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Desert-adapted species are vulnerable to climate change: Insights from the warmest region on Earth

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ABSTRACT

Climate change is eroding biodiversity and conservation efforts have focused on species' potential responses to those changes. Biological traits associated with sensitivity and adaptive capacities may contribute in identifying a species vulnerability to climate change. Desert-living species could be particularly vulnerable to climate change as they may already live at their physiological limits. This work aims to identify functional groups in Sahara-Sahel endemics, to determine their spatial distribution and to evaluate how the predicted magnitude and velocity of climate change in the region might affect them. We collated biological traits data for all Sahara-Sahel endemics. We then summarized the functional strategy of each species into functional groups with different sensitivities and adaptive capacities to climate change. Future climate scenarios were reclassified to identify areas where predicted temperature and precipitation approach the physiological limits of each group. We calculated the velocity of temperature and precipitation change as the ratio of the temporal gradient to the spatial gradient. Specific magnitudes and velocities of environmental change threaten our seven function groups differently according to their level of exposure and geographical distributions. Groups are more exposed to precipitation than to temperature changes. The more exposed functional groups lived mostly in flat areas, where the predicted magnitude and velocities of change were also the highest. Some functional groups with high adaptive capacities (e.g. volant species) may be able to colonize distinct areas. Other groups with low sensitivity and adaptive capacity (e.g.: ectotherms with small home ranges) may be vulnerable to climate change. Different biological traits contributed to the extent to which climate change harms species. The desert-adapted species may be the most vulnerable ones. The vulnerability patterns of Sahara-Sahel functional groups provide indications of combinations of biological traits and biodiversity's exposure to climate change in other warm deserts of the world.

1. Introduction

Climate change is widely accepted as a major threat to biodiversity, with potential to accelerate the pace of its loss (Bellard et al., 2014). We need accurate forecasts of climate change effects on biodiversity to design the most proactive conservation strategies. Most current assessments of its potential impacts are focused either on changes in the geographical extent of

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species' climate space or changes in the exposure of areas to different dimensions of climate change. Yet, models focused on changes in the species' distribution fail to explicitly reflect the broad range of climate-induced stress affecting populations' ecology and species' physiology (Foden et al., 2013; Willis et al., 2015). Studies rarely appreciate the quantifications of areas exposed to the different dimensions of climate change in combination, despite their different implications for biodiversity (Garcia et al., 2014). For instance, decreasing local climate suitability (magnitude) may threaten species living close to their upper climatic tolerance limits, and high velocities of climate change may affect the ability of species to track suitable climatic conditions, particularly those with low dispersal abilities (Garcia et al., 2014). As such, climate change' assessments and identification of the most vulnerable species would profit from the incorporation of biological traits and combined analyse of the effects of different dimensions of climate change.

Rapidly changing climate will likely alter the selective pressures acting on species. Species vulnerability to these changes will yet depend on their level of exposure. That is, to what extent will their geographical environment space change their sensitivity, i.e. the lack of potential for a species to persist *in situ*. And how will it affect their adaptive capacity, i.e. the species' inability to avoid the harmful impacts of climate change through dispersal or micro-evolutionary change (Foden et al., 2013; Moritz and Agudo, 2013; Willis et al., 2015). Among other biological traits correlated with species extinction risk, those related with sensitivity include thermoregulation, activity, habitat specialisation, reproduction, and ecological plasticity. Those related with adaptive capacity include dispersal ability and body size (Brook et al., 2008; Kearney, 2013; Pincheira-Donoso et al., 2013; Bennie et al., 2014; McCain and King, 2014; Buckley et al., 2015). For instance, diurnal ectotherms may be particularly sensitive to temperature changes, as they regulate body temperature directly from external sources and simultaneously present low adaptive capacity due to relatively sedentary behaviour and small home ranges (Barrows, 2011). Increasing body size and activity time in mammals strongly relate to local extirpations, range contractions, and population declines (McCain and King, 2014). Beside species' evolutionary history (e.g.: its exposure to past climate fluctuations) and physiological plasticity or acclimation increase their resilience to environmental fluctuations; the magnitude of future climate change may outstrip species' sensitivity and adaptive capacity (Seebacher et al., 2014). Moreover, species living in flat areas are potentially more exposed to climate change as high change velocities are higher there (Loarie et al., 2009). For species to persist they will need to keep pace with the moving climate, and exhibit high adaptive capacities, such as dispersal (Walther et al., 2002; Massot et al., 2008). As such, the magnitude and velocity climate change will have fundamentally different impacts depending on the species sensitivity and adaptive capacities.

Deserts and arid regions harbour unexpectedly high diversity of species subject to a strong climatic control (Ward, 2009). Due to convergent evolution of biological traits and/or adaptive processes, desert species exhibit unique morphological, physiological and/or behavioural adaptations to climatic extremes (Murphy et al., 2012, 2013; Wilson and Pitts, 2012; Brito et al., 2014). Despite of this, they may be sensitive to increasing temperature, due to physiological limits constraining the evolution of species' tolerances to high temperatures (Araújo et al., 2013). Furthermore, in arid environments, changes in precipitation might have even more dramatic impacts on biodiversity in comparison to other ecosystems. Precipitation changes affects species as it promotes germination and food and water supply (Beatley, 1969; Pianka, 1970; Brown and Ernest, 2002). Moreover, in warming areas, rainfall fluctuations stimulate evaporation or soil warming, promoting aridity (Ward, 2009; Sherwood and Fu, 2014). Indeed, the impact of the progressive aridity conditions on arid adapted species have been already observed by negative population trends, extinctions and range shifts in the Sahara-Sahel (Trape, 2009; Brito et al., 2014). The region displays high topographical and climatic heterogeneity and has experienced recent and strong climatic oscillations (Wang et al., 2008; Claussen, 2009; Brito et al., 2014). Such fluctuations have greatly shaped land-cover and biodiversity distribution (Dumont, 1982; Le Houérou, 1992, 1997; Drake et al., 2011), suggesting that the predicted strong and fast climate changes for the region (IPCC, 2013; Loarie et al., 2009) will threat its biodiversity. Although, Sahara-Sahel endemics are arid-adapted species, they might be sensitive to temperature and precipitation changes, or have a capacity to handle to the predicted changes. Thus, we should identify the groups of species that combine biological traits related to vulnerability to different dimensions of climatic change. Their identification will allow designing future conservation plans for Sahara-Sahel biodiversity under climate change.

Our main goal is to identify the most vulnerable functional groups in the Sahara-Sahel under future climate changes, by addressing four questions: (i) which functional groups are more vulnerable to magnitude of climate change; (ii) which functional groups will likely be able to keep pace with predicted velocity of climate change; (iii) where are located the potentially most vulnerable areas? and (iv) how are the most vulnerable functional groups represented within the current protected areas network? We hypothesise that functional groups comprising diurnal ectotherms with low adaptive capacities (e.g.: small home range and body size) should be most vulnerable to changes in the magnitude and velocity of temperature while groups containing endotherms with low adaptive capacity (low dispersal ability) should be most vulnerable to changes in precipitation. Functional groups harbouring taxa simultaneously sensitive and with low adaptive capacity and living in flat areas are expected to be more vulnerable to the velocity of climate change. The identification of functional groups and their potential vulnerability to climate change are essential to design proactive conservation plans for Sahara-Sahel biodiversity.

2. Material and methods

Our study area covers a total of ≈11,200,000 km^2 and includes the Sahara (≈8,200,000 km^2) and Sahel (≈3,000,000 km^2), as defined by Olson et al. (2001) (Fig. 1). We have divided the study area into 4417 grid cells, using a grid of ∼54 km (∼0.5°) resolution projected to Africa Albers Equal Area Conic projection.