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Original research article

# A model-based framework for assessing the vulnerability of low dispersal vertebrates to landscape fragmentation under environmental change

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ABSTRACT

Environmental changes are driving rapid geographic shifts of suitable environmental conditions for species. These might survive by tracking those shifts, however successful responses will depend on the spatial distribution of suitable habitats (current and future) and on their connectivity. Most herptiles (i.e., amphibians and reptiles) have low dispersal abilities, and therefore herptiles are among the most vulnerable groups to environmental changes. Here we assessed the vulnerability of herptile species to future climate and land use changes in fragmented landscapes. We developed and tested a methodological approach combining the strengths of Species Distribution Models (SDMs) and of functional connectivity analysis. First, using SDMs we forecasted current and future distributions of potential suitable areas as well as range dynamics for four herptile species in Portugal. SDM forecasts for 2050 were obtained under two contrasting emission scenarios, translated into moderate (low-emissions scenario) or large (high-emissions scenario) changes in climate and land use conditions. Then, we calculated and analysed functional connectivity from areas projected to lose environmental suitability towards areas keeping suitable conditions. Landscape matrix resistance and barrier effects of the national motorway network were incorporated as the main sources of fragmentation. Potential suitable area was projected to decrease under future conditions for most test species, with the high-emissions scenario amplifying the losses or gains. Spatiotemporal patterns of connectivity between potentially suitable areas signalled the most important locations for maintaining linkages and migration corridors, as well as potential conflicts due to overlaps with the current motorway network. By integrating SDM projections with functional connectivity analysis, we were able to assess and map the vulnerability of distinct herptile species to isolation or extinction under environmental change scenarios. Our framework provides valuable information, with fairly low data requirements, for optimizing biodiversity management and mitigation efforts, aiming to reduce the complex and often synergistic negative impacts of multiple environmental change drivers. Implications for conservation planning and management are discussed from a global change adaptation perspective.



## 1. Introduction

Climate and land use changes are topics of scientific and political concern, especially when focusing on their potential impacts on biodiversity as well as on ecosystem processes and services upon which human well-being is closely dependent (Thomas et al., 2004; Thuiller et al., 2011). Climate change and habitat loss due to land use change are thus among the most important threats to terrestrial biodiversity (Jetz et al., 2007; Sala et al., 2000), fostering modifications of key ecosystem functions, and often the depletion of essential ecosystem services (Bellard et al., 2012). Habitat loss, degradation and fragmentation, well-known threats to global biodiversity (IUCN, 2014), have been shown to be more important than climate change at regional and

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local scales (Dirnböck et al., 2003). Moreover, their effects are likely to be intensified under climate change (Bellard et al., 2012; Brook et al., 2008). These synergistic interactions between climate, land use and other habitat changes pose constant challenges for species to cope with, and they can produce unexpected responses that might go undetected using conventional monitoring schemes, therefore raising the issue of timely adaption (e.g., migration) (Pullin et al., 2013).

Climate and land use changes are resulting in the geographic shifting of species' suitable conditions (Chen et al., 2011), to which only some organisms can adapt, either via phenotypic or ecological plasticity and/or evolutionary changes (Williams et al., 2008). When suitable conditions change rapidly many species may not have enough time to adapt locally, hence their survival will depend on their capacity to track suitable environmental conditions and habitats at novel locations (Pearson, 2006). Thereby, extinctions may occur if populations cannot migrate or adapt fast enough (Williams et al., 2008).

In this context, landscape fragmentation is a determinant factor of species survival by potentially decreasing the connectivity between source areas and other patches with suitable conditions for the species (Taylor et al., 1993). In fact, habitat connectivity is recognized as one of the most important factors for maintaining biological diversity (Hodgson et al., 2009; Taylor et al., 1993), because gene flow is essential for genetic fitness and adaptation to environmental changes (Hanski, 1998). To minimise the threats associated with fragmentation, landscape connectivity should be enhanced, for example, by protecting linkages between suitable areas (Fahrig and Merriam, 1994), and by building efficient ecological networks to facilitate the movement of species under future environmental conditions (Devictor et al., 2007). This may be particularly important in the context of climate change were enhancing connectivity has been defined as an important strategy (among others) for adaptation (Heller and Zavaleta, 2009).

Functional connectivity, i.e., the degree to which the landscape promotes or hinders movements among resource patches for a given species (Taylor et al., 1993), is a major determinant of processes such as dispersion or gene flow, and includes species-specific aspects and their interaction with landscape structures (Taylor et al., 2006). Functional connectivity is therefore essential to support many conservation decisions and actions (Luque et al., 2012). In contrast, structural connectivity refers to the landscape elements that are physically or spatially connected through, for example, corridors (Taylor et al., 1993), regardless of specific interactions. Developing methods to effectively identify common landscape linkages for multiple species with conservation concern is a major challenge in conservation and landscape ecology (Beier et al., 2011). However, creating a standard approach is challenging due to the plethora of methods for quantifying connectivity and to the distinct ecological requirements of the different species (Luque et al., 2012). Thus, managers often focus on improving the structural connectivity of the landscape (which it is not species-specific), for example by establishing connections among forest patches, assuming an ad hoc equivalence with functional connectivity (Ribeiro et al., 2011). Furthermore, connectivity can be increased by conserving or restoring the habitat lying between current and future suitable areas for selected species (Akçakaya et al., 2007). Such an approach can reduce local extinctions by facilitating the 'rescue effect' of colonization, and also increase the rate of re-colonization after a local extinction (Rudnick et al., 2010).

This study aimed to incorporate the effects of functional landscape connectivity in predictions of species' responses to climate and land use changes in order to improve the design of ecological networks by identifying potential barriers to species movement; and, to prioritize areas for monitoring the responses of vulnerable species. For illustration purposes we selected reptiles and amphibians as they are among those groups potentially more affected by ongoing and future environmental changes due to their low dispersal capacity (Blaustein et al., 2001; Gibbons et al., 2000). Using Species Distribution Models, we assessed whether the extent of potential suitable habitat is projected to increase or decrease under future environmental conditions. For each test species, we analysed functional connectivity from areas projected to lose environmental suitability to areas expected to maintain suitable environmental conditions by including species-specific landscape resistance effects. This approach also allowed the identification and evaluation of multiple least-cost paths (Pinto and Keitt, 2009) potentially establishing dispersal corridors under climate and land use changes in mainland Portugal. Finally, by forecasting how multiple environmental changes may affect the distribution of species under future conditions, our approach also allowed assessing species vulnerability to regional extinction and/or isolation. We concluded by discussing the value of our framework to inform authorities and managers about upcoming conservation priorities and mitigation actions, and to guide the set-up of efficient monitoring schemes to track biodiversity responses to multiple (and interacting) environmental change processes.

## 2. Methods

### 2.1. Analytical framework

The analytical approach (Fig. 1) encompassed three main steps. In the first step, we obtained spatial predictions on the distribution of current and future suitable areas using Species Distribution Models (SDM). In the second step, we combined current and future projections to obtain maps of species distribution dynamics informing about potential range shifts and changes in the distribution of suitable areas under future scenarios of climate and land use change. Finally, in the third step, we evaluated connectivity from areas projected to lose environmental suitability to areas projected to maintain suitable conditions. Connectivity analyses emphasized the assessment of potential barrier effects induced by the Portuguese motorway network.

### 2.2. Study area

The study area comprises mainland Portugal, southwest Europe, with an area of approximately 89100 km$^2$. Elevation ranges from 0 to 1993 meters a.s.l. with the mountain areas occurring mainly in the northern half of the territory. The climate ranges from temperate Atlantic in the northwest to dry Mediterranean in the southernmost areas (for more details see Supplementary material—Appendix S1).

### 2.3. Test species and distribution data

The test species were two amphibian and two reptile species occurring in the study area. Due to their biological characteristics, these two groups of vertebrates are very sensitive to environmental changes, particularly climate change (Araújo et al., 2006) and also, to fragmentation and degradation of habitats by action of human activities (Bennett and Saunders, 2010). In addition, with few exceptions, herptiles have poor dispersal ability (Blaustein et al., 2001), therefore their capacity to move to new suitable habitats is limited in comparison to endotherms. Moreover, during their migration events herptiles are very sensitive to unsuitable conditions being more exposed to predation, desiccation and human barriers. Specifically, large roads have been identified as major barriers for amphibians and reptiles with profound negative impacts on dispersal (Andrews et al., 2008).

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