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Hot and bothered: Using trait-based approaches to assess climate change vulnerability in reptiles

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ABSTRACT

One-fifth of the world's reptiles are currently estimated as threatened with extinction, primarily due to the immediate threats of habitat loss and overexploitation. Climate change presents an emerging slow-acting threat. However, few IUCN Red List assessments for reptiles explicitly consider the potential role of climate change as a threat. Thus, climate change vulnerability assessments can complement existing Red List assessments and highlight further, emerging priorities for conservation action.

Here we present the first trait-based global climate change vulnerability assessment for reptiles to estimate the climate change vulnerability of a random representative sample of 1498 species of reptiles. We collected species-specific traits relating to three dimensions of climate change, sensitivity, low adaptability, and exposure, which we combined to assess overall vulnerability.

We found 80.5% of species highly sensitive to climate change, primarily due to habitat specialisation, while 48% had low adaptability and 58% had high exposure. Overall, 22% of species assessed were highly vulnerable to climate change. Hotspots of climate change vulnerability did not always overlap with hotspots of threatened species richness, with most of the vulnerable species found in northwestern South America, southwestern USA, Sri Lanka, the Himalayan Arc, Central Asia and southern India. Most families were found to be significantly more vulnerable to climate change than expected by chance.

Our findings build on previous work on reptile extinction risk to provide an overview of the risk posed to reptiles by climate change. Despite significant data gaps for a number of traits, we recommend that these findings are integrated into reassessments of species' extinction risk, to monitor both immediate and slow-acting threats to reptiles.

1. Introduction

Latest climate data show that the rate of global surface temperature warming since 1950 continues unabated, rising between 0.113 °C and 0.116 °C per decade (Karl et al., 2015). Impacts from climate change are expected to intensify, with global surface temperature increase likely to exceed 4 °C by 2100 if no mitigation measures are put in place (World Bank, 2014), presenting a major emerging threat to biodiversity (Dickinson et al., 2014; Pacifici et al., 2015). Climate change effects on species include changes to species' ranges, both altitudinal (e.g. Menendez et al., 2014) and latitudinal (e.g. Hill et al., 2002), habitat associations (e.g. Menendez and Gutierrez, 2004), life-history phenology (e.g. Pearce-Higgins et al., 2015), disease emergence (e.g. Sarmiento-Ramirez et al., 2014), and increased extinction risk (Carpenter et al., 2008; Dickinson et al., 2014).

Frameworks for assessing species' extinction risk, such as the IUCN Red List of Threatened Species (IUCN, 2015b), have been criticised for insufficiently incorporating emerging and often slow-acting climate change threats (Keith et al., 2014; Thomas et al., 2011). At present, the most commonly identified threats to species on the IUCN Red List are habitat loss, overexploitation and invasive species (IUCN, 2015b), while only 8% of the 67,000 species assessed under the current criteria system (IUCN, 2001) are recorded as threatened by climate change (IUCN, 2015b). The IUCN Red List Criteria effectively account for climate

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change in threatened species (Akcakaya et al., 2014; Pearson et al., 2014), although a number of factors may still prevent the adequate listing of climate change for threatened species: species may be perceived as susceptible to climate change, but may not yet be exposed to significant changes, or vice versa (Foden et al., 2013); assessors may approach climate change threats inconsistently due to uncertainties surrounding current projections of climate change and their effects on species (Keith et al., 2014; Westoby and Burgman, 2006); other threats, acting synergistically with climate change, may be more easily understood and recorded, thus underestimating the importance of climate change (Hof et al., 2011).

To complement existing frameworks, climate change-specific assessments were developed using a number of different approaches (Pacifici et al., 2015). With over a million terrestrial species potentially already 'committed to extinction' by the middle of the century due to climate change (Keith et al., 2014), climate change vulnerability assessments are of utmost importance to effectively quantify climate change threats, inform mitigation and adaptation policy and prevent adverse effects from climate change (Young et al., 2015).

Since considerable uncertainty exists surrounding climate change projections and their effects on species (Tuberville et al., 2015), assessing intrinsic biological traits which predispose species to climate change risk has more recently emerged as an alternative approach; these are collectively known as trait-based approaches. These approaches have been used to complement IUCN Red List extinction risk assessments, providing a supplementary analysis that can be used to inform overall species risk and identify additional conservation priorities (Foden et al., 2013).

Trait-based approaches collate data concerning different 'dimensions' of climate change vulnerability, typically including species' sensitivity, adaptability, and exposure to climate change (Foden et al., 2013; Pacifici et al., 2015; Still et al., 2015). Trait-based assessments often rank species vulnerability within the dataset, as many of the trait value thresholds used are arbitrary (Foden et al., 2013; Pacifici et al., 2015), and are most often expressed as "low" and "high" vulnerability (Carr et al., 2014; Foden et al., 2013). Comparisons between analyses are therefore difficult (Foden et al., 2013; Pacifici et al., 2015). Despite this shortcoming, trait-based approaches are becoming increasingly common in the scientific literature (Young et al., 2015), with recent assessments of a range of taxa including birds and amphibians (e.g.; Carr et al., 2014; Foden et al., 2013; Hagger et al., 2013), mammals (Dickinson et al., 2014), reptiles (e.g.; Carr et al., 2014; Hagger et al., 2013), insects (e.g.; Conti et al., 2014), plants (e.g.; Still et al., 2015), and corals (Foden et al., 2013). Trait-based approaches have been widely adopted by conservation planning agencies as a prioritization technique for climate change-affected species (Dawson et al., 2011; Pacifici et al., 2015; Williams et al., 2008); they can, however, still be constrained by limited data availability, especially for commonly incorporated traits such as dispersal capacity, for which few data exist beyond well-studied species (Foden et al., 2013; Pacifici et al., 2015). Although being referred to as 'trait-based', traits are often derived indirectly from species' ranges (e.g. climatic and environmental factors), rather than being based on species-specific data (e.g. from laboratory experiments on temperature or water requirements) which are generally sparse.

Of the currently 10,272 described reptile species (Uetz and Hošek, 2015), around one in five species is estimated to be threatened with extinction, based on a random sample of 1500 species (Böhm et al., 2013); climate change was only listed as a threat in 9% of threatened terrestrial reptiles compared to 17% of threatened freshwater and marine reptiles. However, the impacts of climate change on reptiles potentially affect all aspects of their life-history (Meiri et al., 2013). Most reptiles have specific microhabitat, temperature and moisture requirements for metabolism and reproduction; they are thus likely to be highly sensitive to climate change (Tuberville et al., 2015). Approximately 85% of reptiles are oviparous (Tinkle and Gibbons, 1977) and may be affected by increasing temperatures during development (Hawkes et al., 2009), potentially skewing the sex ratio for species with temperature-dependent sex determination, reducing hatching success, or shifting breeding season phenology (Hawkes et al., 2009; López-Luna et al., 2015). Other aspects of reptile life-history affected by climate change include altered behaviour patterns such as time spent foraging, basking, or resting (Bickford et al., 2010; Meiri et al., 2013), changes in the use of habitat and resources (Bickford et al., 2010; Scharf et al., 2014), disease (Sarmiento-Ramirez et al., 2014) and altered habitat structure which may also impact prey diversity and abundance (Whitfield et al., 2007).

Here, we use a trait-based approach (Foden et al., 2013; Carr et al., 2014) to estimate climate change vulnerability of a random representative sample of 1498 species of reptiles from 70 families, all of which have been previously assessed as part of the Sampled Red List Index (SRLI) for the IUCN Red List (Böhm et al., 2013). Specifically, we examine data availability for trait-based climate change vulnerability assessments, determine taxonomic and geographic variability of climate change vulnerability, and discuss how climate change vulnerability assessments complement what we have previously learned about conservation priorities from IUCN Red List assessments.

2. Methods

2.1. Species dataset

Our assessment was based on a sample of 1500 reptile species for which IUCN Red List assessments had previously been carried out as part of the Sampled Red List Index project (Böhm et al., 2013); for the current assessment, two species were no longer taxonomically valid, resulting in a final total of 1498 species for assessment. For the IUCN Red List assessment by Böhm et al. (2013), species had been randomly selected from the species list at the start of the assessment (Uetz and Hošek, 2015) following the approach in Baillie et al. (2008). A sample of this size was previously found to produce a broadly representative picture of extinction risk and trends over time (Baillie et al., 2008), and spatial patterns derived from such samples were found to be in broad agreement with spatial patterns derived from comprehensive assessments in both mammals and amphibians (B. Collen, unpublished data). Of the 1498 species in our assessment, 49 were listed as being threatened by climate change on the IUCN Red List (with 20 of these in the threatened categories Vulnerable, Endangered or Critically Endangered). All analyses and spatial data extractions were carried out in R version 3.1.2 (R Core Team, 2014), unless otherwise indicated.

2.2. Climate change vulnerability assessment

We closely followed the approach by Foden et al. (2013) and Carr et al. (2014) which assesses three dimensions of climate change vulnerability: sensitivity, poor adaptability and exposure (Foden et al., 2013; Fig. 1). Here, species which are both sensitive to climate change and have low adaptability are considered 'biologically susceptible' to climate change. Biologically susceptible species which are also highly exposed to climate change are referred to as 'climate change vulnerable' species (represented by the area where the three dimensions overlap; Fig. 1). We selected traits for three trait sets pertaining to sensitivity and two trait sets pertaining to low adaptability, identified as important factors affecting climate change vulnerability of species by Foden et al. (2013) and Carr et al. (2014) during expert workshops: 1. Specialised habitat and/or microhabitat requirements; 2. Narrow environmental tolerances or thresholds likely to be exceeded due to climate change; 3. Dependence on interspecific interactions likely to be disrupted by climate change; 4. Poor dispersal ability; 5. Low capacity to adapt in-situ through genetic micro-evolution. One of the trait groups assessed by Carr et al. (2014), dependence on environmental triggers likely to be disrupted by climate change, was not included in our analysis due to a lack of data for reptiles in the literature. Similarly, few data are available