

Climate and land-use changes effects on the distribution of a regional endemism: *Melanophryniscus sanmartini* (Amphibia, Bufonidae)

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ABSTRACT. Amphibians are the most threatened vertebrate group according to the IUCN. Land-use and land cover change (LULCC) and climate change (CC) are two of the main factors related to declining amphibian populations. Given the vulnerability of threatened and rare species, the study of their response to these impacts is a conservation priority. The aim of this work was to analyze the combined impact of LULCC and CC on the regionally endemic species *Melanophryniscus sanmartini* Klappenbach, 1968. This species is currently categorized as near threatened by the IUCN, and previous studies suggest negative effects of projected changes in climate. Using maximum entropy methods we modeled the effects of CC on the current and mid-century distribution of *M. sanmartini* under two IPCC scenarios – A2 (severe) and B2 (moderate). The effects of LULCC were studied by superimposing the potential distribution with current land use, while future distribution models were evaluated under the scenario of maximum expansion of soybean and afforestation in Uruguay. The results suggest that *M. sanmartini* is distributed in eastern Uruguay and the south of Brazil, mainly related to hilly and grasslands systems. Currently more than 10% of this species' distribution is superimposed by agricultural crops and exotic forest plantations. Contrasting with a recent modelling study our models suggest an expansion of the distribution of *M. sanmartini* by mid-century under both climate scenarios. However, despite the rise in climatically suitable areas for the species in the future, LULCC projections indicate that the proportion of modified habitats will occupy up to 25% of the distribution of *M. sanmartini*. Future change in climate conditions could represent an opportunity for *M. sanmartini*, but management measures are needed to mitigate the effects of habitat modification in order to ensure its survival and allow the eventual expansion of its distribution.

KEYWORDS. Species distribution modeling, global change, conservation, threatened species.

RESUMEN. Efectos de los cambios climáticos y del uso de la tierra en la distribución de un endemismo regional: *Melanophryniscus sanmartini* (Amphibia, Bufonidae). Los anfibios son el grupo de vertebrados más amenazado en la actualidad según la UICN. El cambio en el uso y cobertura del suelo (CUCS) y el cambio climático (CC) son dos de los principales factores involucrados en el fenómeno de declinación de anfibios. Por lo tanto, investigar sus impactos sobre especies amenazadas o raras es fundamental dado que su vulnerabilidad las convierte en prioridades de conservación. El objetivo de este trabajo fue evaluar conjuntamente el impacto potencial del CUCS y del CC sobre la distribución del endemismo regional *Melanophryniscus sanmartini* Klappenbach, 1968. Esta especie está categorizada como casi amenazada por UICN y estudios anteriores sugieren efectos negativos del CC en su distribución. Utilizando modelos de máxima entropía modelamos la distribución actual y futura (2050) de *M. sanmartini*, bajo dos escenarios de CC del IPCC – A2 (severo) y B2 (moderado). El efecto del CUCS fue evaluado mediante la intersección de la distribución modelada con el uso del suelo actual, mientras que los modelos de distribución futura fueron evaluados bajo un escenario de máxima expansión de soja y forestación en Uruguay. Los resultados indican que *M. sanmartini* se distribuye en el Este de Uruguay y Sur de Brasil, asociada a sistemas serranos y praderas. En la actualidad más del 10% de su distribución está afectada por cultivos agrícolas y forestales. Contrariamente a predicciones recientes, nuestros modelos indican una expansión de la especie hacia la mitad del siglo bajo ambos escenarios de CC analizados. Sin embargo, a pesar del aumento de zonas climáticamente favorables, las proyecciones de CUCS indican un aumento en la proporción de hábitats modificados en hasta un 25% de la distribución de *M. sanmartini*. Si bien el cambio en las condiciones climáticas puede representar una oportunidad a futuro para *M. sanmartini*, sería necesario implementar medidas de manejo para mitigar los efectos de la modificación de sus hábitats, asegurar su sobrevivencia y posibilitar una eventual expansión de su distribución.

PALABRAS-CLAVE. Modelos de distribución de especies, cambio global, conservación, especies amenazadas.

Currently amphibians are the most threatened group of organisms, with 32% of the species assigned to threatened categories, 7% categorized as “Near Threatened” and 22.5% as “Data Deficient” (STUART *et al.*, 2004). While many causes have been proposed for the global decline in amphibians (ALFORD & RICHARDS, 1999), evidence indicates that land-use change is the most important (BECKER *et al.*, 2007; COLLINS & CRUMP, 2009). The biological characteristics of amphibians expose them to many alterations in both, aquatic and terrestrial ecosystems, making their populations highly vulnerable to land-use change (FODEN *et al.*, 2008). Climate change also contributes to amphibian population decline (ALFORD & RICHARDS, 1999). For example, climate change has been pointed as the main cause of the global

extinction of the golden toad: *Bufo periglenes* (POUNDS *et al.*, 1999). In addition, several studies suggest synergetic effects between climate change and chytridiomycosis, an infectious disease generated by the aquatic fungal pathogen *Batrachochytrium dendrobatidis*, which affects amphibian populations worldwide (BOSCH *et al.*, 2007, RÖDDER *et al.*, 2009; BAI *et al.*, 2012).

For the previously described reasons, endangered and rare amphibians are conservation priorities. Considering the rapid progress of these threats, amphibians currently categorized as “Near Threatened” by IUCN (<http://www.iucnredlist.org/>) should also be considered in danger.

Melanophryniscus sanmartini Klappenbach, 1968, commonly called ‘San Martin red-bellied toad’,

is a narrowly distributed and endemic species of the 'Uruguayan savanna ecoregion' (MANEYRO & KWET, 2008). Its known distribution is divided into three regions including northeastern and southeastern Uruguay, as well as new records in southern Brazil (ZANK *et al.*, 2013). *Melanophryniscus sanmartini* was categorized as "Near Threatened", both globally – by the Global Amphibian Assessment (LAVILLA & LANGONE, 2004) - and nationally (CANAVERO *et al.*, 2010a). Currently the IUCN has stated that the species is close to being qualified as "Vulnerable" because its natural habitat is declining in extension and quality (GEOURUGUAY, 2008).

In southeastern South America the replacement of natural grasslands by crops and tree plantations are the major causes of land-use and land-cover change (LULCC) (JOBÁGY *et al.*, 2006; ARBELETCHÉ & CARBALLO, 2007; GAUTREAU, 2014). Currently, LULCC is the main threat for *M. sanmartini* (MANEYRO & CARREIRA, 2012). This species is habitat specialist of hilly grasslands that are seriously threatened by a high expansion rate of tree plantations during the last two decades (BRAZEIRO *et al.*, 2015). Although climate change constitutes a general threat to amphibians (POUNDS, 2001), the 'tropicalization' of the transition zone between subtropical and temperate regions of southeastern South America, predicted for the mid-21st century could favor the geographical expansion of amphibians (LAWLER *et al.*, 2009; TORANZA *et al.*, 2012). Nonetheless, for *M. sanmartini* a substantial contraction in its geographical distribution was recently predicted by ZANK *et al.* (2014). This scenario could be more critical to the viability of the species if LULCC was incorporated into the analysis.

The aim of the present study was to assess the potential effects of both climate change and land-use and land-cover changes on the distribution of *M. sanmartini*. First we modeled all its current distribution, incorporating a procedure not used before for this species, to reduce the probability of overestimation. We then modeled the future distribution, using as drivers the climate projections of one of the atmosphere-ocean general circulation models (AOGCM) with the best performance in this region (i.e., HADCM3). Finally, both the actual and future climatically modeled distribution of *M. sanmartini* were overlapped with land cover maps, both actual and projected according to expected agroforestry expansion in Uruguay.

MATERIALS AND METHODS

Study area. Southeast South America is a transition zone between subtropical and temperate ecosystems known as the *Campos* region, which occupies the south of Brazil and Uruguay. This region is dominated by grasslands with patches of seasonal deciduous forest associated with highlands, rivers and ravines (OVERBECK *et al.*, 2007). From a biogeographical point of view, the region is located within the Pampean province of the Chacoan subregion, with biotic influences of the neighboring provinces (i.e.

Chaco and Paranaense) (MORRONE, 2001; HARETCHE *et al.*, 2012).

This region has a humid warm temperate climate with hot summers and mild winters (KOTTEK *et al.*, 2006). Annual precipitation varies between 1200-1600 mm, and mean annual temperature ranges between 13 and 17 °C. The Fourth Assessment Report of the IPCC presented information on future trends in temperature and precipitation changes for different sub-regions of Latin America (MAGRIN *et al.*, 2007). For southern South America, an increase in mean temperature and a rise in sea level are expected at the end of the 21st century. Additionally, rainfall projections for the future have higher levels of uncertainty, and different climate models show rather distinct patterns, even opposite trends (MAGRIN *et al.*, 2007).

Distribution modeling. Species distribution modelling is rooted in ecological niche theory because it models a fragment fundamental niche of the species, which is defined as the "climatic niche" (PEARSON & DAWSON, 2003). Our study was based on maximum entropy modeling of the current and future distribution of *M. sanmartini*. This technique estimates a target probability distribution by finding the probability distribution of maximum entropy, subject to a set of constraints that represent our incomplete information about the target distribution (PHILLIPS *et al.*, 2006). Namely, the model estimates the potential distribution of a species by linking its sample locations with a set of environmental variables; the output of the model gives the suitability of each cell, as a function of its environmental similarity to those cells with the species was collected.

We obtained occurrence data of *M. sanmartini* from 13 locations: 10 from Uruguay and 3 from Brazil. The main sources were herpetological collections from Uruguay [Colección de Zoología Vertebrados, Facultad de Ciencias (ZVCB) and Museo Nacional de Historia Natural (MNHN)] and the scientific literature (NÚÑEZ *et al.*, 2004; ZANK *et al.*, 2013). For current and future modeling, 37 environmental variables (Tab. I), acquired from the Worldclim database were included (HIJMANS *et al.*, 2005). Climate variables were monthly averages of several meteorological stations during 1950-2000, while altitude corresponded to the "Shuttle Radar Topography Mission" (SRTM) (HIJMANS *et al.*, 2005). All environmental layers had a spatial resolution of 2.5 minutes.

Modeling was conducted with Maxent software version 3.3.3k (PHILLIPS *et al.*, 2006). We used the default settings of Maxent: 500 iterations, duplicate records removal, convergence threshold (0.00001), and regularization parameter $\beta(1)$ (PHILLIPS *et al.*, 2006). To analyze the relationship among variables we selected linear, quadratic and interactive effects features. The contribution of each environmental variable to the model was evaluated with a Jackknife test. Due to the low number of occurrence records, the sample was not divided into test and training samples. The models performance were evaluated through the area under the curve (AUC), obtained from the receiver

Tab. I. List of environmental variables included in the Maxent modelling of current and future potential distribution of *Melanophryniscus sanmartini* Klappenbach, 1968. Data source: Worldclim. Variables numbers indicates the month (i.e. Tmin1= minimum temperature of January).

Variables	Acronyms
Monthly minimum temperatures	T _{min1} , T _{min2} , T _{min3} , T _{min4} , T _{min5} , T _{min6} , T _{min7} , T _{min8} , T _{min9} , T _{min10} , T _{min11} , T _{min12}
Monthly maximum temperatures	T _{max1} , T _{max2} , T _{max3} , T _{max4} , T _{max5} , T _{max6} , T _{max7} , T _{max8} , T _{max9} , T _{max10} , T _{max11} , 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}

operating characteristic curve (ROC). AUC represents an overall measure of model performance across all thresholds and strengths of a prediction and summarizes the model's ability to rank presence records higher than absences records (FRANKLIN, 2010). Although small sample sizes might lead to a decreased in the model predictability, it has been shown that Maxent has good performance even when using small sample sizes (HERNANDEZ *et al.*, 2006). We first applied the "Minimum training presence" threshold to convert continuous maps into presence-absence distribution, as suggested for endemic and narrowly distributed species (L. Gomes-Cortes, unpubl. data).

Species distribution models estimate the potential distribution of species based on presence-only data (FRANKLIN, 2010). To obtain an 'adjusted distribution', it is useful to incorporate information on the locations where the species is absent, avoiding overestimation of its geographical extent (PINEDA & LOBO, 2009). Here we applied the method proposed by PINEDA & LOBO (2009) to check for omission or commission errors based on well-known cells of amphibians in Uruguay, which comprises the greater portion of *M. sanmartini* known distribution. We started by pre-selecting those cells with 100 or more amphibian records. Such "sampling effort" was described as adequate for sampling amphibian species richness (CANAVERO *et al.*, 2010b). The number of records was considered as an indicator of sampling effort (HORTAL & LOBO, 2005). Then we built a matrix of species records by cell and apply different species richness estimators: Chao1, Chao2 and Jackknife 1 using the program EstimateS v8.2. (Appendix 1). Those cells with an observed richness equal to or greater than 75% of maximum richness given by the estimators were consider a 'well-known cells', and therefore observed absences were validated as true. Then we adjusted the original model seeking the best fit with the occurrences and new "true absences". This methodology allowed us to improve the results validation and reduce commission errors.

Climate and land use change scenarios. To assess the future distribution of *M. sanmartini* in the *Campos* region (southern Brazil and Uruguay), we used the output of the AOGCM of the Hadley Centre -HADCM3- for 2050. This model was selected because downloads study suggest that it has one of the best performance to fit the climate of this region (BIDEGAIN & CAMILLONI, 2006). Future modelling was done under two IPCC socioeconomic scenarios: A2 (severe) and B2 (moderate) (IPCC, 2001). Assessment of the effects of LULCC was made on the basis that both advancement of crops and tree plantations

negatively affect the viability of *M. sanmartini* through loss of natural habitat and degradation of soils and water (FOLEY *et al.*, 2005).

In order to explore current and future impacts of land-use change on the distribution of *M. sanmartini*, we analyzed the surface area currently affected by agriculture and tree plantations and under a land-use change scenario for 2030. Due to the lack of information about the land use change and future scenarios of change from southern Brazil, the effects of LULCC were analyzed only for Uruguay portion of distribution. First, we overlapped the current distribution with a land-use map of Uruguay, generated from satellite imagery analysis (LANDSAT 5TM, scale 1:120.000) from 2012 (ACHKAR *et al.*, 2012). Then, maps of modeled future distribution for each scenario (A2 and B2) were overlapped with a map of land-use change scenario developed for 2030, based on expectations of production growth under the assumption of maximum expansion of soybean cultivation and forestry in Uruguay (BRAZEIRO *et al.*, 2008). We thus obtained maps that reflected the degree of land alteration due to crops and forestry, within those areas where the potential presence of the species was predicted. This analysis was done only for Uruguay, due to the lack of land-use change scenarios for southeastern Brazil. However, the land-use change trends are very similar in the whole *Campos* region (GAUTREAU, 2014).

RESULTS

Distribution models. According to our model *M. sanmartini* is currently distributed in Uruguay and southern Brazil. The distribution model was robust with an AUC of 0.997. The validation procedure applied here detected 26 'well-known cells' for amphibians for Uruguay (Appendix 1). This analysis indicates that *M. sanmartini* is absent from all of western and central Uruguay. Based on the foregoing, we discard the *a priori* selected threshold (minimum training presence= 0.304), and applied a larger and more conservative threshold (lowest 10% percentile in the training records= 0.683). The presence/absence distribution obtained covers all the species' records, with the exception of one locality in Sierra de San Miguel (Fig. 1). The use of smaller thresholds to include this record lead to an overestimated distribution with a significant increase in commission errors. The extent of occurrence of the species occupies 79,665 km², which mainly comprises hilly grasslands. The Jackknife test indicated that minimum temperature of June was the variable with the highest gain when used in isolation, while December precipitation and

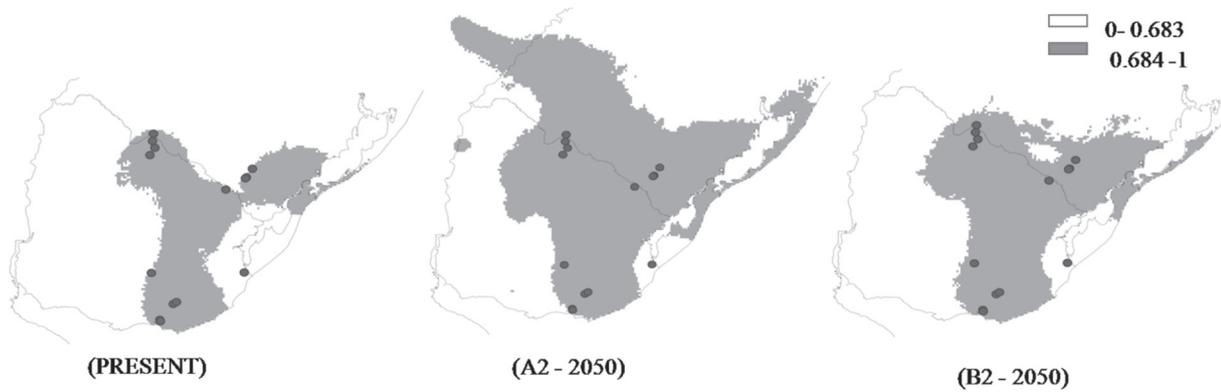


Fig. 1. Current and future potential distribution of *Melanophryniscus sanmartini* Klappenbach, 1968 modeled with Maxent program using climate variables and applying '10th percentile training presence' threshold.

altitude were the environmental variables that decreased the gain the most when they were omitted.

For both IPCC scenarios (A2 and B2) the AUC was > 0.995 . Both models predicted an expansion of the geographical range of *M. sanmartini* (Fig. 1), but none model capture the San Miguel location. For 2050 the suitable area for the species would occupy 218,710 km² and 121,737 km² according to A2 and B2 scenarios, respectively. This implies a potential expansion of the species of 175% and 53% under the A2 and B2 scenarios, respectively. The two studied scenarios predict an expansion of the range size of *M. sanmartini* in the west and southwest direction, while the Río de la Plata represents a geographic barrier for the southwards expansion of the species.

Potential effects of land-use change. A large proportion of the *M. sanmartini* distribution range is in Uruguay (72% -57,793 km²). The assessment of land use cover reveals that at present 12% of the species distribution range in Uruguay is used for agro-forestry purposes, with 6% corresponding to agricultural areas and 6% to forested areas (Fig. 2). Crops are located mainly in lowlands, while forestry is distributed in the hilly areas and ravines (Fig. 2).

Even though the distribution range of *M. sanmartini* could expand by 2050, the area devoted to agriculture and exotic forest plantations in Uruguay would also increase according to the LULCC scenario (Fig. 3). By mid-century about 22% and 25% of the projected distribution of *M. sanmartini* in Uruguay would be devoted to crops and

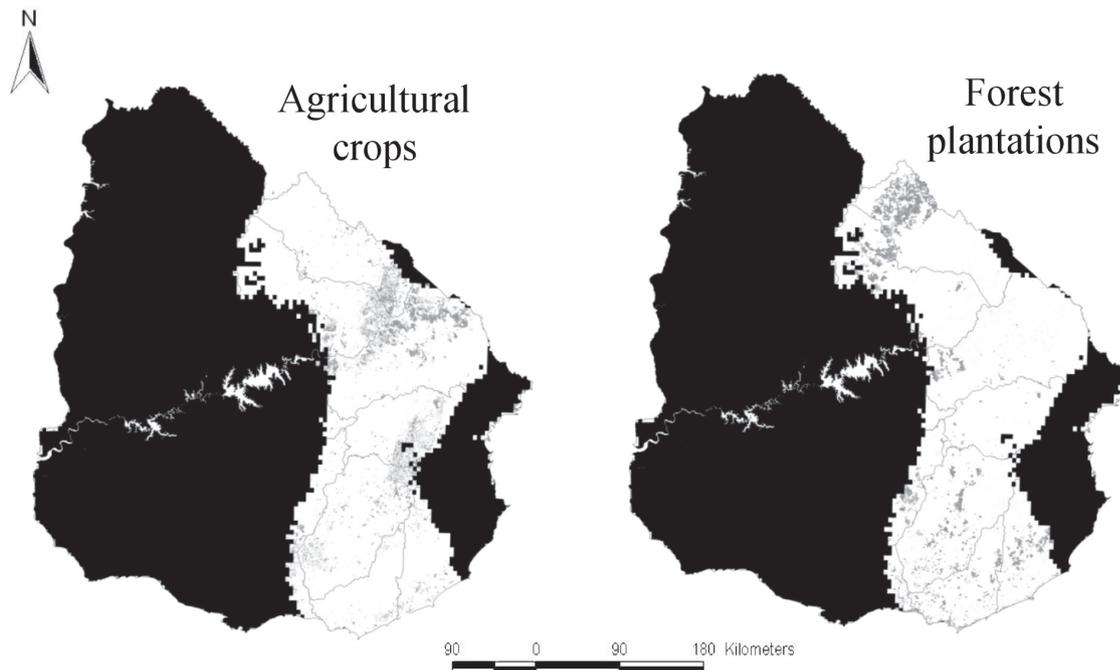


Fig. 2. Current land-use within the distribution area of *Melanophryniscus sanmartini* Klappenbach, 1968 in Uruguay. Distribution of crops and exotic forest plantations (light gray) are shown separately within the distribution of the species.

forestry under A2 and B2 scenarios respectively (Fig. 3). It should be highlighted that even when the proportion of cultures and forest plantations increase in the future, according to the models the total area not under agro-

forest systems or ‘cultures-free area’ in the distribution of *M. sanmartini* would also increase with respect to the present (Fig. 4).

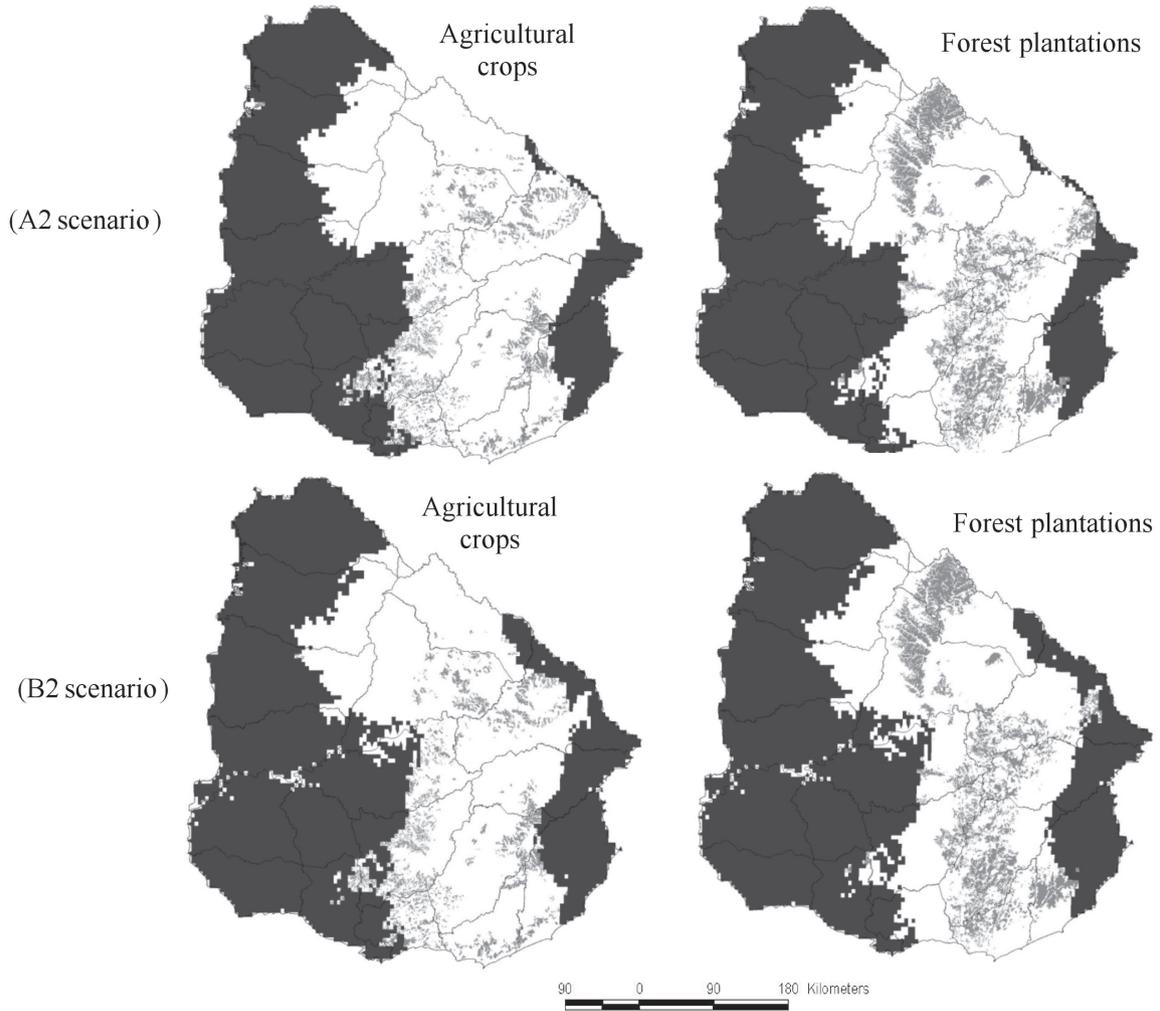


Fig. 3. Combine effects of land-use and land cover change and climate change on the potential distribution of *Melanophryniscus sanmartini* Klappenbach, 1968 by mid-century in Uruguay. Distribution of crops and exotic forest plantations (light gray) are shown separately within the future distribution range of the species, under A2 and B2 emission scenarios.

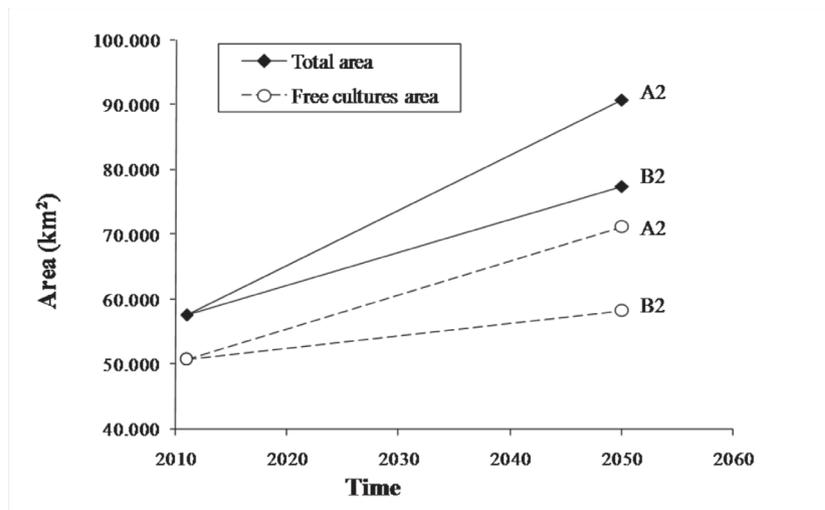


Fig. 4. Projected change in the total area of distribution and in the area free of agro-forest crops of *Melanophryniscus sanmartini* Klappenbach, 1968 under two emission scenarios by mid-century.

DISCUSSION

Species distribution models are considered a useful tool to predict species' potential distribution (THULLER *et al.*, 2006; FRANKLIN, 2010). Our results suggest that the current distribution of *M. sanmartini* is higher than the currently known distribution. The model predicts an expansion of the *M. sanmartini* distribution by mid-century, under both IPCC scenarios considered. Moreover, the species expansion in range would exceed the loss of suitable habitats due to land-use change projected for Uruguay.

Our study suggests a continuous potential distribution of *M. sanmartini* across the landscape, although the known distribution is considered disjunct (LAVILLA & LANGONE, 2004). The species is associated with ravines and the biological corridor 'Sierras del Este - Serra do Sudeste', a system of low hills extending from southern Brazil to southeastern Uruguay.

The potential distribution of *M. sanmartini* predicted here is far smaller, about half of the modelled distribution proposed by ZANK *et al.* (2014). Aside from the use of different AOGCM and sets of climatic variables (see ZANK *et al.*, 2014), there is a key factor determining such a difference between both modelling studies. The validation procedure applied here contributes to avoid commission errors, and thus allows us to get a distribution more similar to the 'realized distribution' of the species (PINEDA & LOBO, 2009). Likewise, the applied threshold (i.e. '10th percentile training presence') to get presence/absence maps is conservative in estimating species distribution (ZHU *et al.*, 2012), and avoids the overestimation (JARNEVICH & REYNOLDS, 2011). This is particularly relevant when studying endangered species.

The model-predicted absence of *M. sanmartini* at the Sierra de San Miguel -where the species was actually recorded - deserves special attention. The Maxent output predicts low suitability of San Miguel locality for this species. Such omission error is related to the selected threshold, which predicts absent the 10% most extreme presence observation, assuming that extreme could represent errors or unusual microclimatic condition in a cell (MORUETA-HOLME *et al.*, 2010). The record at Sierra de San Miguel is reliable, but the site-specific climatic conditions of this locality are unusual within the range size of *M. sanmartini*. Sierra de San Miguel is very close to the coastline and has a strong oceanic influence, therefore temperatures are lower than the other localities where the species is found (DINAMA, 2005). Despite the climatic difference and the relative geographic isolation, this locality have the typical 'hilly physiognomy' of the habitat used for *M. sanmartini*. This suggests that the presence of this amphibian in Sierra de San Miguel could be better explained by habitat than by climatic suitability. Anyway, despite the minor omission error of the model in the case of San Miguel, the procedure applied here to select the proper threshold allowed us to prevent major commission errors.

In contrast with previous models for *M. sanmartini*

(ZANK *et al.*, 2014), our model suggests an expansion in distribution range by mid-century under the IPCC scenarios considered (A2 and B2). Our predictions agree with the recently reported effect of climate change on the amphibians of Uruguay (TORANZA *et al.*, 2012). This result also coincides with the poleward expansion expected for subtropical amphibians under climatic conditions projected for the 21st century in South America (LAWLER *et al.*, 2009). Amphibian distribution in temperate regions is highly constrained by low temperatures (WIENS *et al.*, 2006). According to our analysis the minimum temperature of the coldest month had a strong influence on *M. sanmartini* distribution. The predicted increases in temperature could favor the expansion of the species in the future, representing therefore an opportunity to recover its status from the near threatened category. *Melanophryniscus sanmartini* could take an advantage of this opportunity to expand depending on habitat availability in future landscapes as mediated by land use change.

LULCC is primarily responsible for the global amphibian decline (TODD *et al.*, 2009). Forestry expansion has been identified as the main risk factor for *M. sanmartini* (LAVILLA & LANGONE, 2004). Our study shows that 12% of its distribution is currently affected by agro-forestry activities. Moreover, according to land use change scenarios the total surface area of crops and forestry will increase in coming decades. Despite the projected expansion of suitable climatic zones for the species, its conservation and eventual expansion in the future depends upon habitat availability and quality.

Another effect of LULCC is habitat fragmentation (FOLEY *et al.*, 2005; FISCHER & LINDENMAYER, 2007). One of the main impacts of fragmentation is limiting species movement between patches of suitable habitat, due to the presence of a hostile landscape matrix that generates isolation (WEINSHEIMER *et al.*, 2010). Previous studies show the negative impact of fragmentation on the persistence of amphibian populations by limiting their ability to disperse (FUNK *et al.*, 2005) and increasing demographic stochasticity (CUSHMAN, 2006). The effects of the agro-forestry expansion on the fragmentation of *M. sanmartini* habitat are still unknown.

The consequences of predicted climate change on species could be considered as a threat or an opportunity; undoubtedly an expansion in the size of a species range is an opportunity. However, it is necessary to implement management measures aimed to ensure survival and effectively allow the expansion of *M. sanmartini*. The *Campos* region is one of the most globally threatened biomes due to land use changes and also one of the least protected (OVERBECK *et al.*, 2007). Conservation actions are urgent in order to stop the loss of natural habitat and curb species extinction.

Studies such as this show the importance of considering the projections of both, climate and land use change, in order to implement effective strategies for long-term conservation. A deeper understanding of the

biology of *M. sanmartini* would increase the effectiveness of management measures to be implemented to conserve this species, currently categorized as “Near Threatened”.

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Appendix 1: Identification of well-known cells for amphibians in Uruguay.

Nonparametric estimators of species richness

$$Chao1 = S + a^2/2b$$

S: number of species observed

a: number of species represented by one individual in the sample

b: number of species represented by two individual in the sample

$$Chao2 = S + L^2/2M$$

L: singletons (number of species with only a single occurrence in the sample)

M: doubletons (number of species with exactly two occurrences in the sample)

$$Jack\ 1 = S + L(m-1/m)$$

m: total number of samples