Journal of Arid Environments 109 (2014) 65–73

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Biogeographical analysis of the Atlantic Sahara reptiles: Environmental correlates of species distribution and vulnerability to climate change

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A R T I C L E I N F O

Article history:
Received 13 September 2013
Received in revised form
26 May 2014
Accepted 28 May 2014
Available online 18 June 2014

Keywords:
Biodiversity conservation
Biogeographic groups
Deserts
Ecological niche-based model
Mauritania
Parc National du Banc d'Arguin

A B S T R A C T

Habitat loss and climate change are eroding global biodiversity. Identification of environmental correlates between species richness and climate factors is essential to understand the main drivers of richness distribution and species potentially vulnerable to climate change. Deserts allow testing influences of climatic factors on biodiversity distribution given that anthropogenic habitat change is usually reduced. This study combines reptile presence data (1×1 km scale) with environmental factors to derive distribution models for individual species and richness. Relationships are tested in a coastal desert area of the Atlantic Sahara in Mauritania that covers a UNESCO World Heritage Site and National Park. Five environmental clusters were identified and two reptiles exhibited strong selection for the cluster of smallest area. Maximum entropy modelling identified one climatic and two habitat-related factors (temperature, sandy and bare areas) as main predictors of species occurrence. Consistent negative relationships observed between temperature and species distributions suggest that global warming may affect reptile richness. Despite lack of information on species abilities to face climate change, 14 reptile species should be targeted for population monitoring. Hotspots of reptile richness were identified within the Parc National du Banc d'Arguin but also in unprotected areas currently subjected to increasing human activities.

1. Introduction

Human-related factors, such as habitat loss and climate change, are eroding global biodiversity (Butchart et al., 2010). Although habitat loss is currently the most striking factor, empirical data have confirmed current effects of climate change on many species' biology (e.g. Parmesan, 2006; Thuiller, 2007). Predictions for the near future suggest dramatic changes in distributional patterns of biodiversity and increased threat to species presently not affected by habitat loss (Leadley et al., 2010; Matthews et al., 2011). Species ecological traits (e.g., life-history strategies, dispersal capabilities) and their relationships to environmental factors (e.g., physiological tolerance) play important roles in the distributional shifts as responses to climate change (Bellard et al., 2012; Parmesan, 2006; but see Moreno-Rueda et al., 2012). For instance, species with distribution limits tightly linked to temperature variation may be particularly vulnerable to global warming (Chen et al., 2011; Sinervo et al., 2010). As such, there is an urgent need to identify species vulnerable to climate change as well as species-rich areas where goals of representativeness and complementarity in the designation of protected-areas systems may be more easily attained (Araújo, 2002; Kati et al., 2004). The identification of environmental correlates for the distribution of individual species and richness is basal for developing such assessments and for establishing conservation priorities and population/habitat monitoring programmes.

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http://dx.doi.org/10.1016/j.jaridenv.2014.05.023
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The Sahara desert is an excellent area for identifying correlations between species distribution and environmental variation, given the climatic extremes present that generate sharp ecological gradients (Schulz et al., 2009). The region has been subjected to periodical and strong climate change events (Brito et al., 2014). Aridity processes are generally thought to have begun at approximately 7 Mya in Chad (Schuster et al., 2006) or even more recently, at around 6–2.5 Mya in western areas (Swezey, 2009). Since the Pliocene (5.3–2.5 Mya), the region has experienced multiple dry–wet cycles (Le Houérou, 1997). The latest humid period occurred at the Holocene, when the region was covered with extensive vegetation, lakes and wetlands (Gasse, 2000; Kröpelin et al., 2008), and ended at about 6–5000 yr ago, when aridity greatly increased, mesic vegetation communities gradually disappeared, and lake levels decreased (Foley et al., 2003; Holmes, 2008). More recently, episodic periods of extreme aridity have been documented, like the catastrophic droughts in the 1970's that reduced tree cover and animal populations, and caused the deaths of a quarter million people in the Sahel (Brooks, 2004; González et al., 2012). Given that anthropogenic habitat change is almost absent in the region (Ellis et al., 2010), there is the opportunity to test for the influence of climate factors on the distribution of biodiversity.

Geographical Information Systems (GIS) and Ecological Niche-based Models (ENM) are useful tools for identifying relationships between environmental variation and species occurrence and also to map the distribution of species richness patterns (e.g. Carvalho et al., 2010; de Pous et al., 2011). In African desert environments, both techniques have been used to model species distributions (e.g. Brito et al., 2009, 2011) and species richness (e.g. El-Ghani, 1998; Ficetola et al., 2013; Thuiller et al., 2006). However, the understanding of relationships between environmental factors and animal species richness is still lacking at local operative scales (i.e. 1 × 1 km). Most of the research performed so far has addressed regional to continental scales (e.g. 10′ Thuiller et al., 2006; 1° Ficetola et al., 2013). Combining fine scale distribution data with GIS and ENM allows for the inference of species vulnerability to climate change and the identification of areas in need of protection.

Reptiles are excellent models to analyse relationships between environment and distribution, especially under the climate change context. Their ectothermic physiology makes them highly dependent of some environmental factors, like thermal and habitat ones; whereas their usual low dispersal ability precludes tracking rapid environmental shifts as those predicted with climate change (Pough, 1980; Sinervo et al., 2010). Reptiles are recognised as one of the most endangered groups of vertebrates to climate change for which shifts in abundance and activity patterns, range fragmentation and elimination of suitable habitats have been predicted (Carvalho et al., 2010; Sinervo et al., 2010). However, some species may be more vulnerable than others to climate change when they: 1) lack enough genetic variation to adapt to new environmental conditions (e.g. tropical species); 2) are adapted to narrow environmental conditions or specific habitats (e.g. specialist species), and/or 3) inhabit areas predicted to be highly affected by climate change (Carvalho et al., 2010; Chown et al., 2010; Huey et al., 2012; Sinervo et al., 2010). The latter may be the case of reptiles living in West Africa, where predicted rise in of temperature is among the highest in the world, especially in desert environments (Hulme et al., 2001; IPCC, 2007; Loarie et al., 2009). Thus, relationships between reptile species distributions and climatic drivers in this region are in urgent need of estimation. The availability of high-resolution distribution data of reptiles in coastal Mauritania (Sow et al., 2014), combined with the existence of a UNESCO World Heritage Site, Ramsar Site, and National Park in the area (www.pnba.mr/pnba), constitute an excellent framework for assessing such relationships and prioritising conservation strategies in the context of climate change scenarios (Brito et al., 2014).

The main objectives of this study are to identify correlations between environmental factors and the distribution of reptiles, and to predict reptile species richness within a coastal desert area of the Atlantic Sahara. The specific questions are: 1) can distinct biogeographic groups of reptile species be identified based on environmental constraints? 2) Which climatic, topographical and habitat factors are most related to reptile distribution? 3) How is species richness related to the environmental variation? 4) Where are hotspots of reptile species richness spatially located? Results of this study are intended to increase knowledge on relationships between the distribution of reptiles and environmental variation at local scales, to identify reptiles potentially vulnerable to climate change in desert environments, and to contribute to local scale conservation planning of biodiversity in a World Heritage site.

2. Materials and methods

2.1. Study area and species observations

The study area is located in Mauritania (latitude from N18.0 to N21.34 and longitude from the coast line to W15.21), in an area comprising the Parc National du Banc d'Arguin (PNBA) and surrounding areas up to the border with Morocco (north), down to Nouakchott (south), and 100 km to the east from the PNBA limits (Fig. 1). The area is mostly flat (max. elevation 164 m) with a main rock outcrop located in the north-western area (Kerekchet et Teintâne). The arid and hot climate is influenced by both the Sahara and the Atlantic Ocean, with annual precipitation and annual average temperature ranging between 15 and 117 mm and 21.6 and 25.4 °C, respectively (Hijmans et al., 2005). The most representative land-cover categories are bare areas; consolidated bare areas (hardpans, gravels, bare rock, stones, boulders), and non-consolidated bare areas (sandy desert) (Bicheron et al., 2008). The northern region is mostly dominated by consolidated bare areas associated with the Chibkha alluvial floodplain, which is mostly dry and covered with sparsely distributed *Acacia* trees that often follow the river course. The central region is dominated by non-consolidated bare areas associated with the sand seas of erg Azeffâl and Akchâr, which are separated by the Khatt el 'Ogol alluvial floodplain. The southern region is dominated by the salt pan of Sebkha Te-n-Dghâmcha and associated plains and dunes (Fig. 1).

A total of 583 observations from 18 species (Table 1) were used to develop analyses (Sow et al., 2014). Analyses were not developed for three species present in the area (*Stenodactylus mauritanicus*, *Acanthodactylus boskianus*, and *Psammophis sibilans*) due to low sample size of observations. In the case of *Acanthodactylus dumerili* and *Acanthodactylus senegalensis*, species were lumped (*A. dumerili/senegalensis*) for the purposes of the present study as there are specimens with intermediate morphological traits present in the area (Crochet et al., 2003; Sow et al., 2014), suggesting that the systematics of the group remains unsolved. Observations were collected from the period between 1909 and 2011 (Sow et al., 2014): 69% were from after 2000 and 3% were from before 1990. For 484 observations, the geographic location was recorded with a Global Positioning System (GPS) on the WGS84 datum, whereas the remaining 99 observations were georeferenced using topographical maps to a precision of 1 km^2 (Sow et al., 2014).

2.2. Environmental factors

Environmental factors or ecogeographical variables (hereafter EGV) included one topographical grid (USGS, 2006) that was used to derive Slope, with the "Slope" function of Geographical