Environmental Conservation

Appendix S1

Supporting methods

Expert-based assessment of the climate change vulnerability of amphibians and reptiles of Uruguay

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Species dataset

Species assessed in this study were taken from Frost (2021), for amphibians, and Uetz et al. (2021), for reptiles. The nomenclature used in this assessment follows these databases. Here, we evaluated the relative vulnerability to climate change of 48 amphibian and 64 reptile species. We excluded non-continental reptiles (i.e. sea turtles) and alien species.

Vulnerability framework and scoring

Trait-based approaches for assessing species vulnerability to climate change are becoming increasingly used (Young et al., 2015). The framework proposed by Foden et al. (2013) takes into account three dimensions of vulnerability to climate change: sensitivity, low adaptive capacity, and exposure. Sensitivity is the lack of potential of a species to persist *in situ* and is directly related to its life-history traits. Low adaptive capacity is the inability of a species to undergo the negative impacts of climate change through dispersal and/or micro-evolutionary change. Exposure is related to the rate and magnitude to which a species' physical environment is expected to change due to climate change (Carr et al., 2014; Foden et al., 2013). Usually, the traits to assess species vulnerability to climate change are comprised into trait sets. Following Foden et al. (2013) we used four trait sets for sensitivity: A. Specialized habitat and/or microhabitat requirements; B. Narrow environmental tolerance or thresholds that are likely to be exceeded due to climate change at any stage in the life cycle; C. Dependence on a specific environmental trigger or triggers likely to be disrupted by climate change; and D. Dependence on interspecific interactions which are likely to be disrupted by climate change. For low adaptive capacity, we used: A. Poor dispersability; and B. Poor evolvability. Finally, for exposure we selected: A. Exposure to sea level rise, and B. Range decline due to shift in climatic conditions. We selected and adapted traits for each of the trait groups and taxa studied.

This approach used a method in which every trait received scores of 'low', 'high', or 'unknown' for each species. Species that have received a 'high' score in at least one of the traits considered for a dimension were classified as 'high' for that dimension. Species qualified with 'high' scores in all three dimensions, sensitivity, low adaptive capacity, and exposure, were considered as highly vulnerable to climate change.

Sensitivity trait sets

A. Specialized habitat and/or microhabitat requirements

Species that have specific requirements are likely to be more sensitive to environmental changes driven by climate change since they have a narrow range of available habitats or microhabitats. On the contrary, generalist species in terms of their habitat requirements would tend to be more resilient since they will have a wider range of habitats and microhabitats options available.

B. Narrow environmental tolerance or thresholds that are likely to be exceeded due to climate change at any stage in the life cycle

It refers to species that are tightly coupled to a narrow range of temperature or precipitation regimes, and therefore, might be negatively affected by climate change. For instance, species normally experienced a greater thermal range, have more resilience to extreme temperatures than species with smaller ranges (Jiguet et al., 2006). We used the range size and latitude of the northern limit of species as a proxy of physiological tolerance following Gardali et al. (2012).

C. Dependence on a specific environmental trigger or triggers likely to be disrupted by climate change

Many species rely on environmental triggers (or cues) to initiate some stage of their life cycle (e.g. reproduction, migration, egg laying, hibernation, etc.). Species that depend on changes in the weather and seasons to initiate some stage of their life cycle are likely to be negatively affected by climate change, for instance producing an imbalance between migration and the food source (Şekercioğlu et al., 2012).

D. Dependence on interspecific interactions which are likely to be disrupted by climate change

Changes induced by climate change in species’ ranges, phenologies, and relative abundances may indirectly affect other species that rely on interspecific interactions. For example, changes in climate may induce variations in the temporal partitioning of the breeding period, leading to an increase in interspecific competition (Ahola et al., 2007). Thus, species that are highly dependent on these beneficial or detrimental interspecific interactions are likely to be more sensitive to climate change.

Low adaptive capacity trait sets

A. Poor dispersability

Species ability to disperse to new areas with suitable environmental conditions would be important to withstand the negative effects of climate change. Species with greater mobility capacity and long distances of dispersal may avoid these negative effects. On the contrary, species with poor dispersability could not disperse fast enough to keep up with the environmental changes, and as a consequence, would be at higher risk of extinction (Foden et al., 2013). Furthermore, extrinsic barriers could become a challenge even for species with high dispersal capacity. Barriers may be geographical, such as elevation (e.g. species occurring only in hilly areas) and rivers; or unsuitable microhabitats and anthropogenic modifications. In our case, we were unable to use a trait that defines species restricted to high-altitude habitat, 1,000 meters above sea level, as used by Carr et al. (2014) and Böhm et al. (2016), since we do not have that altitude in the country. Nonetheless, there are species that are exclusively associated with Uruguayan low altitude hilly areas, defining a clear ecosystem. Thus, we redefine high-altitude habitat for Uruguay, as "species occurs only in the hilly range (in Uruguay)" for the trait "Extrinsic barriers to dispersal".

B. Poor evolvability

The potential of species genetic change may determine whether the adaptation is coming at a velocity to keep up with climate change-driven. Species with short generation times have the potential to evolve rapidly, thus keeping up with climate changes (Hoffmann & Sgrò, 2011). Therefore, species with long life cycles, like large animals, may not keep up with environmental changes induced by climate change.

Exposure trait sets

Temperature and precipitation inferences were based on the local and regional climatic projections that rely on the ensemble of four General Circulation Models (ACCESS1.0, CanESM2, CCSM4, and HadGEM2) presented by Nagy et al. (2016), who considered two emissions scenarios (4.5 and 8.5 RCP) for 2050 (2040-2060). This model predicts an increase in temperature ranges from 1.0 °C to 1.4 °C and 1.7 °C to 2.0 °C, for 4.5 and 8.5 RCP, respectively, with maximums in the northern region of Uruguay (Fig. S1). The model also predicts increases in precipitation between 0.1 mm/day to 0.3 mm/day and 0.1 mm/day to 0.5 mm/day, for 4.5 and 8.5 RCP, respectively, with extreme values in the northeast region as well (Fig. S2). The referred authors also calibrated satellite data with tidal scales installed at different places over the Uruguayan coast, and projected an annual sea level rise of 3.0 - 4.0 mm. The coastal zones of Uruguay are considered among the most exposed to extreme events and sea level rise in Latin America (Losada et al. 2013, Nagy et al. 2015). Both sea level rise and an increase in temperature and precipitation, expose species to novel conditions that would jeopardize their persistence in significant portions of their current range in Uruguay.

For these reasons, we included traits that considered the vulnerability of species potentially affected by sea level increase in Uruguay, and considered their global latitudinal range. We considered exposed species those with a distribution restricted solely to coastal habitats or also in only one additional habitat type. We assumed for these cases that a large portion of the species suitable habitat might disappear or become deeply modified due to CC. We also considered as exposed those species with a global geographic range that has part of its northern boundary within Uruguay (i.e. are not found at latitudes lower than 30°S). Uruguay is inserted in a biogeographic transitional zone (Ferro & Morrone 2014), where faunas from more tropical biomes face their southern limits of distribution, while others from colder and drier environments reach their northern limits. With an expected increase in both temperature and precipitation in the near future, we assume that many of these species will undergo a poleward contraction in their ranges due to the disappearance of suitable climatic conditions (e.g. with novel conditions exceeding their thermal tolerance) in some parts of Uruguay (Sunday et al. 2012, Bradshaw et al. 2014, Diamond 2018, Boisvert-Marsh et al. 2019).

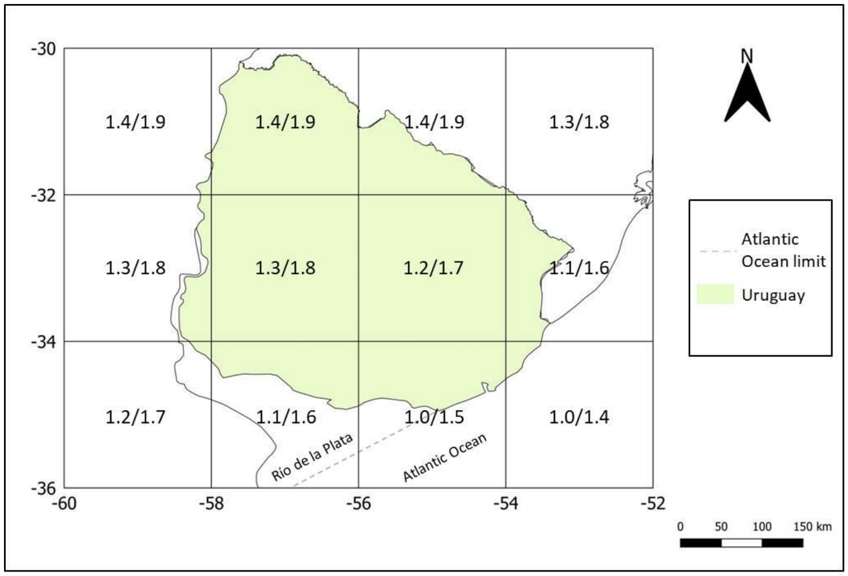

Fig. S1. Change in mean annual temperature (°C) projected for 2050 in Uruguay and its immediate surroundings. Value to the left of "/" indicates change according to RCP 4.5 scenario, on the right RCP 8.5 scenario. Modified from Nagy et al. (2016).

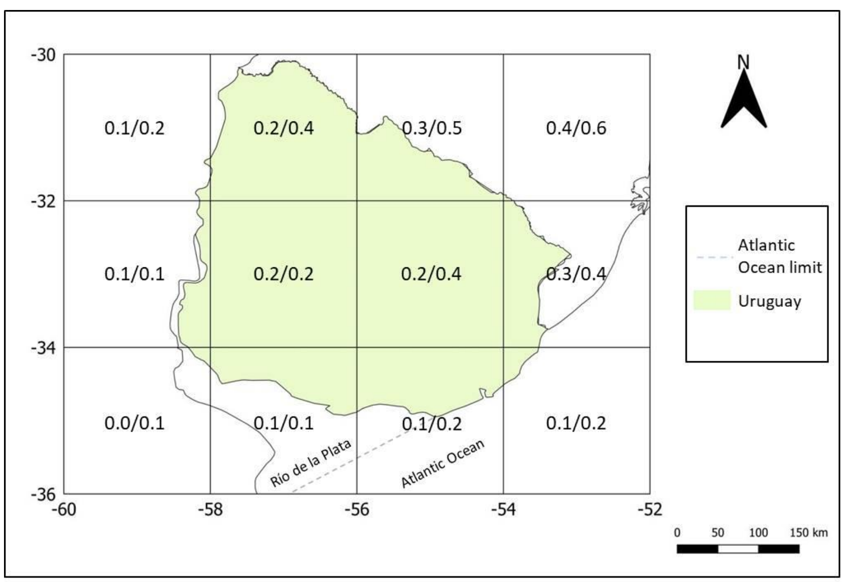

Fig. S2. Change in annual precipitation (mm/day) projected for 2050 in Uruguay and its immediate surroundings. Value to the left of "/" indicates change according to RCP 4.5 scenario, on the right RCP 8.5 scenario. Modified from Nagy et al. (2016).

A. Exposure to sea level rise

Species occurring exclusively in coastal habitats are likely to be negatively affected as a consequence of an increase in sea level induced by climate change. We assigned ‘high’ scores if the species largely occurs in coastal habitats exposed to flooding, and no more than one other habitat type in Uruguay: intertidal salt marshes, coastal freshwater, brackish or saline lakes and lagoons, coastal caves, intertidal shorelines (including rocks, beaches, flats and tide pools), and coastal sand dunes.

B. Range decline due to shift in climatic conditions

To assess species’ distribution area exposed to climate change in the near future (i.e. 2050), we used the latitudinal range of the species as a proxy. Predictions suggest that some amphibian species with northern distributions in the country are likely to expand their geographical range in Uruguay, in a southward direction as a consequence of CC (Toranza et al., 2012). Therefore, we assigned scores of ‘high’ to species with their northern distribution limits in Uruguay (≥ 30° South latitude), understanding that these species would be negatively affected by climate change in Uruguay.

Trait selection

Amphibians

Sensitivity

To assess the sensitivity of amphibian species to climate change, we selected seven traits into the four trait sets (adapted from Foden et al., 2013).

Habitat specialization: here defined as the number of IUCN Red List habitat types occupied by a given species by expert criterion. Species were classified as ‘high’ if they rely on 1 habitat.

Dependence on a particular microhabitat: species were classified as ‘high’ if they are freshwater-dependent and present larval development, and occur exclusively in an unbuffered habitat (i.e. not forest).

Physiological tolerance: species with moderate or small regional distribution (i.e. northern limit of geographic distribution above 26° S) were assigned ‘high’ scores.

Dependence on an environmental trigger: explosive breeders depending on rainfall or increased water availability cues, with few reproductive events per year (less than three) (not in forest), were assigned 'high' scores.

Increasing negative interaction with other species: species were assigned with 'high' scores considering the likelihood of increasing risk predation or competition as a result of climate change.

Increasing susceptibility to diseases: species were assigned as 'high' if there were records of infection by *Batrachochytrium dendrobatidis* or other pathogens, or future identification of infection is highly likely according to the available information.

Diet specialist: we classified amphibian species as diet specialists if their diet is composed of up to three of the following categories: spiders, ticks, other mites, cockroaches, mantises, butterflies, moths, beetles, bees, aphids, cicadas, fleas, flies, dragonflies, ants, centipedes, millipedes, non-arthropod invertebrates, amphibians, fish and bird.

Low adaptive capacity

To assess the adaptability of amphibian species to climate change, we selected three traits into the two trait-sets (adapted from Foden et al., 2013).

Low intrinsic dispersal capacity: we assigned 'high' scores when the species has not become established outside its natural range, is not associated with flowing water, and its range size is ≤ 4,000 km^2.

Extrinsic barriers to dispersal: species were assigned 'high' values when there was evidence of fragmented distributions in Uruguay due to specific barriers (i.e. urbanization) and/or inadequate microhabitats, and/or occurs only in hilly areas (in Uruguay).

Low reproductive capacity: species were qualified as 'high' when annual reproductive output is ≤ 50 offspring or the species being viviparous.

Exposure

To assess the exposure of amphibian species to climate change, we selected two traits into the two trait sets (adapted from Foden et al., 2013).

Exposure to sea level rise: we assigned 'high' scores if the species largely occurs in coastal habitats exposed to flooding, and no more than one other habitat type in Uruguay: intertidal salt marshes, coastal freshwater, brackish or saline lakes and lagoons, coastal caves, intertidal shorelines (including rocks, beaches, flats, and tide pools), and coastal sand dunes.

Latitudinal range of the species: to assess the area exposed to climate change in the near future (i.e. 2050), we used the latitudinal range of the species as a proxy. Species with their northern distribution limits in Uruguay (≥ 30° South latitude), were assigned with 'high' scores.

Reptiles

Sensitivity

To assess the sensitivity of reptile species to climate change, we selected eight traits into the four trait-sets (adapted from Carr et al., 2014).

Habitat specialization: here defined as the number of IUCN Red List habitat types occupied by a given species by expert criterion. Species were classified as 'high' if they rely on 1 habitat.

Dependence on a particular microhabitat: species were scored as 'high' if they exhibit a strong dependence on one or more of the following: streams or ravines in hilly areas; ephemeral ponds, vines, fallen trees, deadwood, tree hollows, trees at the water's edge, gallery or riparian forests, anthills, termite mounds, dunes, open patches in grasslands, rocky areas and outcrops, cliffs, and caves; freshwater or forest dependent.

Physiological tolerance: species with moderate or small regional distribution (i.e. northern limit of geographic distribution above 26° S) were assigned 'high' scores.

Tolerance of flooding: here, qualified as ´high´ if species rely on a specific flooding regime (or lack of) across its entire range.

Temperature-dependent gender: species were assigned 'high' scores when the gender of offspring is known or supposed to be dependent on the temperature incubation regime (temperature-sex determination).

Dependence on an environmental trigger: was considered as 'high' if species relies upon a weather change for one or more of the following: breeding; egg deposition; aestivation (or emergence from); hibernation.

Diet specialist: species were assigned high scores if its diet consists of a low number of items from a single dietary category from the following: Leaf matter; fruit; seeds; nectar; a single taxonomic group of arthropods; a range of arthropods; other invertebrates; small sized mammals (≤ 300 mm SVL); large sized mammals (300 mm SVL); adult/sub adult birds; bird eggs/juveniles; adult/juvenile reptiles; reptile eggs; adult amphibians; tadpoles; freshwater fish; feces; and an 'other' category for anything outside of these parameters (e.g. anthropogenic food, unspecified taxa) (following Böhm et al. 2016).

Interspecific habitat creation: species depending upon another to modify or create suitable habitat for themselves were scored as 'high'.

Low dispersal capacity

To assess the adaptability of reptile species to climate change, we selected four traits into the two trait-sets (adapted from Carr et al., 2014).

Low intrinsic dispersal capacity: we assigned 'high' scores when the species has not become established outside its natural range, is not associated with flowing water, and its range size is ≤ 4,000 km^2; or species is fossorial.

Extrinsic barriers to dispersal: species were assigned 'high' values when there was evidence of fragmented distributions in Uruguay due to specific barriers (i.e. urbanization) and/or inadequate microhabitats, and/or occurs only in hilly areas (in Uruguay).

Low reproductive capacity: we assessed this trait as reproductive output (mean litter size x mean litters per year). Since for this trait, there was no *a priori* basis to established a threshold, we arbitrarily selected a threshold of the 25% of species with lower reproductive output as having low adaptability, following Carr et al. (2014).

Genetic turnover: we used longevity as a proxy for generation length. Since there was no *a priori* basis to establish a threshold, we selected the 25% of species with the longest lifespans as unadaptable.

Exposure

To assess the exposure of reptile species to climate change, we selected two traits into the two trait sets (adapted from Carr et al., 2014).

Exposure to sea level rise: we assigned 'high' scores if the species largely occurs in coastal habitats exposed to flooding, and no more than one other habitat type in Uruguay: intertidal salt marshes, coastal freshwater, brackish or saline lakes and lagoons, coastal caves, intertidal shorelines (including rocks, beaches, flat, and tide pools), and coastal sand dunes.

Latitudinal range of the species: to assess the area exposed to climate change in the near future (i.e. 2050), we used the latitudinal range of the species as a proxy. Species with their northern distribution limits in Uruguay (≥ 30° South latitude), were assigned as exposed to climate change.

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