

Potential worldwide impacts of sea level rise on coastal-lowland anurans

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Abstract. Amphibians are the most severely threatened terrestrial vertebrates and we are witnessing a global decline phenomenon, which is even suggested to be of the same level as the historical mass extinctions. Albeit the myriad of causative stressors identified in the last decades, future sea level rise (SLR) and its impact on coastal terrestrial fauna remains essentially unreported. Even if there is no consensus on the magnitude of the future SLR, several studies suggest that it is likely to be greater than previously reported by the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC). Therefore, it is reasonable to expect severe impacts on the coastal terrestrial fauna at a worldwide scale. Here, we assembled a worldwide data set of coastal-lowland anuran species in an attempt to quantify the potential habitat loss caused by flooding according to different SLR scenarios. We also assessed potential habitat suitability under climate change (CC) in order to evaluate its expected effects on species' climatic niches, by building species distribution models for three future scenarios (A2a, A1b and B2a). Our results revealed that SLR has the potential to produce negative impacts on ~ 86% of the selected coastal-lowland species in different magnitudes, whereas CC is expected to produce a greater impact on the same taxa. Thus, species predicted to persist under the new climatic conditions may be exposed to effects associated with SLR. Breaking our results down to biogeographic realms, we found that Australasia harboured most amphibian species suffering the dual impacts of SLR and CC. Based on our results, we advocate for the inclusion of potential future impacts of SLR in conservation action plans, anticipating and preventing biodiversity loss.

Key words: Amphibians, BIOCLIM, climate change, declining populations, species distribution models.

Introduction

Global climate change (CC) is claimed to be one of the major drivers of change on biodiversity (Barnosky et al. 2011, Bellard et al. 2012). The likely increase in the amount of atmospheric CO₂ for the year 2100 is expected to affect several other climatic parameters such as temperature, moisture and precipitation rates (IPCC 2007). This is predicted to impact life on several organization levels, i.e., from individual organisms to entire ecosystems (Yasuhara et al. 2008, Svenning et al. 2011, Bellard et al. 2012, Lučan et al. 2013, Sorte & White 2013). Likewise, it is plausible to assume that these changes are potential drivers of generalized biodiversity loss (Wake & Vredenburg 2008, Blaustein et al. 2010, Alford 2011, Hof et al. 2011), since CC *per se* can modify environmental conditions and push species to their physiological boundaries (Huey et al. 2010, Silva et al. 2013), leading taxa to shift their geographical ranges or simply to succumb *in locus*, when they are not able to overcome barriers (Early & Sax 2011, Wake 2012). In addition,

the existing synergisms between CC and other factors are expected to interact with or boost other hazards (e.g. Hayes et al. 2010, Hof et al. 2011, Foden et al. 2013).

Besides CC, the expected sea level rise (SLR) is another disturbing factor that may become relevant for the future of biodiversity (Menon et al. 2010, Bellard et al. 2013). This phenomenon is an expected consequence of CC for two main reasons, namely water expansion caused by the increasing entropy of water molecules and also the progressive melting of glaciers and ice sheets, both as a result of warmer temperatures (IPCC 2007). Furthermore, even though the IPCC's Fourth Assessment Report (AR4) (2007) predicts a SLR not higher than 60 cm, several studies present more pessimistic SLR scenarios (e.g. Overpeck et al. 2006, Grinsted et al. 2007, Rahmstorf 2007, Rahmstorf 2010), with SLR potentially reaching up to 6 m in the coming centuries. In fact, a precise and definitive SLR projection for the 21st century is still absent owing to the lack of knowledge on the polar ice sheet dynamics (Church et al. 2013).

Nonetheless, only few studies have discussed the SLR impacts on biodiversity (Menon et al. 2010, Wetzel et al. 2012, Bellard et al. 2013) preventing the anticipation and adoption of relevant conservation actions. Thus, assessment of the potential impacts of SLR on terrestrial fauna is imperative for the effective conservation of biodiversity.

In the current extinction crisis, amphibians are facing severe biodiversity loss (Wake 1991, Stuart et al. 2004, Barnosky et al. 2011), including dramatic population declines and worldwide species extinctions (Kiesecker et al. 2001, Wake & Vredenburg 2008, Alroy 2015). This alarming situation is attributed to several causes, including habitat loss, habitat fragmentation, invasive alien species, over-exploitation, infectious diseases and climate change (Becker et al. 2007, Wake & Vredenburg 2008, Blaustein et al. 2010). Besides assembling a complex puzzle, these factors may interact synergistically (Blaustein et al. 2010, Hayes et al. 2010, Hof et al. 2011), making amphibians the most threatened vertebrates on Earth (Hoffman et al. 2010). However, parallel to studies on multiple effects, during the last two decades researchers employed great efforts to understand the causative aspects of the amphibian decline puzzle. As an example, after the discovery of the *Batrachochytrium dendrobatidis* in 1999 (Longcore et al. 1999), more than 1000 articles have been published in regard to several aspects of chytridiomycosis (James et al. 2015). Although this gain of knowledge is a great step forward, other pieces of the amphibian crisis puzzle remain unclear. Thus, in order to reveal additional threats, we must evaluate the whole scenario in a comprehensive fashion to play an effective role in conservation.

The vast majority of the amphibians cannot live in salty water, i.e. the salinity is lethal for most species in every stage of their life cycle (Brown & Walls, 2013). However, many amphibian species worldwide are exclusively distributed in association with coastal-lowland zones (mainland and/or islands), with several cases of restricted distribution ranges and endemism in such regions (Vences et al. 2009). Thus, in this sense, it is expected that coastal-lowland amphibian species are likely to suffer some effects of SLR.

Here we investigate how coastal-lowland amphibian species respond to the potential impacts of SLR. We used species distribution models (SDM) (Franklin 2009) in a species-specific approach to explore the potential magnitude of the immediate effects of SLR on coastal-lowland anuran species

worldwide. We focused our approach on anurans because they have some particular features, as susceptibility to environmental changes (Wake 2012, Foden et al. 2013), notoriously low ability to migrate (Kovar et al. 2009, Heermeyer & Lannoo 2012), and low tolerance to salinity (Brown & Walls, 2013). Also, their position as endangered group (Hoffman et al. 2010) is another element that encourages studies with this group. We specifically addressed the following questions: 1) which anuran species in the world are most susceptible to the impacts of SLR?, 2) is there a specific region where such effects are expected to be greater?, 3) how will SLR affect the future habitat availability for the coastal-lowland anuran species?

Methods

Data sources

We assessed the comprehensive global data set comprising 5487 anuran species provided by The IUCN (International Union for Conservation of Nature and Natural Resources) Red List of Threatened Species, version 2010.4 (IUCN 2010), to select those taxa that may be potentially affected by the future SLR. Our selection predominantly followed three criteria: i) species with distribution range associated with coastal zones or restricted to islands; ii) taxa presenting populations at sea level (especially those with altitudinal range in a range between sea level up to 100 m above sea level (asl)); iii) taxa considered as typically lowland species by specialists. However, even gathering these characteristics, we exclude from the analyses species that presented missing (e.g. original polygon unavailable) or imprecise (inaccurate altitudinal range distribution) information that prevented modeling.

Albeit commonly used in several modelling approaches, we avoided using point location for three reasons: i) on the scale at which our analyses were performed (i.e. global); precise species records are available only partly for our data set, potentially leading to a bias in results; ii) the cost of additional field surveys to assemble a comprehensive set of species record was prohibitive; iii) point location may offer additional bias, because samples are often performed in areas with easy access, increasing omission errors (Loyola et al. 2013; Ficetola et al., 2014). Instead, we transformed the IUCN shape file polygons into rasterized digital

range maps with spatial resolution of 2.5 arc-minute (approximately 5 km). The available range information in terms of polygons summarizes the area of occupancy or the extent of occurrence (Gaston & Fuller 2009, Ficetola et al., 2014). We used these maps to generate presence-only point locations by randomization within the polygons. Number of points varied from 10 up to 8348, and was generated considering the range extent of polygon for each species.

To assess potential effects of SLR, we used raster files of 1, 2 and 3 m of SLR scenarios provided by the Center for Remote Sensing of Ice Sheets (www.cresis.ku.edu). Likewise, current climatic data used to build the distribution models were obtained from WorldClim (www.worldclim.org) (Hijmans et al. 2005), whereas future climatic scenarios were downloaded from the CIAT webpage (www.ccafscclimate.org). We used a comprehensive set of 19 bioclimatic variables (see details in www.worldclim.org/bioclim) to build distribution models for the present and also for three future scenarios (A1b, B2a and A2a) for the year 2080. We used future scenarios developed by the IPCC AR4 and, in order to minimize the source of uncertainty, we averaged the following climatic models: MPI-ECHAM5, NCAR-CCSM3, UKMO-HADCM3, UKMO-HADGEM1, CCMA-CGCM2, CSIRO-MK2, HCCPR-HADCM3 and NIES99 (see IPCC 2007, 2014).

Distribution model development

We built all the distribution models based on bioclimatic variables in the statistical software R (R Development Core Team 2013) using the BIOCLIM algorithm as implemented in the *dismo* package (Hijmans & Elith 2013). SDMs outputs included models for the present and future (2080) conditions, and were evaluated by the inspection of the area under the receiver operating characteristic curve (AUC) values. Even if there are several techniques for modelling a species' potential distribution (Franklin 2009), there is a lack of consensus on the finest method to predict species' presence or absence giving the environmental variables. Therefore, to choose a reliable modelling technique, it is important to avoid or minimize errors inherent to the modelling (Lobo et al. 2008). Thus, we carefully selected the BIOCLIM algorithm, which may best fit the rather coarse nature of the input data. BIOCLIM is a correlative presence-only modelling tool that summarizes a spe-

cies' climatic envelope to predict its potential distribution (Beaumont et al. 2005). It is largely used for modelling purposes and also has shown good performance in modelling (e.g. Tôrres et al. 2012), especially when the aim is to assess a species' potential distribution rather than its realized distribution (Jiménez-Valverde et al. 2011).

Modelling algorithms build models inferred from abiotic variables without considering biotic interactions (Franklin 2009); usually generating overpredictions (i.e. commission errors). One possibility to avoid this undesired outcome is to incorporate historical and biotic attributes to the resulting map (Soberón & Nakamura 2009). We worked under the general assumption that anurans are unable to migrate long distances, especially those species that have a restricted distributional range (e.g. Becker et al. 2007, Semlitsch 2010). Thus, we applied a buffer of 100 km to each species' original polygon to assess potential distribution and range shift under different conditions within the buffer.

Computing the SLR potential impacts

We calculate the percentage of future range loss caused by SLR per species and per scenario, considering both current (1950 - 2000) and future (2080) distributions. We evaluated the potential consequences of SLR including the current species' distribution because several of them show distribution ranges restricted to islands. As for such species migrations overseas are unlikely, we opted to analyse the potential loss of available land considering the current distribution, including the complete data set to avoid or minimize sources of unbalance. To calculate the percent range loss caused by flood per scenario, we overlaid the current distribution estimate in terms of IUCN shape files and the potential distributions derived from the SDM with raster files of three SLR simulations, and we then subtracted the overlap using ArcGIS 10 (ESRI 2011). The SLR scenarios were cautiously chosen to simulate optimistic, intermediate and pessimistic possibilities, in agreement with the relevant literature (e.g. Rahmstorf 2007; Grinsted et al. 2010, Rahmstorf 2010). We attempted to reduce under and overestimations concerning SLR projections, since the debate about the magnitude of the reach of the SLR is ongoing (Rahmstorf 2010), and the comprehension about ice sheet dynamics and its contribution to this phenomenon is still incomplete (Bamber et al. 2009, Mitrovica et al. 2009, Gomez et

al. 2010, Shepherd et al. 2012).

We estimated the potential loss of land for each species by calculating the differences in terms of grid cells through the different scenarios to verify which set of variables (CC or SLR) is expected to produce larger magnitude of effects. Then, we transformed the results in percentage of gain or loss of land per species in each scenario. Finally, we assessed the final results to verify and compare the magnitude of the different potential threats (SLR and CC) on the current and suggested future distribution for each species in the three future scenarios. It is important to emphasize that we considered different effects of SLR and CC to reach our aims. Despite SLR is a consequence of CC, we took into account the primary SLR effect of loss of available land where a given species could occupy. On the other hand, we computed the CC effects of changing environmental conditions, which may influence the suitability of the climatic niche for a given species. Finally, we compared the results through six different world biogeographic realms, namely Palearctic, Nearctic, Neotropic, Afrotropic, Indo-Malay and Australasia (Olson et al. 2001), following the anuran distribution worldwide (Stuart et al. 2008). We estimated whether SLR or CC is expected to cause larger impact in distinctive regions of the world.

Results

Global threatened taxa

The final data set comprised 123 lowland anuran taxa worldwide (~ 2 % of the global anuran diversity), from which 33 % (n = 41) are distributed exclusively below 60 m asl. We excluded 55 species from the analyses owing to lack of precise information. We analysed a total of 1845 models considering outputs of current and future climatic conditions and SLR scenarios. All models were considered acceptable presenting AUC values of 0.98 in average (± 0.02). Approximately 34 % (n = 42) of the species are current listed as least concern (LC) by the IUCN (2013), and ~ 37 % (n = 46) are assigned as near threatened (NT: ~ 13 %; n = 6) or at some category of threat, i.e. vulnerable (VU: ~ 28 %; n = 13), endangered (EN: ~ 48 %; n = 22), and critically endangered (CR: ~ 11 %; n = 5). Finally, ~ 28 % (n = 35) are current listed as data deficient (DD). The family Hylidae presented the highest number of species (n = 23), followed by Microhylidae (n = 21). On the other hand, the

families Petropedetidae and Ceratobatrachidae had the highest proportion of species potentially at risk (~ 16 % (n = 2) and ~ 15 % (n = 13), respectively).

Besides the loss of land by flooding, we detected regions that are potentially threatened by fragmentation by marine water intrusions on lowland areas. Nevertheless, the overall magnitude of the suggested impacts through the three SLR scenarios were similar, i.e. the amount of loss of land for the species' current distributions were merely slightly different, increasing proportionally as the sea level rises in the simulations (1, 2 and 3 m). In fact, for most of the species (n = 74), potential losses by SLR are expected to be less than 10 %. However, we detected loss of land by flood for ~ 86 % (n = 106) of the analysed taxa under the present conditions. For four species (all endemic to islands), we detected a 100 % potential loss of land by flood due to SLR, i.e. complete habitat unavailability (see an example in Fig. 1A and B). We also detected potential habitat losses greater than 10 % and perceptible fragmented habitat suitability for at least 28 species (~ 23 %) (Fig. 1C and D).

Under the perspective of the biogeographic realms, an overview on the anuran species richness revealed an unbalanced magnitude of potential impacts throughout the world (Fig. 2). Whereas for the Palearctic, Nearctic, Neotropic, Afrotropic and Indo-Malay regions the predicted loss of land for their local coastal-lowland anurans is approximately 1 %, for the Australasian region ~ 8 % of the local coastal anuran richness may be displaced. Likewise, we detected potential loss of land by flood in magnitudes greater than 10 % for at least one species in the Afrotropic, Indo-Malay and Australasia regions. However, most species of these biogeographic realms are expected to have losses below 10 %. We also identified possible 100 % loss of land and fragmented suitable habitat caused by marine intrusion for certain species in the Neotropic, Afrotropic and Australasia regions. Thus, Australasia was identified as the biogeographic realm most likely to receive severe potential impacts caused by SLR.

Future habitat suitability

According to our SDM outputs, we categorized three distinctive possibilities in terms of future climatic conditions (Fig. 3): increase, decrease, and complete habitat unsuitability. Even if the amount of suitable habitats within a 100 km buffer is expected to increase for some species in the near fu-

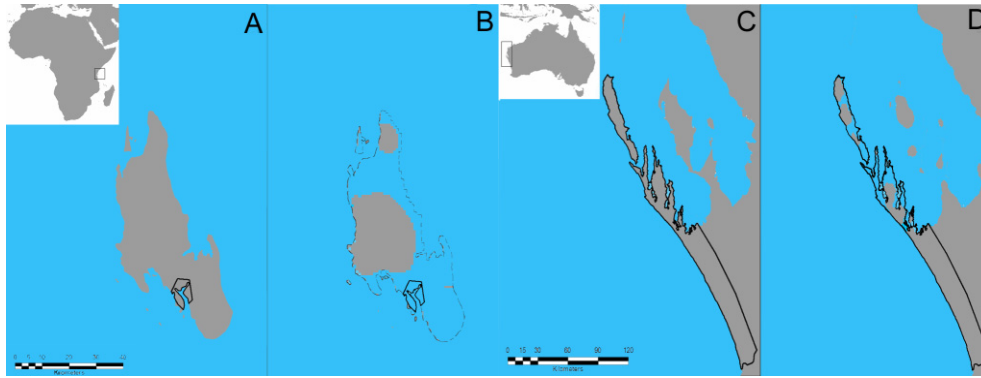


Figure 1. SLR has the potential to submerge current distributional areas for coastal-lowland anurans as we observed for *Mertensophryne howelli* (A and B), an endemic insular lowland species from Zanzibar with a potential flood of 100 % of its distributional range; and *Arenophryne rotunda* (C and D), an endemic species from Western Australia for which SLR may fragment suitable habitats. Current distributional range is represented by black lines.

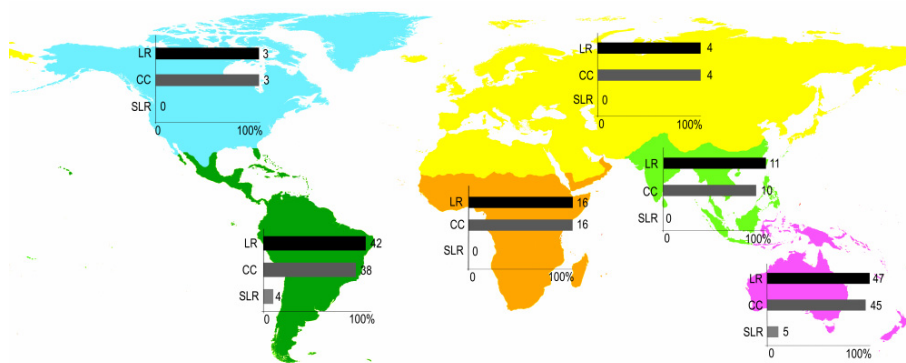


Figure 2. Proportion of species potentially threatened by future sea level rise (SLR) (light grey bar), climate change (CC) (dark grey bar), and the corresponding local richness (LR) (black bar) within the analysed species (numbers after bars indicate number of species) per world biogeographic realm (adapted from Olson et al. 2001): Palearctic (yellow), Nearctic (light blue), Neotropical (green), Afrotropic (dark yellow), Indo-Malay (light green), and Australasia (pink).

ture (further details in the supplementary material, Table S1), decreases may be expected for the majority of analysed taxa, with several cases of apparent spatial shifts where taxa may be pushed completely outside of their currently distribution. However, in such cases a small portion of suitable habitat remains. Nevertheless, in a third possibility, the models suggest complete habitat unsuitability for several species through the different scenarios, i.e. numerous species are expected to be pushed out of their currently realized niches, even within a buffer of 100 km around their present distributional ranges. As observed in the SLR simulations, the magnitude of possible CC impacts is similar among the scenarios and we cannot distinguish an optimistic or pessimistic scenario (Fig. 4).

The potential effects of CC on future habitat suitability by biogeographic realms also revealed a similar pattern (further details in Table S1 and S2). In the Palearctic realm, no future suitable habitats can be expected for ~ 0.5 % of the local coastal-lowland anuran richness, as well as decreasing suitable areas were identified for another ~ 0.5 %. In the Nearctic, complete habitat unsuitability is expected for an average of ~ 1 % of the local richness, and a decrease in suitable areas for one additional species (~ 0.7 %). At the same time, we observed increasing suitable habitats for some species (~ 0.6 %, $n = 5$) in the Neotropical region, but decreased or complete unsuitability for ~ 28 % of the local coastal-lowland anuran richness. As for the present conditions, the Afrotropic, Indo-Malay

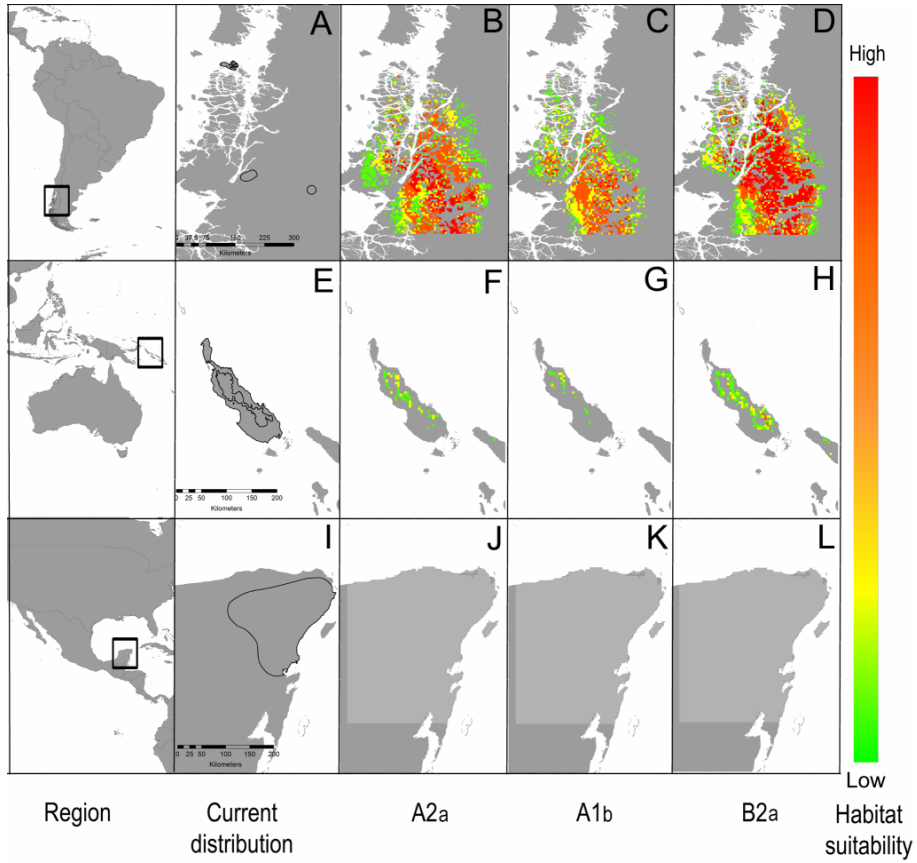


Figure 3. Three patterns of SDM outputs observed for three emission scenarios (A2a, A1b, and B2a). Future habitat suitability is expected to increase for few species (A to D: *Batrachyla nivaldoi*, an endemic South American species), but for several other taxa a decrease in habitat suitability (E to H: *Cornufer mediodiscus* from the Solomon Islands) or total unsuitability (I to L: *Craugastor yucatanensis* from Mexico, in the Caribbean Sea) is predicted for the year 2080. Current distribution is represented by black lines.

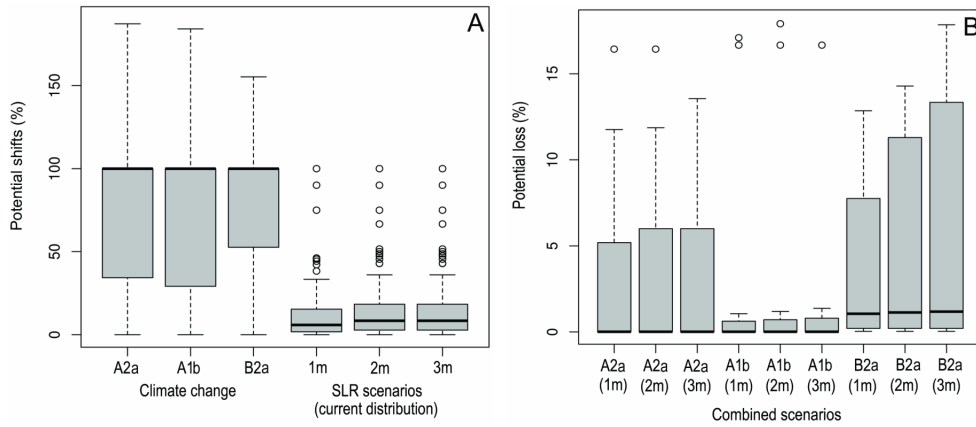


Figure 4. Comparative magnitude of the potential effects of CC and SLR in terms of shifts in suitable grids (a) and potential losses for persistent species under CC in terms of loss of suitable grids by flood in different SLR scenarios (b).

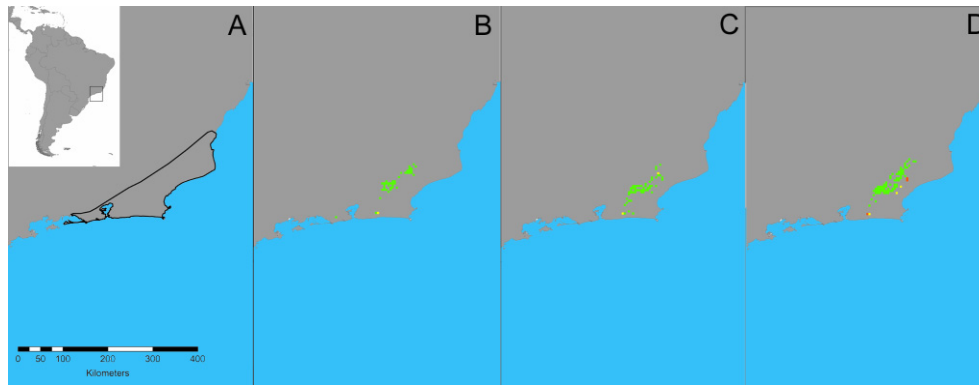


Figure 5. An example of predicted habitat suitability toward inland for *Rhinella pygmaea*, an endemic toad from the Brazilian Atlantic forest lowlands. Its current distribution is shown in (A), and the potential suggested future suitable areas for three emission scenarios are presented as follows: (B) A2a, (C) A1b, and (D) B2a.

and Australasia realms showed similar patterns in terms of CC potential impacts, with few cases of expected increasing suitable habitats. However, several cases of decreasing suitable habitats in the future were detected in the Afrotropic, Indo-Malay, and Australasia regions, but also cases of complete habitat unsuitability. Summarizing, Australasia remains as the biogeographic realm most likely to be severely affected by future CC in terms of coastal-lowland anuran richness.

Analysing the potential SLR effects for the future species' distribution under the imminent climate conditions, we also detected distinctive magnitudes of such possible implications (Fig. 4). The overlapping layers (modelled distributions and SLR scenarios) followed by the calculation of loss of land by flood suggest future losses for only twelve species (~ 9 %) of the complete data set, most of them ($n = 7$) with losses estimated to be below 1 %. However, we identified losses of ~ 20 % for two species (*Crinia tinnula* and *Litoria longiburensis*) in at least one coupled SLR-CC scenario. In addition, we identified loss of land greater than 10 % for four species (*Crinia insignifera*, *Crinia tinnula*, *Litoria longiburensis* and *Uperoleia martini*) in a scenario, and also a potential total loss by flood for one exclusively insular species (*Leptodactylus fallax*), which is considered as CR by IUCN. Specifically for this species, the potential distribution suggested by the SDM is only one suitable grid in the B2 scenario, which may be inundated in the future.

Moreover, after the intersection of the SDMs and SLR scenarios, we noticed that most of the

species for which an increase or decrease in suitable habitats may be expected tend to shift their potential distribution range from the current condition toward inland (~ 38 % ($n = 47$, A2a), ~ 42 % ($n = 51$, A1b), ~ 46 % ($n = 57$, B2a); Fig. 5). On the other hand, SDMs suggest that some species may be able to shift their distribution ranges and remain in the coastal region, even under the new climatic conditions ($n = 6$ (A2a and A1b), $n = 12$, (B2a)). In such cases, fragmentation of suitable habitats by marine water intrusion can be expected.

Discussion

As far as we are aware, this is the first global approach focused on the potential impacts of SLR on the coastal-lowland anuran species. Previously, Bellard et al. (2013) identified several living taxa (plants and terrestrial and freshwater vertebrates) in insular biodiversity hotspots that may be threatened by SLR, which included one to two anuran species in two to three meters of rising sea simulations. Our study comprises continental species as well, and shows potential losses by SLR (*per se*) for up to five species, depending on the scenario in the same sea level simulations used by Bellard et al. (2013). However, if we include the potential effects of CC on the species' niche for future suitability, approximately 50 % of our data set is predicted to suffer impacts in some future scenario, independently of SLR. In other words, at this point, it is important to emphasize that our re-

sults revealed that CC has the potential to produce greater negative impacts on coastal-lowland anurans than SLR itself. Despite the fact that SLR is a consequence of CC, the potential effects incurred by each one are different in several aspects. For example, whereas CC is expected to produce consequences on the species' climatic niche (Lemes & Loyola 2013; Loyola et al. 2013), SLR has the potential to submerge climatically available areas that could be occupied in the future, i.e. turning them into unsuitable habitats.

By analysing different scenarios we showed that these two phenomena have the potential to affect more than 100 anuran species worldwide. Some taxa in our data set are already classified as threatened, but several others are considered LC or NT. If the SLR is taken into account in future evaluations, it is likely that some of these non-threatened species may have their threat status changed. Besides the plethora of current pressures (Blaustein et al. 2010, Becker et al. 2007, Wake 2012) SLR may represent an additional threat by the potential flooding of habitats and/or fragmentation of future suitable areas (Menon et al. 2010, Wetzel et al. 2012, Bellard et al. 2013). Besides this, some threats may not be so definitive as SLR will be. For example, chytridiomycosis may be lethal to some individuals, but not to others (Pilliod et al. 2010), therefore, population declines due to fungal infection are not certain. Conversely, the majority of amphibians do not tolerate flooding by salt (sea) water (Hopkins and Brodie 2015).

Anuran species richness is highest in the Tropical regions (Frost 2015), especially in the Neotropics (Stuart et al. 2008). Consequently, coastal-lowlands within this region could be expected to be the most severely affected in terms of potential losses in biodiversity as a result of SLR. However, even if Australasia is not the richest biogeographic realm concerning the anuran biodiversity, our results indicate it to be the region with proportionally most anuran taxa potentially at risk by SLR in terms of magnitude of impacts. Australasia is characterized by the presence of numerous islands and fjords (Olson et al. 2001), which may be more susceptible to marine water intrusions (Michener et al. 1997). Additionally, including the potential effects of CC, comparably higher impacts along coastal lines in some continents may be expected (e.g. Loyola et al. 2013), including associated islands (Bellard et al. 2013), since distribution range shifts by dispersion or migration may be hampered for freshwater vertebrates in such cases

(e.g. Furlan et al. 2013). Furthermore, the sea level is rising more rapidly in the Western Pacific (Nicholls & Cazenave 2010), which may represent an immediate threat for the associated coastal terrestrial fauna in this region. Indeed, Wetzel et al. (2012) identified several endemic mammals potentially threatened by SLR in Indo-Malaysian islands, whereas Bellard et al. (2013) stressed that several species (plants and other vertebrates) from the Caribbean islands may suffer the most severe impacts from the SLR, while Menon et al. (2010) revealed Southeast Asia as the region most potentially impacted from flood caused by SLR. Therefore, it seems that SLR may threaten several ecoregions in the world in the next century. This is a bleak panorama that reinforces how complex it is to anticipate the SLR effects and, at the same time, highlights that SLR cannot be ignored.

Moreover, there are also the potential local effects of SLR, which are difficult to predict precisely. In the case of amphibians, marine water intrusions into coastal fresh water bodies (Menon et al. 2010, Nicholls & Cazenave 2010), even sporadically, have the potential to increase salinity, decreasing the suitability of the habitat and jeopardizing larval development (e.g. Rios-López 2008). Another aspect is represented by the possibility of introducing potential marine predators (fishes and invertebrates) into the freshwater bodies (Blaustein et al. 2010), which could also reduce anuran populations. Finally, extreme events as hurricanes and flood tides are expected to become more frequent and intense with CC (Michener et al. 1997, IPCC 2007), potentially increasing the incidence of marine water intrusions and consequently boosting the issues mentioned above.

Concurrently, our results clearly support the idea that CC is one of the most certain future stressors that will lead to loss of biodiversity worldwide (Hof et al. 2011, Loyola et al. 2013, Foden et al. 2013). In fact, there are several uncertainties inherent to SDMs (Diniz-Filho et al. 2012). Nevertheless, some biological traits support the observed patterns for our SDMs as, for instance, the reproductive mode of the species. Species with more specialized reproductive modes have narrow habitat requirements for reproduction and could be more susceptible to environmental changes (Loyola et al. 2013). Thus, reproductive mode can be interpreted as one cause for predicted unsuitability or range contraction. Moreover, at a finer scale, anurans that exhibit low thermal tolerance may experience physiological con-

strains under elevated temperatures in their microhabitats (Duarte et al. 2012). Although tadpoles of some species have a higher tolerance for warm temperatures, adults may experience different effects of climate change (e.g. higher air temperatures or dehydration) (Duarte et al. 2012), which also support our SDM predictions. Besides, CC is expected to require adjustments in some biological traits (e.g. reproduction, calling phenology), consequently altering breeding seasons and promoting niche overlap among species (Geyer et al. 2011, Todd et al. 2011, Walpole et al. 2012), which ultimately may lead to modifications at the community level (e.g. Walpole et al. 2012), or even local extinctions of sensitive species (Geyer et al. 2011, Loyola et al. 2013).

Simultaneously, in regard to those species for which habitat suitability is expected to increase, CC could be misinterpreted as beneficial. In fact, it seems that CC has the potential to favour species that are able to tolerate warmer and variable conditions, relatively increasing their performance to stand in a new climatic state (Blois et al. 2013). Such species probably represent taxa that are able to tolerate higher temperatures (e.g. Duarte et al. 2012). Consequently, these taxa will potentially have expanded distribution ranges in the near future. Conversely, it is important to highlight that SDMs possess several caveats and limitations, and they only suggest habitat suitability based on bioclimatic variables (Franklin, 2009). Thus, for a complete statement on the species' realized future distributions, we need to take into account processes at several levels, such as the interactions among species (e.g. Todd et al. 2011, Blois et al. 2013), habitat fragmentation (e.g. Becker et al. 2007), dissemination of emergent diseases (e.g. Hof et al. 2011), and capacity of migration (e.g. Heermeyer & Lannoo 2012), especially upslope migration, i.e. towards cooler conditions (e.g. Loyola et al. 2013). All of these conditions may affect the future persistence of species in the current and suggested distributional locations.

The SLR issue is far from being completely elucidated and further studies are welcome. We recommend the development of additional modeling approaches at finer scales, regional and more accurate SLR projections (Nicholls & Cazenave 2010, Willis & Church 2012), local monitoring programs (Verdade et al. 2012), and the inclusion of biological traits (e.g. physiological limits) in the models to better understand the magnitude and anticipate the impacts of SLR on biodiversity.

Worldwide sea level rise is caused by global warming (Nicholls & Cazenave 2010) and, as we showed, it may play an important role in the amphibian decline puzzle. Thus, since SLR was largely ignored in previous conservation plans for amphibians (e.g. Gascon et al. 2005, Verdade et al. 2012), we strongly suggest its inclusion in future actions.

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