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Comparison of climate vulnerability among desert herpetofauna

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ABSTRACT

Globally, biodiversity is declining, and a major driver of this decline is climate change; consequently, we need ways to evaluate the vulnerability of species to this change. We assessed 25 species of herpetofauna (7 amphibians and 18 reptiles) using multi-model averaging of NatureServe's Climate Change Vulnerability Index (CCVI), a qualitative trait-based vulnerability assessment tool. We calculated vulnerability across model runs varying type and extent of spatial data and climate model scenario. Amphibians were more vulnerable than reptiles. The most vulnerable species were those that were dependent on water for their habitat, high elevation species, and habitat specialists. For reptiles in particular, the projected downscaled extent of temperature change and change in moisture availability were also important in delineating vulnerability. Unfortunately, the invasive American Bullfrog was less vulnerable than any of the native amphibians, which highlights the importance of considering invasives when planning for climate change. Snakes that were riparian specialists also were ranked as highly vulnerable. Lizards were ranked as less vulnerable related to projected differences in the proportion of their range experiencing larger changes in temperature. We suggest improvements to the CCVI vulnerability index. For example, certain aspects of reptile biology that are critical to climate-related vulnerability are not included in the current generation of the Climate Change Vulnerability Index, specifically reproductive strategy and the difference in vulnerability between viviparous and oviparous species. Methods for assessing vulnerability will need continued refinement as we contend with climate change and other human-caused factors that are driving the biodiversity crisis.

1. Introduction

Globally, biodiversity is declining as a result of human activities including climate change and land use change (Butchart et al., 2010; Bellard et al., 2012). Over the next several decades, climate change is expected to surpass land use change as the greatest global threat to biodiversity (Leadley et al., 2010). Climate change is altering humans' influences on biodiversity by changing the conditions that organisms experience: altering access to food and other resources, changing interspecific relationships, and causing mismatches in physiological tolerances (Stenseth and Mysterud, 2002; Yang and Rudolf, 2010). Mitigation of climate change and adaptive management are expected to be the most effective methods to minimize biodiversity loss in rapidly changing environments. To effectively plan climate mitigation and adaptive management, we must understand (1) how species will be influenced by this change, (2) the relative vulnerability of species, and (3) what factors make certain species more vulnerable.

Desert regions across the world are changing faster than other nonpolar regions, experiencing increases in temperature and declines in precipitation (Kunkel et al., 2013; IPCC, 2013; IPCC, 2014). The southwestern United States, including portions the Chihuahuan, Sonoran, and Mojave Deserts, will experience significantly more extremely hot days (max > 35 °C) (Kunkel et al. 2013). In these areas, declines in water availability, including stream discharge, will lead to reduced humidity and declines in soil moisture (Komuscu et al., 1998; Seager et al., 2007; Ye and Grimm, 2013). These changes in climate are expected to occur faster than evolution and natural selection can respond in populations for at least some physiological tolerances

Abbreviations: CCVI, Climate Change Vulnerability Index; CMIP, Coupled Model Intercomparison Project; Herp, Herpetofauna (e.g. reptiles and amphibians); IPCC, Intergovernmental Panel on Climate Change; IUCN, International Union for the Conservation of Nature; RCP, Representative Concentration Pathways

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(Etterson and Shaw, 2001, Huey et al., 2003; Cayan et al., 2010; Stahlschmidt et al., 2011; IPCC, 2014).

These increases in temperature and declines in humidity and soil moisture are expected to have significant detrimental effects on desert herpetofauna (herps) (Inman et al., 2014; Hatten et al., 2016). To predict species' responses to climate change, researchers use vulnerability analyses, which combine species' sensitivity to stressors with their exposure to these pressures (Glick et al., 2011). There are three main categories of vulnerability analyses, (1) physiological models of vulnerability that include detailed information on energetics and physiological responses and can provide an estimate of extinction risk (e.g. Kearney et al., 2009; Sinervo et al., 2010), (2) species distribution models that calculate correlations between current species locations and conditions and use those relationships to predict species ranges under future conditions (e.g. Thomson et al., 2016; Hatten et al., 2016), and (3) qualitative models that allow a relative ranking of vulnerability and prioritization for conservation and management (e.g. Siegel et al., 2014; Young et al., 2015). Previous efforts have projected select herp sensitivity and vulnerability to climate change (e.g. Kearney et al. 2008, Sinervo et al., 2010, Thomson et al., 2016, Hatten et al., 2016), but up until now, we have not had a focus on a wide range of herpetofauna across the North American southwestern deserts or used qualitative vulnerability analyses to rank these species.

We present a series of vulnerability analyses for 25 species of desert amphibians and reptiles. Our goal is to assess relative vulnerability of species and species groups and to identify patterns in species' life histories that we should consider when planning management strategies for desert herp species. We chose to evaluate relatively common species because amphibians and reptiles as a group are likely to be vulnerable: they are ectothermic – sensitive to thermal and hydric changes – as well as being relatively poor dispersers. Management efforts are already focused on species in decline and species with small populations. Assessments of common species will give us a better understanding of how the group as a whole will fare as a result of changing climate and will provide a synthesis and information that is not already available. We chose to use a qualitative trait-based assessment framework, because it is more readily accessible and usable for managers when initiating planning strategies for species prioritization (Rowland et al., 2011).

2. Methods

We assessed the vulnerability of 25 species of herpetofauna using a qualitative, trait-based vulnerability assessment tool. Seven amphibian and 18 reptile species that are relatively common across the desert southwest of North America (Table 1) were selected based on expert opinion and consensus with the Desert Landscape Conservation Cooperative Reptile and Amphibian Working Group. We calculated vulnerability using the freely available Climate Change Vulnerability Index (CCVI) tool (version 3.0) from NatureServe (Young et al., 2012, 2016). Vulnerability scores are point estimates based on imprecise data; consequently, we chose to average vulnerability scores from four spatial scales and three climate scenario combinations.

Information on species' ecology, life history, location, and range data came from a variety of resources (Appendices 1 and 2, respectively). We used the species identification from the data sources. In some cases more recent taxonomic analysis has split the species into either subspecies or different species (e.g. *Phrynosoma hernandesi*; Montanucci, 2015). However, we stayed consistent with identifications provided by the spatial data sources as we would be unable to parse out the different species from these location records. Consequently we dealt with several groups as species complexes: *Phrynosoma* hernandesi (with *P. ornatissimus* in the desert ecoregion and *P. douglassii* complex at larger spatial scales), *Ambystom*a spp., and *Sceloporus* spp. The inputs for this qualitative vulnerability modeling technique do not include ways that would differentiate life histories between these similar species.

2.1. Spatial data

Spatial data is used in NatureServe's CCVI to calculate the exposure of a species to downscaled changes in temperature and moisture. Other aspects associated with spatial data, such as the size of the species' range, are not included in the analysis as it was created by NatureServe (Young et al., 2012). Spatial data was gathered from a variety of sources for the analyses (Appendix 2) and includes four types: range data clipped to the contiguous United States, range data clipped to the desert region of the United States, point data, and minimum convex polygons based on the point data. We did not include the Mexican portion of the range because we did not have access to the same detailed species' point locations. This may affect vulnerability scores because climate data is input into the model as the proportion of the species range experiencing a specific level of temperature increase or moisture decrease. However, because of the similar projected changes across the region, we do not expect there would be significant differences in overall vulnerability scores.

The first category of spatial data, range data retrieved from the International Union for the Conservation of Nature (IUCN), is based on expert opinion. We downloaded this range data from the Red List GIS unit (IUCN, 2016). Then to create two of the spatial scales assessed, we clipped the IUCN data, first to the US portion of the species' ranges, and second to the US desert ecoregion as provided by the Desert Landscape Conservation Cooperative.

The second category of spatial data included point locations and minimum convex polygons based on those points. We screened point data for accuracy, completeness, duplication, and time period. To ensure accuracy of species identification when downloading citizen science records, we only used corroborated records (e.g. research grade records in iNaturalist) (Appendix 2). We screened records for completeness, only including records that had a coordinate location, full species information, and a date of detection. We also screened records for duplicates making sure the same record was not supplied through more than one source, such as from both a state biologist and the repository for museum collections. Because we assessed the consequences of climate change, we only used spatial data back to 1975 to reduce the "noise" of climate change that had already occurred. After screening points, we created minimum convex polygons (MCP) by geospatially processing point locations using the Convex Hull setting of the Minimum Bounding Geometry tool in ArcGIS (ESRI, 2014). To align all spatial data with climate data grids, we used forced cell snapping and cell size environment settings from the climate scenarios map.

2.2. Climate data

Species' vulnerability to climate is a combination of a species' spatially explicit risk to changes in temperature and moisture and their sensitivity to the changes. We used climate data from the Coupled Model Intercomparison Project (CMIP) 5 for Representative Concentration Pathways (RCP) 2.6 – strict climate policy implementation, 6.0 – intermediate climate policy changes, and 8.5 – no policy changes (Meinshausen et al., 2011; van Vuuren et al., 2011). To calculate overall vulnerability using the NatureServe CCVI tool, we first calculated direct exposure to changes in temperature and moisture. These are included in the model as the proportion of the range experiencing the specific degree of change listed in tool-determined categories: for temperature, the proportion of range that will be > 3.3, 3.2 to 3.3, 2.8 to 3.1, 2.5 to 2.7, 2.2 to 2.4, and < 2.2 °C warmer by mid-century; for Hamon AET:PET Moisture Metric (measure of moisture deficit; Hamon, 1961), the proportion of the range that will experience < −0.119, −0.097 to −0.119, −0.074 to −0.096, −0.051 to −0.073, −0.028 to −0.050, and > 0.028 (Young et al., 2012). These data were then combined by the index with species-