°26'12''S; 55°53'24''W	Kolenc et al. (2008)
Playadito, Corrientes	27°53'05"S; 55°55'11"W	Carrizo (1990)
Manantiales, Corrientes	27°55'26"S; 58°06'12"W	Carrizo (1990)
Condor, RS	28°12'28"S; 53°29'14"W	Garcia et al. (2007b)
Panambi, RS	28°17'33"S; 53°30'06"W	Garcia et al. (2007b)
Santo Antônio das Missões, RS	28°30'40"S; 55°14'01"W	Garcia et al. (2007b)
Cruz Alta, RS	28°38'19"S; 53°36'23"W	Garcia et al. (2007b)