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Synergistic effects of climate and land-use change on representation of African bats in priority conservation areas

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ABSTRACT

Bats are considered important bioindicators and deliver key ecosystem services to humans. However, it is not clear how the individual and combined effects of climate change and land-use change will affect their conservation in the future. We used a spatial conservation prioritization framework to determine future shifts in the priority areas for the conservation of 169 bat species under projected climate and land-use change scenarios across Africa. Specifically, we modelled species distribution models under four different climate change scenarios at the 2050 horizon. We used land-use change scenarios within the spatial conservation prioritization framework to assess habitat quality in areas where bats may shift their distributions. Overall, bats' representation within already existing protected areas in Africa was low (~5% of their suitable habitat in protected areas which cover ~7% of Africa). Accounting for future land-use change resulted in the largest shift in spatial priority areas for conservation actions, and species representation within priority areas for conservation actions decreased by ~9%. A large proportion of spatial conservation priorities will shift from forested areas with little disturbance under present conditions to agricultural areas in the future. Planning land use to reduce impacts on bats in priority areas outside protected areas where bats will be shifting their ranges in the future is crucial to enhance their conservation and maintain the important ecosystem services they provide to humans.

1. Introduction

Current rates of species extinctions and declines are unprecedented (Butchart et al., 2010). Species extinction rates are now 1000 times higher than the 'background' rate (De Vos et al., 2014). Across vertebrates, 16–33% of species are considered to be globally threatened (Hoffmann et al., 2010). This biodiversity 'crisis' is driven by anthropogenic factors, such as overutilization of species, habitat destruction, pollution and the introduction of invasive species (Diamond, 1984). Human-induced climate change is also expected to affect species persistence into the future (Bellard et al., 2012). While the original cause of decline may be driven by one anthropogenic factor, extinction is often driven by multiple interacting pressures (Brook et al., 2008). Hence, more studies are urgently needed to unveil the combined effects of extinction drivers on biodiversity.

Spatial conservation prioritization deals with the identification of priority areas where limited resources should be allocated for conservation actions (Moilanen et al., 2009). An important goal of spatial conservation prioritization deals with the identification of areas where threats will impact biodiversity (Margules and Pressey 2000). However, conservation planning assessments often ignore the dynamic nature of threats (Moilanen et al., 2009). Particularly, conservation planners should anticipate the rates and patterns of dynamic threats, such as future climate change and land-use change (Krauss et al., 2010; Bellard et al., 2012). Quantitative scenarios can be used to evaluate the impact of future socio-economic

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development pathways on biodiversity and ecosystem services to optimize current conservation actions to reduce future biodiversity loss (Pereira et al., 2010).

Bats (Order Chiroptera) constitute about 23% of mammal diversity (Wilson and Reeder, 2005). Further, bats provide important ecosystem services such as predation of insects (Kalka et al., 2008), seed dispersal (Shilton et al., 1999) and pollination (Sazima et al., 1989). They are also important bioindicators (Jones et al., 2009; Mehra et al., 2011), as well as indicators of specific human impacts, such as the quality of water courses (Scott et al., 2010). Globally bats are under threat from anthropogenic activities, such as agricultural and urban expansion and over-utilisation of resources (Voigt and Kingston, 2016). Arguably, the highest threat to bats can be ascribed to widespread changes in land use systems predicted in the future (Hannah et al., 1995; Verburg et al., 2013), because these will impact bat fitness directly in terms of roost, food and water loss. At the same time, climate change will shift bats' ranges and likely drive species to local extinction (Rebelo et al., 2010). However, it is less clear how synergistic effects of climate and land use change will affect priority areas for the conservation of bats (Hughes et al., 2012).

Compared to other continents, African bats have been poorly monitored and knowledge of their distribution is still very scarce (Martin et al., 2013). More than 30% of African bat species are classified as threatened or data deficient (IUCN, 2014). Our goal was to identify the spatial priorities for the conservation of 169 bat species under expected climate and land use change across Africa. Our objectives were (i) to model bats' distributions under present and future climatic conditions; (ii) assess bats' representation inside already existing protected areas; and (iii) identify priorities for conservation actions outside protected areas under future climate and land use change.

2. Materials and methods

2.1. Biodiversity features

Recorded locations for 169 bat species (14,050 total records with the number of locations per species ranging from 5 to 604) of the approximately 250 species in Africa were used to model species distributions (SDMs) for the African continent (Appendix Table A.1, Appendix Fig. A.1). Because occurrence data were based on museum records, and we lacked absence data, we used MaxEnt to estimate the distribution for each bat species (Phillips et al., 2006). Among the many options for building SDMs from presence-only species records (Latimer et al., 2006; Thuiller et al., 2009; Renner and Warton, 2013), MaxEnt has good predictive performance (Elith et al., 2006; Radosavljevic and Anderson, 2014).

We downloaded 19 current climate variables from the World Clim for present climate and future climate in 2050 (Hijmans et al., 2005). We performed a principal components analysis on these variables to control for autocorrelation between variables (Garcia et al., 2012; Schoeman et al., 2013). Variables with the largest eigenvalues associated with the principal component axes were extracted ($n = 10$ variables), and compared using a correlation matrix. For pairs with $r > 0.8$, the variable with the higher eigenvalue was kept. Six variables were used in the SDMs: Temperature Seasonality, Minimum Temperature of Coldest Month, Mean Temperature of Warmest Quarter, Precipitation of Driest Quarter, Precipitation of Warmest Quarter, and Precipitation of Coldest Quarter. Future climate variables were derived from the Intergovernmental Panel on Climate Change (IPCC) AR5 scenarios RCP2.6 (Van Vuuren et al., 2007), RCP4.5 (Smith and Wigley, 2006; Clarke et al., 2007; Wise et al., 2009), RPC6.0 (Fujino et al., 2006; Hijioka et al., 2008) and RPC8.5 (Riahi et al., 2007).

SDM performance was evaluated with tenfold cross-validation, by partitioning data into two subsamples: one for calibration–validation and the other for evaluation (Hastie et al., 2005). The average distribution likelihood from 10 repetitions was used as an input for the spatial conservation prioritization (see below). The predictive value of the likelihood maps were calculated against the test data using the receiver operator curve (ROC) value, which produces an area under the curve (AUC) value (Appendix Table A.2). The AUC value indicates the discriminatory value of the models to predict the likelihood of a presence point being higher than the likelihood of a pseudo-absence point (Phillips et al., 2006). SDMs were run at 5 arc-minute resolution, which was also the resolution of the spatial conservation prioritization (see below) and suggested default settings for MaxEnt (Phillips and Dudík, 2008). We produced raster grids of the standard deviation for each species to be used in the prioritization analyses (Phillips et al., 2006).

2.2. Spatial conservation prioritization

We implemented spatial priority ranking with the Zonation (v4) methods and software (Moilanen et al., 2005; Lehtomäki and Moilanen, 2013; Di Minin et al., 2014; Moilanen et al., 2014) to identify the priority areas for the conservation of bats under future land use and climate change scenarios. As output, Zonation produces priority rank maps and corresponding performance curves, which describe how well represented each feature entered into the analysis is in any given top or bottom fraction of the priority map (landscape). The ranking balances all factors—including species distribution, connectivity, and possible costs—entered into the analysis. The additive-benefit function cell removal rule for aggregation of conservation value was used (see Moilanen et al., 2011). The additive-benefit function computes a maximum-utility type solution, where value is additive across biodiversity features, and where feature-specific representation is converted to value via concave power functions, which most commonly are parameterized according to the canonical species-area curve (Moilanen, 2007).

Appendix Fig. A.2 shows a flowchart of analysis and data inputs used in Zonation. In Zonation, weights assigned to features influence the balance among features in the prioritization solution. Typically, weights have positive values, but can also be set to 0.0 in surrogacy analyses (Di Minin and Moilanen, 2014), or even have negative values, for example when multiple opportunity costs are included in the analysis (Moilanen et al., 2011). In this study, species were weighted according to their current International Union for Conservation of Nature and Natural Resources (IUCN) Red List assessment: Least Concern (weight = 1), Near Threatened (weight = 2), Vulnerable (weight = 3) and Endangered (weight = 4) (Appendix Table A.1). As a precautionary measure, species that were Data Deficient were included with the same weight as vulnerable species in the analyses (Butchart et al., 2010).

To account for connectivity and the scale of landscape use of bat species, we induced aggregation by using distribution smoothing on species distribution grids (Moilanen et al., 2014). Distribution smoothing is a species-specific aggregation method that emphasizes areas that are well connected to others, thereby resulting in a prioritization with more compact priority areas (Moilanen et al., 2014). The smoothing effectively identifies important semi-continuous regions where the species has high levels of occurrence. In contrast, scattered occurrences in fragmented habitat lose relative priority. The connectivity of cells is determined with a smoothing kernel, where the radius of the kernel was approximated as the radius of the mean dispersal distances. In the analysis, we used the mean dispersal distances for three functional groups of bats (Schnitzler and Kalko, 2008) to calculate the parameter of a dispersal kernel for each species. Moilanen et al. (2014)