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Global Protected Areas as refuges for amphibians and reptiles under climate change

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Protected Areas (PAs) are the cornerstone of biodiversity conservation. Here, we collated distributional data for >14,000 (~70% of) species of amphibians and reptiles (herpetofauna) to perform a global assessment of the conservation effectiveness of PAs using species distribution models. Our analyses reveal that >91% of herpetofauna species are currently distributed in PAs, and that this proportion will remain unaltered under future climate change. Indeed, loss of species' distributional ranges will be lower inside PAs than outside them. Therefore, the proportion of effectively protected species is predicted to increase. However, over 7.8% of species currently occur outside PAs, and large spatial conservation gaps remain, mainly across tropical and subtropical moist broadleaf forests, and across non-high-income countries. We also predict that more than 300 amphibian and 500 reptile species may go extinct under climate change over the course of the ongoing century. Our study highlights the importance of PAs in providing herpetofauna with refuge from climate change, and suggests ways to optimize PAs to better conserve biodiversity worldwide.

Human-induced environmental degradation is dragging global biodiversity into its sixth mass extinction[1–3]. Population and whole-species declines have rapidly spread across the animal tree of life –a phenomenon termed 'defaunation'[4]–, with thousands of species on the brink of extinction and >500 species declared or believed to be extinct in the last 500 years only among terrestrial vertebrates[5–8]. Animal declines are the outcome of multiple factors operating in synergy[4,9], with anthropogenic climate change widely identified as one of the major drivers of population extirpations and whole-species extinctions in the coming century[6,10,11]. Therefore, the development of quantitative, integrative and global-scale analyses aimed at identifying the lineages (especially species) and geographic regions more likely to

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undergo declines driven by climate change ranks among the major challenges for implementing effective conservation actions with the potential to mitigate these losses of biodiversity worldwide[7,12,13].

Protected Areas (PAs)—geographic regions legally designated for the protection of biodiversity and cultural resources[14]—play an essential role in maintaining global biodiversity[15,16], underpinning conservation programs worldwide to mitigate the impacts of multiple human-induced threats, including climate change[17]. Existing PAs have been designed to protect present-day biodiversity and ecosystems[18,19]. However, their effectiveness in conserving biodiversity under future climate change has only been evaluated for a few taxa, and mostly at regional scales. Therefore, the extent to which the currently established global PAs can be expected to play a dominant role under the increasing threat of climate change remains fundamentally unassessed. For instance, current models predict that PAs are likely to protect European bird populations in the face of climate change[20,21], whereas a number of areas in southern Africa are expected to become less effective for conserving endemic birds under this same threat[22,23]. Consequently, a global analysis of PA effectiveness for the conservation of species under future climate change is urgently needed to provide timely suggestions for conservation management strategies (e.g., additions to the global PA network, identification of species and regions where more intensive conservation measures such as assisted migration may be necessary, and conservation gaps more widely[24,25]).

Species distribution models (SDMs) are widely used to quantify the responses of species (e.g., rapid range shifts) under climate change[17,26]. The increasing availability of vast species occurrence datasets and environmental layers allows for the development of robust predictions of species ranges[27,28], and analyses using SDMs can clarify how their ranges have and will be affected by environmental change[17,26,29]. As expected, using species range dynamics to evaluate the role of PAs under climate change and to develop effective conservation strategies has become increasingly feasible through such analyses[18,30,31]. For example, SDMs have been used for predicting endangered species' range shifts under climate change[32–34], and for evaluating the risk of biological invasions in PAs[27,35]. SDM studies in China[18], the USA[31], Mexico[36] and South Africa[36] have revealed that current PAs may provide consistently suitable habitats under future climate conditions for tetrapods.

Amphibians and reptiles (hereafter 'herpetofauna') stand out as the most threatened terrestrial vertebrates[37,38]. In fact, amphibians are widely recognized as nature's most endangered animals[6,39]. Within both lineages, alarming proportions of species are known to be undergoing progressive population declines[2], and 41% of amphibians and 21% of reptiles are listed as facing extinction risk under IUCN red list categories[38]. In addition to land-use change[40,41], disease outbreaks[42,43], and alien species invasions[44,45], climate change has been implicated as one of the major factors involved in the decline of amphibian and reptile abundance both directly[46,47] and indirectly (e.g., by increasing susceptibility to disease[48], or enhancing demographic susceptibility to declines[49]).

The effectiveness of PAs in protecting the global herpetofauna from climate change has been evaluated in some regions and groups, such as for amphibians in China[18] and for amphibians and reptiles in the USA[31]. However, significant limitations have prevented a comprehensive global assessment of the role of PAs across these lineages worldwide. First, the availability of herpetofauna distributional data in online databases is highly biased towards high-income countries. For example, there are over 1,000,000 observed records of amphibians and reptiles in both the United States of America (USA) and Australia listed in the Global Biodiversity Information Facility (GBIF, https://www.gbif.org/), compared to only 5,327 and 22,694 observed records from mainland China and Brazil, respectively (records since 1970; accessed Aug. 15, 2022). Such huge discrepancies in data availability are a major impediment to meaningful and systematic estimations of herpetofauna distribution and PA coverage. Second, we still lack a precise global estimation of PA coverage for herpetofauna and their predicted habitat shifts under future climate change, despite the fact that the effectiveness of PAs has been evaluated at some regional scales[18,31]. Third, most research undertaken to evaluate the effectiveness of PAs has been based on analyses using a relatively low spatial resolution (e.g., 10 km × 10 km; Supplementary Table 1). This low resolution may not be compatible with the current PA size (median = 0.37 km^2), resulting in overestimations of the range size of narrow-range species. Identifying such knowledge gaps will enable us to better understand the effectiveness of PAs in conserving herpetofauna globally, and enhance our ability to protect amphibians and reptiles based on scientifically-informed decisions.

To address these limitations, we compiled a comprehensive global database with over 3.5 million filtered observation records spanning 5,403 amphibian species and 8,993 reptile species from online databases, fieldwork data, museum collections and published references. For all species in our database, we predicted the availability of suitable habitats under current (1960–1990) and future climate scenarios (2060–2080) at high spatial resolution (1 km × 1 km) using ensemble species distribution models (SDMs). Because of the limited dispersal ability of amphibians and reptiles, we assumed no occupation of newly emerged suitable habitat conditions that may become available (e.g., due to climate change) in the future[50,51]. We then evaluated the effectiveness of PAs for conserving herpetofauna by calculating species richness, range coverage of species in and out of PAs, and the proportion of species with benchmark amounts of habitats (e.g., 15% or 30% of habitat) inside PAs under present and future climate conditions (under the assumption that future land use remains unchanged for the duration of this study). Our study aims to (1) evaluate the conservation effectiveness of existing PAs in protecting herpetofauna under current and future climate scenarios, and (2) identify conservation gaps to outline a roadmap for the development of conservation actions based on the current role of PAs at a global scale. We found that the current global network of PAs already plays an important role for the conservation of current amphibian and reptile global biodiversity, and will continue to do so under future climate change. However, many species still do not occur within existing PAs and over 70% of amphibian and reptile species have under 15% of their range occurring within PAs. The conservation gaps were mainly concentrated in tropical and subtropical moist broadleaf forests, and non-high-income countries.

Results

Species richness inside PAs

The overall performance of our ensemble SDMs is generally good for all analyzed species ($AUC = 0.95 \pm 0.03$, $TSS = 0.87 \pm 0.07$; Supplementary Data 2). In terms of species richness, over 93.1% of amphibians and 91.4% of reptiles currently have suitable habitats in PAs. Additionally, 90.8% of amphibians and 90.0% of reptiles are projected to still have suitable habitats in PAs by 2070 under the RCP 4.5 scenario (Fig. 1A; Supplementary Data 3 and 4), and ≥ 90.0% under the other three RCPs scenarios (Supplementary Fig. 2). Rarity weighted richness (RWR) is predicted to increase for both amphibian and reptile species under climate change (from 89.0 to 116.0 and 147.8 to 161.9, respectively; Fig. 1B); RWR also increases under the other three RCPs scenarios, except for reptiles, which decrease under RCP 2.6 (Supplementary Fig. 2). We observed similar patterns for small-range species and IUCN threatened species (Supplementary Figs. 3 and 4), as well as for specific continents (Supplementary Figs. 5-7). When all PAs are included (Class I to VI), over 97.1% of species have suitable habitats in PAs at present, and 96.5% of all species are predicted to have suitable habitat in PAs in the future. The RWR is also predicted to increase for both amphibian and reptile species under climate change (Supplementary Fig. 8). However, our models predict that 359 to 770