Phyllomedusa 12(2):97–106, 2013

ISSN 1519-1397 (print)
ISSN 2316-9079 (online)

Potential effects of climate change on the distribution of an endangered species: *Melanophryniscus montevidensis* (Anura: Bufonidae)

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Abstract

Potential effects of climate change on the distribution of an endangered species: *Melanophryniscus montevidensis* (Anura: Bufonidae). Species distributions are linked with climate. Among the effects predicted by the Intergovernmental Panel on Climate Change are changes in precipitation patterns and increases in mean temperatures—factors potentially having a major impact on threatened, rare, and endemic species. Using models to forecast possible changes in the distributions of different species under different climate-change scenarios, we can identify probable impacts on species and build effective conservation strategies. We modeled the effects of two climate-change scenarios on the geographical distribution of the regionally endemic bufonid, *Melanophryniscus montevidensis*, categorized as vulnerable by the IUCN and as endangered by the Uruguayan Red List of amphibians. Ecological niche models were generated to describe the present and possible future distributions of this species in 2050 and 2080, given severe (A2) and moderate (B2) climatic changes. Legacy data for *M. montevidensis* were obtained from Uruguayan biocollections and climate data were acquired from the WorldClim database. At present, *M. montevidensis* could occur along the Atlantic Uruguayan coast and a small section of the southern Brazilian coast. However, changes in climate may lead to a loss of suitable environmental conditions for this toad; thus, this endangered species is vulnerable and in urgent need of protection.

Keywords: amphibians, geographical distribution, niche models, threatened species, Uruguay.

Received 5 April 2013.
Accepted 25 October 2013.
Distributed December 2013.

Resumen

Efectos potenciales del cambio climático sobre la distribución de una especie amenazada: *Melanophryniscus montevidensis* (Anura: Bufonidae). La distribución de las especies está relacionada con el clima. Entre los efectos predichos por el Panel Intergubernamental de Cambio Climático, se encuentran los cambios en los patrones de precipitación y los aumentos en la temperatura media global. Estos factores tienen un impacto mayor en especies amenazadas, raras o endémicas. Usando modelos para predecir posibles cambios en la distribución de especies bajo diferentes escenarios de cambios climático, podemos identificar probables impactos sobre las especies y construir estrategias efectivas de conservación. Modelamos los efectos de dos escenarios de cambio climático en la distribución geográfica de un bufónido regionalmente endémico, *Melanophryniscus montevidensis*, categorizado como Vulnerable por la UICN, y como amenazado según la Lista Roja de Anfibios de Uruguay. Fueron generados modelos de nicho para describir la distribución presente y futura en 2050 y 2080, bajo los escenarios A2 (severo) y B2 (moderado). Los registros fueron obtenidos de las principales colecciones del país y los datos climáticos se tomaron de la base de datos WorldClim. Actualmente, *M. montevidensis* podría encontrarse en la costa Atlántica de Uruguay, y una pequeña parte de la costa del sureste de Brasil. Sin embargo, los cambios en el clima pueden llevar a la pérdida de condiciones ambientales adecuadas para este anfibio, por lo que la especie amenazada es vulnerable y necesita protección urgente.

Palabras Clave: anfibios, distribución geográfica, especies amenazadas, modelos de nicho, Uruguay.

Resumo

Efeitos potenciais da mudança climática sobre a distribuição de uma espécie ameaçada: *Melanophryniscus montevidensis* (Anura: Bufonidae). A distribuição das espécies está relacionada ao clima. Entre os efeitos previstos pelo Painel Intergovernamental sobre Mudanças Climáticas encontram-se mudanças nos padrões de precipitação e aumento na temperatura média global. Esses fatores têm um impacto maior sobre espécies ameaçadas, raras ou endêmicas. Usando modelos para prever possíveis alterações na distribuição das espécies sob diferentes cenários de mudanças climáticas, podemos identificar prováveis impactos sobre as espécies e construir estratégias de conservação eficazes. Nós modelamos os efeitos de dois cenários de mudanças climáticas na distribuição geográfica do bufonídeo regionalmente endêmico *Melanophryniscus montevidensis*, categorizado como Vulnerável pela IUCN e como ameaçado de acordo com a Lista Vermelha de Anfíbios do Uruguai. Foram gerados modelos de nicho para descrever a distribuição presente e futura em 2050 e 2080 nos cenários A2 (grave) e B2 (moderado). Os registros foram obtidos a partir das principais coleções do país, e os dados climáticos, do banco de dados WorldClim. Atualmente, *M. montevidensis* poderia ser encontrado no litoral atlântico do Uruguai e uma pequena parte da costa do sudeste do Brasil. No entanto, mudanças no clima podem provocar a perda das condições ambientais adequadas para esse anfíbio, indicando que a espécie ameaçada é vulnerável e precisa de proteção urgente.

Palavras-chave: anfíbios, distribuição geográfica, espécies ameaçadas, modelos de nicho, Uruguai.

Introduction

Owing to the global declines in populations of amphibians, anurans are one of the most endangered groups of vertebrates, with 32% of the species included in IUCN threatened categories (Stuart *et al*. 2004). The present extinction rate of this group is thought to be greater than its basal extinction rate (McCallum 2007). The process of anuran population declines involves multiple factors, including habitat loss, pollution, UV radiation, biological invasions, diseases, and climate change (Alford and Richards 1999).

There is a general consensus that climate change is occurring. The increase in greenhouse gases has led to an increase in the mean global temperature during the last century, and this, in turn, drives many other, correlated climatic changes (IPCC 2001), such as sea-level rise, changes in precipitation patterns, and an increase in global average temperatures (1.8–4.0ºC) that are expected in the 21st century. Such changes are expected to cause further population declines in anurans (Pound *et al*. 1999), as a result of diminished fitness and survival (Reading 2007), phenological modifications (Gibbs and Breisch 2001), and geographical shifts in species distributions (Hickling *et al*. 2006) that lead to species extinction (Pounds *et al*. 1999). Moreover, studies propose that climate change is promoting the expansion of the *Batrachochytrium dentrobatidis*, the fungus responsible for chytridiomycosis (Rohr and Raffel 2010).

The Montevideo red-belly toad, *Melanophryniscus montevidensis* (Philippi 1902), is a regionally endemic species, distributed along the southern coast of Uruguay, with a few records of species occurrence on the Brazilian coast (Núñez *et al*. 2004, Bernardo-Silva *et al*. 2012). *Melanophryniscus montevidensis* has been recognized globally as "Vulnerable" by the IUCN (IUCN 2013) and as "Endangered" in the Uruguayan Red List of amphibians (Canavero *et al*. 2010). The biology of this species is poorly understood, but preliminary studies show that this toad is an "explosive breeder" that breeds in ephemeral ponds with sandy soils (Maneyro and Carreira 2012). Given the documented decline in populations, narrow geographical distribution, and fragmentation of the toad's habitat, *M. montevidensis* is threatened. The species usually in found along the edges of the Río de la Plata and the Atlantic Ocean, where it interfaces with urban development activities related to tourism and housing construction (Maneyro and Carreira 2006). Some researchers (Langone 1994, Maneyro and Carreira 2012) think that *M. montevidensis* may be locally extinct in the departments of Montevideo and Canelones, and critically endangered in most of the Departamento de Maldonado. Additionally, Borteiro *et al*. (2009) reported that some anurans sympatric with *M. montevidensis* are infected with chytridiomycosis.

During the past century, the documented changes in the Uruguayan climate include: an increment of approximately 20% in mean cumulative annual precipitation (Kane 2002); a rise in mean annual temperature of Montevideo from 1883–2003 (Bidegain *et al.* 2005); a warming trend with respect to mean and extreme temperatures in the summer and winter, with the latter more pronounced (Rusticucci and Renom 2008, Renom 2009); and an increase in the number of extreme precipitation events in the last 40 years (Marengo *et al.* 2010). Furthermore, an intensification of these changes over the 21st century is expected (DINAMA 2005).

We analyzed potential negative effects of climate change on *Melanophryniscus montevidensis* by modeling with envelope niche models the spatial distribution of the species, and forecasting the potential changes in its distribution in the event of two climate-change scenarios (A2, severe; B2, moderate) of the Intergovernmental Panel on Climate Change (IPCC) in 2050 and 2080, respectively.

Materials and Methods

Study Area

Uruguay has a continental surface area of 176,215 km^2 in the southeastern part of South America (30–35º S and 53.5–58.5º W). The landscape is dominated by plains and peneplains and is composed of areas of hills and ravines reaching a maximum elevation of 513 m. The country has 650 km of shoreline, extending from the fluvial coast of the Río de la Plata in the southwest to the Atlantic coast in the southeast. Uruguay has a temperate, wet climate with hot summers (type "cfa" *sensu* Kottek *et al.* 2006) and a mean annual temperature of 17.5ºC. Mean annual precipitation varies between 1100 mm and 1400 mm along a south–north gradient (DINAMA, 2005).

Biological and Climatic Databases

Species occurrence data were obtained from the Colección de Zoología Vertebrados, Facultad de Ciencias (ZVCB) and the Museo Nacional de Historia Natural (MNHN) in Uruguay. We compiled 114 records of *Melanophryniscus montevidensis* from 47 localities (Figure 1), some of which had been georeferenced (Nuñez *et al*. 2004). We used the digital cells of the Military Geographic Institute of Uruguay and Google Earth version 7.1.1 (Google, Inc.) to determine geographical coordinates for the remaining records following the georeferencing techniques of Chapman and Wieczorek (2006).

Climatic data were acquired from the WorldClim database (WorldClim 2012). We used 36 climatic variables and one topographic variable, with a resolution of 2.5' arc-minutes (≈ 5 km) (Table 1). Experts of the WorldClim used ANUSPLIN-SPLINA software to interpolate layers of weather station records for the period of 1950–2000 (Hijmans 2005). Forecast climate layers correspond to projections of the HadCM3 model from the Hadley Center of the United Kingdom for the decades of 2050 and 2080, under the IPCC scenarios A2 (severe) and B2 (moderate), according to the 3rd communication of the IPCC (IPCC 2001).

Species Distribution Modeling

The climate envelope model, which estimates the potential distribution of a species by correlating occurrence data with environmental predictors, is widely used to estimate the potential distribution of species (Lobo *et al*. 2010). The approach is rooted in ecological niche theory because it models a fragment of the fundamental niche of the species, which is defined as the "climatic niche" (Pearson and Dawson 2003). To model current and future

Table 1. List of environmental variables included in the Maxent models of current and future potential distribution of *Melanophryniscus montevidensis*. Data source: WorldClim. Subscripted numbers correspond to the month (i.e. T_{min1} = minimum temperature in January).

Variables	Acronyms
Monthly minimum temperature	T_{min1}, T_{min2}, T_{min3}, T_{min4}, T_{min5}, T_{min6},T_{min7}, T_{min8}, T_{min9}, T_{min10}, T_{min11} y T_{min12}
Monthly maximum temperature	T_{max1}, T_{max2}, T_{max3}, T_{max4}, T_{max5}, T_{max6},T_{max7}, T_{max8}, T_{max9}, T_{max10}, T_{max11} y T_{max12}
Annual accumulated precipitation	P_{rec1}, P_{rec2}, P_{rec3}, P_{rec4}, P_{rec5}, P_{rec6}, P_{rec7}, P_{rec8}, P_{rec9}, P_{rec10}, P_{rec11}, P_{rec12}
Mean elevation	$Elev_{mean}$

Figure 1. **A**) *Melanophryniscus montevidensis,* photo by Raúl Maneyro; (**B**) Map of the geographical distribution of species collections used in this study (ZVCB and MNHN).

geographical distributions of *Melanophryniscus montevidensis,* we applied Maximum Entropy Models, using Maxent Version 3.3.1, a type of climatic envelope model (Phillips *et al*. 2006). This program uses a machine-learning algorithm to estimate the probability of species occurrence at certain localities, based on the environmental conditions at sites where the species were recorded. Maxent has many practical advantages that make it easily applicable to occurrence data. It requires presence-only data, and functions with both continuous and categorical predictors. The program provides a continuous model output that can be categorized according to different thresholds, and provides results that can be interpreted with Geographic Information Systems (Phillips *et al*. 2006). Maxent is thought to be one of the most robust modeling approaches (Elith *et al*. 2006).

We ran Maxent using the default features—i.e., 500 iterations, duplicate records elimination, the convergence threshold = 0.00001 and the regularization parameter β = 1 (Phillips *et al.* 2006). To analyze the relationships among variables, we selected linear and quadratic relationships, as well as interactions between pairs of variables. The Jackknife option was used to evaluate the contribution of variables to the model. The sample was divided into training (70%) and testing samples (30%) used for model validation. Models accuracy were evaluated through the area under the curve (AUC), obtained from the receiver operating characteristic curve (ROC). We applied the "Minimum training presence" threshold to convert continuous maps into presence-absence distribution, as suggested for endemic and narrowly distributed species (Gomes-Cortes 2009).

Results

Current Potential Distribution

The modeling exercise indicated that *Melanophryniscus montevidensis* currently is distributed on the central and eastern coasts of

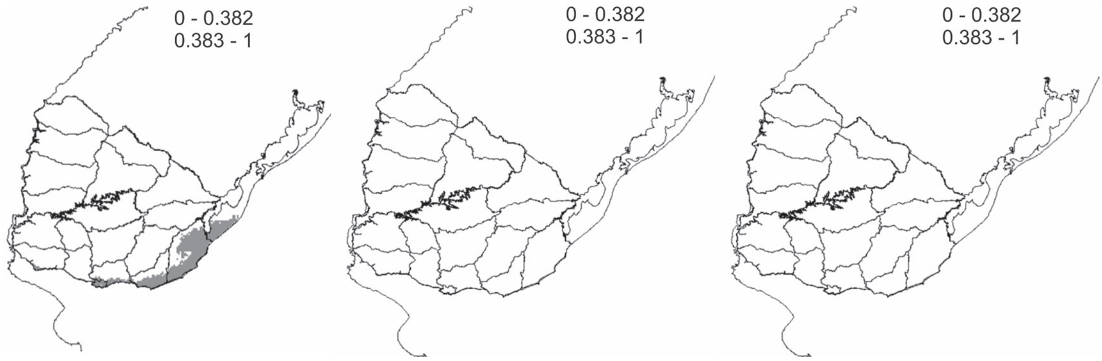

Figure 2. Potential distribution of *Melanophryniscus montevidensis* generated with Maxent, applying the "Minimum training presence" threshold. (**A**) Current potential distribution; (**B**) potential distribution at 2050 (under the A2 scenario); (**C**) potential distribution at 2050 (under the B2 scenario).

the Río de la Plata and Atlantic Ocean of Uruguay (departments of Montevideo, Canelones, Maldonado, and Rocha), and scarcely entering the Brazilian coast. As indicated by the model, the geographical extent of the species is approximately 9270 km^2 (Figure 2A). These results agree with previous studies that also used niche models to estimate distribution of *M. montevidensis* (Bernardo-Silva *et al*. 2012), as well with the distribution proposed by the Global Amphibian Assessment, based on expert opinion (IUCN, 2013).

The training and test data yielded an AUC value of 0.998, indicating the strength of the model. The threshold (minimum training presence) corresponded to 0.458, whereas the training and test omission rates, as well as the *p*-value calculated by the binomial probability, were greater than 0.001. The analysis of the relative contribution of the environmental variables to the Maxent model indicated that elevation and maximum temperatures of May, September, and January were the most important. The contribution of each variable to the model was 20.5%, 16.4%, 12.5%, and 12.4%, respectively. These variables increase in this proportion the regularized gain of the model when included.

Future Potential Distribution

Under both IPCC scenarios (A2 and B2), models predict a complete change of the prevailing climatic conditions to which the species would be subject in 2050 (Figures 2B, C). Should *Melanophryniscus montevidensis* not adapt to these climatic changes, the species will be extinct by the middle of the 21st century. Models of the potential distribution of *M. montevidensis* in 2080 indicate that the climatic conditions would remain altered. However, under the B2 scenario of 2080, the model indicates suitable conditions for the species on the coast of the Department of Rocha.

Discussion

Ectothermic species are particularly sensitive to environmental change (Navas and Otani 2007). The current, modeled distribution of *Melanophryniscus montevidensis* based on climate conditions, coincides with previous distributions proposed for this species (Bernardo-Silva *et al*. 2012, IUCN 2013).

Climate change, and particularly temperature increase, is driving species poleward (Parmesan 2006). We found that predicted changes in temperature and precipitation for the southeastern portion of South America will promote a poleward shift in the distribution of *Melanophryniscus montevidensis*, potentially leading to their extinction in the midterm. According to the model, *M. montevidensis* responds to changes in maximum temperatures; thus, if high temperatures exceed tolerance levels (i.e., the maximum lethal temperature) *M. montevidensis* will be affected (Snyder and Weathers 1975). Like all anurans. these toads depend on cutaneous gas exchange for respiration (Duellman and Trueb 1994, Hermida *et al*. 2003), which is affected by changes in ambient temperature. We detected an influence of temperature on *M. montevidensis* distribution. However, this variable could be a surrogate of other variables (moisture, evapotranspiration) not included in the model.

The reproductive behavior of *Melanophryniscus montevidensis* may be impacted by climate change because explosive reproduction is linked to precipitation events that generate temporary ponds (Maneyro and Kwet 2008). Reproductive periods are constrained by high temperatures; thus, reproductive activity is uncommon in summer months. Not only must ponds form, they must persist long enough for the larvae to complete development. Extreme weather events such as heat waves and droughts affect South America and vary regionally. A recent study found an increase in climate variability (incidence of extreme events) between 1960 and 2000 in southeastern South America (Marengo *et al*. 2010). Of particular concern is the increasing trend in the maximum number of consecutive dry days (Marengo *et al.* 2010). Such increases in temperature and drought incidence could result in the desiccation of ponds and diminishing of the survival of pre-metamorphic stages, which require approximately a month to complete development (Garrido-Yrigaray 1989).

It has been proposed that climate change favors the expansion of *Batrachochytrium dendrobatidis*, the fungus responsible for chytridiomycosis (Lips *et al.* 2008). A synergistic interaction between climate change and the pathogenic chytrid fungus may be responsible for the extinction of other bufonid frog, the Monteverde harlequin frog (*Incillus periglenes*) (Pound *et al.* 2006). Although the relationship between climate change and chytridiomycosis was not evaluated here, this disease has been detected in wild populations of other amphibian species that coexist in the same ponds with *Melanophryniscus montevidensis* tadpoles in the Rocha Lagoon on the east coast of Uruguay (Borteiro *et al.* 2009).

Finally, shifts in species distribution induced by climate are especially dangerous for narrowly distributed species (Foden *et al.* 2008). For example, tropical montane species may be at serious risk, because altitudinal changes can decrease the extent of their ranges and ultimately force them to extinction (Colwell *et al.* 2008, Forero-Medina *et al.* 2010). Similarly, a study of the bufonid genus *Atelopus*, showed that the risk of extinction increases from the lowlands to mountain tops, because geographic ranges tend to decrease in size with increasing elevation (Pounds *et al.* 2006). According to our model, the distribution of *Melanophryniscus montevidensis* is primarily affected by elevation, as they are generally restricted to low elevations. However, we think that the geographic restriction of *M. montevidensis* to coastal environments may be analogous to species adapted to living near mountain tops. The potential southward migration of climate conditions could narrow its range, because the Río de la Plata and the Atlantic Ocean constitute barriers for its dispersion to more southern latitudes.

Our results suggest that there is a pressing need for further study on the biology of *Melanophryniscus montevidensis*, especially its physiology and autoecology. Such information would be key for determining its response to predicted climate changes and its ability to adapt to such change. Given the multiple threats currently faced by the species and our findings presented here, we suggest reconsideration of its global conservation status, including an increase in threat category to attend to the features stated by several authors (Canavero *et al*. 2010, Laufer 2012, Maneyro and Carreira 2012). We also recommend the implementation of active *in-situ* and *ex-situ* conservation actions, including an increase in the number of protected areas within its geographical range (Bernardo-Silva *et al*. 2012) and the application of *ex-situ* conservation measures based on previous successful experiences with other species within Bufonidae (AmphibianArk 2013).

Acknowledgments

This article was funded by a National Graduate Fellowship from ANII (Agencia Nacional de Investigación e Innovación) and performed within the Master's Program for Biology of PEDECIBA (Programa de Desarrollo de las Ciencias Básicas), Facultad de Ciencias, Universidad de la República, Uruguay. We thank Dr. Christine Lucas for revision of English.

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Editor: Stephen J. Richards