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Direct modelling of limited migration improves projected distributions of Himalayan amphibians under climate change

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ABSTRACT

Amphibians are one of the most vulnerable taxa at risk of rapid decline under climate change. Here, we evaluated the impact of different migration constraints on projected future distributions of four high elevation frogs, belonging to the genus *Scutiger*, in the Eastern Himalaya. We explored differences between the output of conventional models assuming no or unlimited migration versus models considering plausible migration rates to ascertain future species distributions under climate change. Distributions of the four *Scutiger* species, namely *S. boulengeri*, *S. glandulatus*, *S. sikimmesis* and *S. tuberculatus*, based on field data and other sources were modelled using MaxEnt and projected for three future time periods (2021–2040; 2041–2060; 2061–2080) under the relatively ambitious RCP4.5 and the more pessimistic RCP8.5 climate change scenarios using three global circulation models. Projected species distributions were compared at different spatial resolutions (1 km, 5 km and 10 km) and for five assumptions about species migration: (1) no migration; (2–4) low, medium and high migration abilities using the KISSMig model; and (5) unlimited migration. Without migration, the projected future distribution of all four species showed a significant decrease of −15% to −64% by 2080. In contrast, three out of the four study species were projected to expand their distribution under unlimited migration scenarios. Models with more realistic migration rates, however, demonstrated considerable deviance from both no migration and unlimited migration scenarios. These results were consistent across models with different spatial resolutions. Our study shows that ignoring realistic migration constraints can lead to ineffective conservation measures by overestimating the future distribution of Himalayan amphibians. The proposed framework can be used to project more realistic ranges of future species distributions by considering the accessibility of future suitable areas, a key factor for species persistence under climate change.

1. Introduction

Global climate change is a major threat to biodiversity in many ecosystem types and is one of the main drivers in brewing a ‘perfect storm’ for the sixth mass extinction (Barnosky et al., 2011). There has been a remarkable increase in the global average temperature, by 0.85 °C from 1880 to 2012 (IPCC, 2013). By the end of this century it is expected to rise further, by a minimum of 0.3 °C to 1.7 °C and by a maximum of 2.6 °C to 4.8 °C (IPCC, 2013). Climate change is expected to cause the greatest change in biodiversity in high latitude/elevation ecosystems (Sala et al., 2000) and may surpass habitat loss as the primary threat to global biodiversity over the next decades (Leadley, 2010).

The Himalayan mountain chains are one of the largest geomorphological features of the world. They include three biodiversity hotspots and are home to a remarkably large number of species, including > 10,000 species of plants, 300 mammals, 977 birds, 176 reptiles and 105 amphibians, many of which are endemic (WWF, 2015). Temperature in the Himalaya is rising at twice the average rate of warming in the northern hemisphere (F. Chen et al., 2009). As a result, species in the Himalaya tend to undergo range shifts (Li et al., 2016), range expansion (Shrestha and Bawa, 2014) or range contraction (Telwala et al., 2013). The existence of large patches of climate refugia in the Himalaya sheltered its biodiversity during past glacial–interglacial cycles (Li et al., 2011). However, under the current combination of accelerating global warming and habitat fragmentation, many

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Himalayan species probably will not be able to keep pace with and adapt to the changing climate (Xu et al., 2009).

Amphibians belong to the most vulnerable taxa because of their low dispersal ability in the face of rapid ongoing climate change (Lawler et al., 2009; Warren et al., 2013) and they are rapidly declining worldwide (Bishop et al., 2012; Yiming and Cohen, 2013), with 41% of the described species falling under the threatened category (IUCN, 2016; Leung et al., 2017). Warren et al. (2013) suggested that without proper mitigation strategies about half of the amphibian species will lose more than half of their climatic range by the 2080s. A recent review of climate change research on amphibians and reptiles concluded that there is a severe geographical bias in the study of climate change effects on herpetofauna, with the highest percentage (70%) of publications coming from Europe and North America and the lowest percentage (5%) from Asia (Winter et al., 2016). Further, the authors reported a lack of studies related to climate change effects on herpetofauna between longitudes 26° and 136° E. The Himalaya, one of the world's most vulnerable regions to climate change, falls between these longitudes. In this context, there is a pressing need to better understand the effects of climate change on Himalayan amphibians.

One of the current approaches to quantifying the future distribution of species under climate change is the application of environmental niche models (ENMs). These models can provide information on the potential changes in species distributions (Thuiller et al., 2005), identify critical habitats and prioritize conservation areas (Heinrichs et al., 2010; DEPI, 2013), guide the management of invasive species (Jiménez-Valverde et al., 2011), help assess disease risk to biodiversity (Murray et al., 2011) or contribute to examinations of the efficacy of reserve systems (Araújo et al., 2004). However, under climate change one of the most implausible assumptions of conventional ENMs is that the species distribution is in equilibrium with climate, i.e., species will immediately react to the changing climate by shifting, expanding or contracting their ranges. This assumption is highly improbable, as it does not consider species' biotic responses and dispersal or migration constraints (Barve et al., 2011; Nobis and Normand, 2014), thus resulting in under- or overestimation of species distributions. Hence, the migrational ability of a species is a crucial factor for predicting its distribution under climate change. Most future ENM projections of species distributions still assume either unlimited or no migration, while the reality falls in between these two extremes (Pearson, 2006).

Nevertheless, there are methods available which enable species-specific dispersal and migration constraints in ENM projections. For instance, the MigClim model (Engler and Guisan, 2009) incorporates parameters such as species dispersal distance, barriers to dispersal and potential propagule production to obtain more realistic future species distributions compared with predictions from models that assume unlimited or no dispersal. To parameterize such models, a deep understanding of the ecology and life history of each single species is crucial. This information, however, is not available for most species, and dynamic models like MigClim that are built upon basic processes still assume a range of potential parametrization for their dispersal or demography components. In such cases, the KISSMig model (Nobis and Normand, 2014) is a useful alternative because it requires no assumptions about demography or dispersal/movement processes. Without simulating the underlying processes, KISSMig can be directly used for the evaluation of different migration rates, and it was proven successful in simulating species distributions under climate change scenarios (Nobis and Normand, 2014; Kissling et al., 2016).

To explore effects of climate change on the future distribution of amphibians in the Himalaya, we developed ENMs in combination with various migration scenarios for four species of high elevation frogs belonging to the genus *Scutiger*. This genus is found in high mountains and cold deserts across High Asia and is represented globally by 21 species (Hofmann et al., 2017). Nearly half of the species (43%) are in the threatened category (IUCN, 2016). We chose four *Scutiger* species as model systems based on (1) their varying range sizes and (2) the availability of sufficient and reliable occurrence records throughout their entire species range. The general aim of our study was to form a better understanding of varying migration constraints on the future distribution of high elevation amphibians under climate change.

In the current study, we set three major objectives:

a. To develop ENMs of four high elevation frogs with varying range sizes in the Himalaya for the current period and for three future periods under two contrasting climate change scenarios.
b. To use these models to simulate future species distributions without migration, with unlimited migration, and with three plausible migration scenarios to generate more realistic projections of future species distributions.
c. To assess the relevance of migration constraints and discuss implications for conservation of the four *Scutiger* species, as well as other high elevation amphibians in the Himalayan ecoregion.

2. Materials and methods

2.1. Current species ranges and choice of predictors

Our study species were four high elevation anurans belonging to the genus *Scutiger*, i.e., *S. boulengeri*, *S. tuberculatus*, *S. glandulatus* and *S. sikimmensis*. While *S. boulengeri* has a wide distribution in the Himalaya, the other three species have relatively narrow ranges (Fig. 1). *Scutiger boulengeri* is one of the frog species occurring at the highest elevations in the world; it is reported to be found up to 5490 m a.s.l. (Subba et al., 2015). We documented species occurrences during field surveys from 2013 to 2016 by recording GPS coordinates and elevation. The elevation of species occurrences in our records ranged from 2400 to 5500 m a.s.l. The species records were complemented by secondary data points from the Global Biodiversity Information Facility (GBIF, http://www.

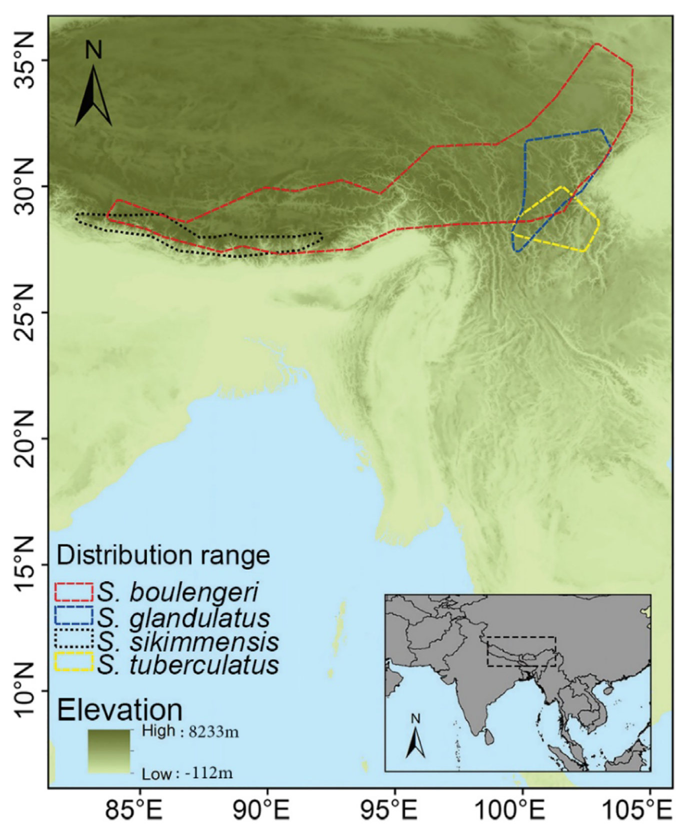

Fig. 1. Calculated species ranges of the four study species, *Scutiger boulengeri*, *S. glandulatus*, *S. sikimmensis* and *S. tuberculatus*. The map in the inset shows the location of the study area.