Predicting the Impacts of Climate Change on Protected Areas: A Case Study of Land Snails in Madeira Island

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Abstract

Global climate is constantly changing, and such changes have irreversible impacts on the fauna and flora at all scales. Some progress has been made in order to properly understand the impact of climate on some vulnerable *taxa*; and species distribution models coupled with GIS and climate change scenarios have become crucial to understanding the relations between species distribution and environmental conditions, identifying threats and determining biodiversity vulnerability.

With the use of predictive models, important changes in the species' suitable areas were obtained. Laurel forest land snails, which are highly dependent on precipitation and relative humidity, may face major losses of their future suitable areas, leading to the possible extinction of several endangered species. Despite the complexity of the biological systems, the intrinsic uncertainty of species distribution models, and the lack of information about land snails' functional traits, this analysis contributed to a pioneer study on the impacts of climate change on endemic species of Madeira Island. The future inclusion of predictions of the effect of climate change on species distribution as part of International Union for Conservation of Nature (IUCN) assessments could contribute to species prioritizing, promoting specific management actions and maximizing conservation investment.

1 Introduction

Climate change is emerging as one of the major threats to natural communities of the world's ecosystems. Mid-range climate change scenarios projected for the next decades (IPCC 2007) will create new challenges for biodiversity conservation (HELLER & ZAVALETA 2009), and might increase recent human-caused extinction rates. Changes in climate have already provoked responses at all levels from individuals and species, through to changes in community structure and composition.

Natural reserves located in higher latitudes and altitudes, coastal and oceanic islands, and protected areas surrounded by unsuitable anthropogenic habitats are at high risk, simply because there is no scope for the habitats and the species they contain to move in response to changes in the climate system (SALA et al. 2000). Biodiversity hotspots, such as the Madeiran archipelago, with high densities of endemic species, which have small range sizes, may be particularly vulnerable to climate change (RAXWORTHY et al. 2008). With the

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species' shift due to their adaptation to new environmental variables, existing natural reserves and protected areas will no longer accommodate all designated species (ARAÚJO et al. 2004, 2011, HELLER & ZAVALETA 2009), especially where surrounding areas are unavailable due to human exploitation. Successful mitigation of the impact of climate change on biodiversity will depend on our protection strategies (HANNAH et al. 2002). These require a widening of the temporal and spatial perspective in which such strategies are conceived. Climate change scenarios must be factored into such plans (PETERS & DARLING 1985, FERRIER & GUISAN 2006), and additionally require a better understanding of the species' responses to climate change (physiological, behavioural, and demographic) (PETERS & DARLING 1985, SEKERCIOGLU et al. 2007). The creation of buffer zones to increase connectivity among protected areas, and to provide space for adaptive shift (HUGHES et al. 2003, CHAMBERS et al. 2005, MILLAR et al. 2007) is one of the main recommendations for climate change adaptation strategies for biodiversity. This in turn requires increased coordination among all stakeholders in the region (ARAÚJO et al. 2004, HELLER & ZAVALETA 2009).

Despite the fact that biodiversity policy of the European Union is considered as one of the more advanced and effective intergovernmental nature conservation instruments, the ambitious target of halting biodiversity loss by 2010 has not been met (EU, 2010). With a new perspective, the new targets for the year 2020, the European Union identified climate change as one of the key challenges for biodiversity conservation in the near future. Climate change threatens biodiversity both directly, through spatial and temporal changes in climate suitability and resource availability, and indirectly, through mitigation and adaptation responses in other policy sectors.

1.1 Species Distribution Models for Conservation Planning

The effective conservation of biodiversity depends on a very specific set of skills related to the analysis of the distribution of species (ARAÚJO & WILLIAMS 2000), and the identification and understanding of the underlying causes of their trends (TEIXEIRA 2009). In this context, predictive models of species distribution, coupled with the use of GIS and climate change scenarios, have become crucial to identifying threats, and to informing actions to limit loss (DANGERMOND & ARTZ, 2010). They have been developed and debated by many researchers (e.g. PETERS & DARLING 1985, HUANG et al. 1998, DA FONSECA et al. 2005, GUISAN & THUILLER 2005, FERRIER & GUISAN 2006, ELITH & LEATHWICK 2009, HELLER & ZAVALETA 2009).

Several approaches have been used to assess the impact of climate change on species diversity and community composition (ARAÚJO et al. 2006). Species distribution models (SDMs) are based on the statistical relationship between records of species' current distribution and their associated environmental variables. The mutual analysis allows the estimation of the probability of species' occurrence in a particular location, and permits the delimitation of potential distribution areas in unsampled locations (HIJMANS & GRAHAM 2006, FRANKLIN 2009). Assuming that species' responses to particular environmental variables remain unchanged, these statistical tools can also be used to relate present day distributions with current environmental conditions, and then use future potential climate conditions to predict future species distributions (Pearson & Dawson 2003).

Because large presence/absence data sets are frequently unavailable and unreliable, a number of recent analyses have used presence-only data (e.g. museum collections; ELITH et al. 2011), producing large extent and fine-resolution maps that summarize many of the interactions between species and their environment (BELLAMY et al. 2013). One of the most popular techniques and best predictive tools for modelling species, based on presence-only data, is the algorithm of maximum entropy, available in MaxEnt software (PHILLIPS et al. 2006, PHILLIPS & DUDIK 2008). Launched in 2004, this software has been widely used by a broad panel of researchers, enabling the establishment of correlations between the occurrence of species, mapping and predicting their future distributions under hypothetical climate scenarios (PHILLIPS et al. 2006, YATES et al. 2010).

Despite some difficulties associated with this approach (WEBSTER et al. 2002), such as the disregard of inter-specific interactions and the residual spatial autocorrelation in data, sampling bias, and inadequate testing with independent data, these models are able to make reasonable predictions about the consequences of climate change (ARAÚJO et al. 2005a), and they can be used with very simple location data. They can be applied to large numbers of species in the same region. They can therefore be applied to assess potential changes in regions where data are not extensive, but environments are diverse. They form the basis of the analytical procedures used in this study, which intends to conduct a preliminary analysis on the use of predictive models and GIS to inform the climatic tolerance of species and their possible responses to future climatic change. This analysis will evaluate the predicted trends of various native species of terrestrial molluscs facing a changing climate scenario for Madeira Island.

2 Methodology

The Madeira archipelago is located in the Atlantic Ocean, approximately 1000 km from Sagres, on the Portuguese coast, and 500 km from Africa, between 32º24’ and 33º07’ north and 16º16’ and 17º16’ west. It is composed of three main groups of islands: Madeira, Porto Santo, and the Desertas, occupying a total area of 740 km^2.

On the island of Madeira itself, 75% of the island is subject to some degree of legal protection; and seven *Special Areas of Conservation* (SAC) and two *Special Protection Areas* (SPA) are designated within the Natura 2000 framework. The study area was restricted to the Laurel forest (*SPA/SAC Laurissilva da Madeira*) and central peaks of Madeira Island (*SAC Maciço Montanhoso Central*; see figure 1). These protected areas contain the most humid and highest habitats, which are expected to show the greatest changes under the anticipated climate change. It is also assumed that a significant number of endemic terrestrial snails survive in these areas.

Thirty-six *taxa* of endemic snails are recorded exclusively in the target areas. Their distribution data were collected from Madeira’s Biodiversity Database (BIOBASE), and the species’ distribution records, referenced to the UTM grid of 500x500 m, were exported. In order to complement the information about the distribution and current conservation status of Madeira’s land snails, the first stage of this work comprised the identification and sampling of 15 sites (squares of 30x30m) in Laurel forest and alpine habitats.

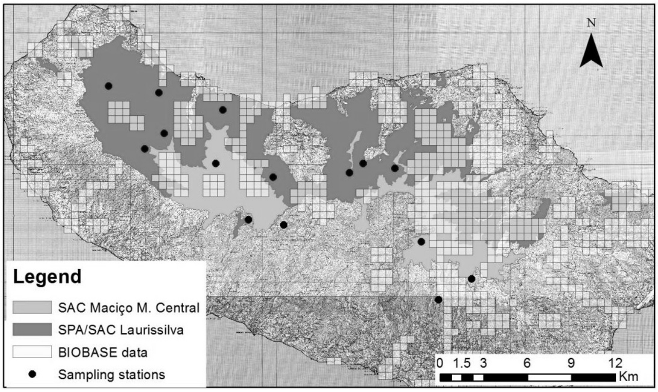

Fig. 1:
Data distribution and sampling stations within the study area

To model the species' distributions under present and expected future climate, climate data was produced within the project CLIMAAT II (SANTOS & AGUIAR 2006). CLIMAAT data were produced based on IPCC Special Report Emission Scenarios, using the A2 and B2 greenhouse gas concentration scenarios, and climate scenarios for 1961-1990 (control period), 2040-2069, and 2070-2099 were produced. Ten bioclimatic/geographic variables were selected in a first step, in order to represent biologically meaningful measures for characterizing species distributions: annual mean, maximum, and minimum temperature, precipitation, relative humidity, and altimetry. Correlation between variables was analysed using ENM Tools (www.ENMTools.com; WARREN et al. 2010), and annual maximum temperature, annual minimum precipitation, and annual minimum relative humidity were the selected variables to run the model for each period.

Future projections regarding land use changes are missing for the Madeira archipelago. In order to add some information on habitat future changes, we used data regarding vegetation and edaphic variables, such as soil type, slope, and geology. To identify the species' current potential distribution areas, and predict changes in species distributions as a result of climate and habitat change, MaxEnt version 3.3.3k was used (see PHILLIPS et al. 2004, 2006, freely available under https://www.cs.princeton.edu/~schapire/maxent/). This machine learning method is based on the maximum entropy algorithm for predicting species distribution models, when only presence data are available (MaxEnt has achieved good results in the determination of current potential distribution areas in Madeiran malacofauna (see TEIXEIRA 2009)). For each species, models were run using the default settings, which were adjusted to perform well across a multiplicity of organisms and regions (PHILLIPS & DUDIK 2008), except for the iterations set for 1000. To evaluate model performance, metrics of model fit are required (LIU et al. 2011). The area under the receiver-operator curve (AUC) was broadly used for model evaluation, and is part of MaxEnt output. Modelling outputs were exported in ASCII file, as a continuous prediction of site suitability for each species, ranging from 0 to 1. Grid cells with values closer to 1 correspond to higher site suitability for species distribution (PHILLIPS et al. 2006). Although continuous site or habitat suitability maps express more information (VAUGHAN & ORMEROD 2005), binary output maps, using a probability threshold for conversion to presence/absence have been used in a wide range of studies, such as biodiversity assessments, protected areas identification, and climate change impact assessments (REBELO & JONES 2010). According to recent studies on threshold selection with presence-only data (LIU et al. 2013), Max SSS (which is based on maximizing the sum of sensitivity and specificity) produces higher sensitivity in most cases, and higher true skill statistic (TSS). This criterion was used in producing the binary maps.

As there are no estimates of climate change impacts on land use or vegetation for Madeira, we first had to model the future distribution of the different habitat types, assuming that they currently occupy their entire historical climatic range, to model the species' current potential distribution areas and predict changes in species distributions as a result of both climate and habitat change. A new analysis was conducted in order to evaluate changes in species distribution under both climate and habitat/vegetation type change scenarios. In addition to climate (annual maximum temperature, annual minimum precipitation and annual minimum relative humidity) and habitat (natural forest, natural shrub areas and natural herbaceous vegetation: classes of vegetation extracted from COSRAM (Occupation Soil Map of the Autonomous Region of Madeira)), geographical variables (latitude and longitude) were added to the model, so that the orography of the region with consistent barriers to dispersal were taken into account. In fact, complex orography was previously found critical for the distribution of snails (TEIXEIRA 2009) and other *taxa* such as beetles (BOIEIRO et al. 2013). A simplified diagram of the methodology can be found in the following flowchart (see figure 2).

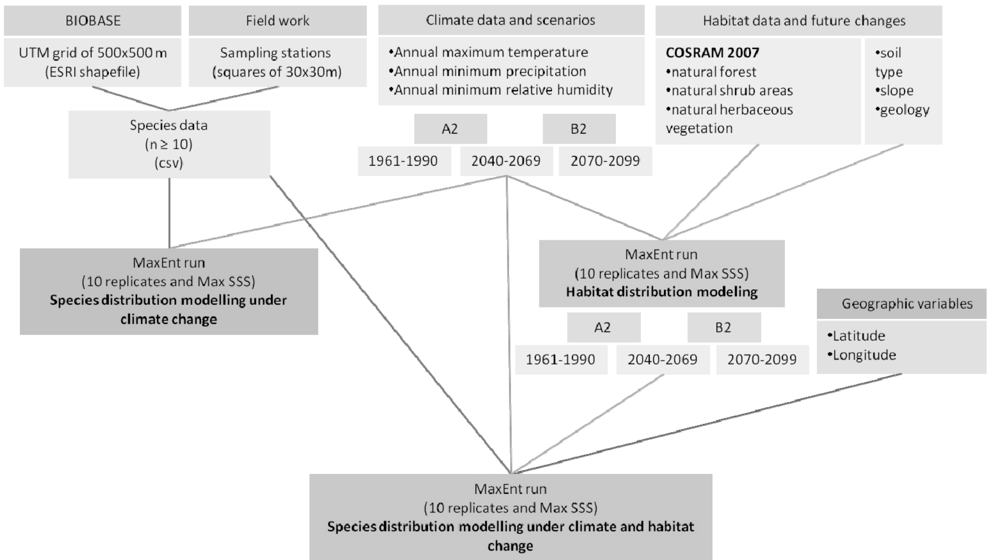

Fig. 2: Flowchart of modelling methodology

3 Results

Two datasets were modelled for 31 endemic land snails: a) under current and future climate scenarios (A2 and B2 scenarios); and b) under current and future climate scenarios and changes in vegetation, further considering the current geographical boundaries. Five species were excluded from the analysis, due to a low number of records (n≤10), resulting in the probable unreliability of the considered models.

The majority of the models (53.23%) were considered very good (AUC > 0.90), and the remaining 46.77% were classified as good (0.70 < AUC < 0.90). The importance of climatic/habitat/geographical variables was evaluated by jackknife analysis from MaxEnt outputs (test of variable importance). When considering climatic variables only, all three variables were the main delimiters of the envelope for roughly the same number of species. The second analysis, including vegetation changes and geographical variables, suggests a different pattern, with longitude and the existence of natural forest representing the most important features in species distribution for most species. In this case, climatic variables seem to be less important than habitat and spatial variables.

Important changes in distribution emerged for both scenarios (A2 and B2), and the model projects a multiplicity of potential responses to climate and habitat change, ranging from the loss of suitable areas, to a significant increase of areas with appropriate climate conditions (see figure 3).

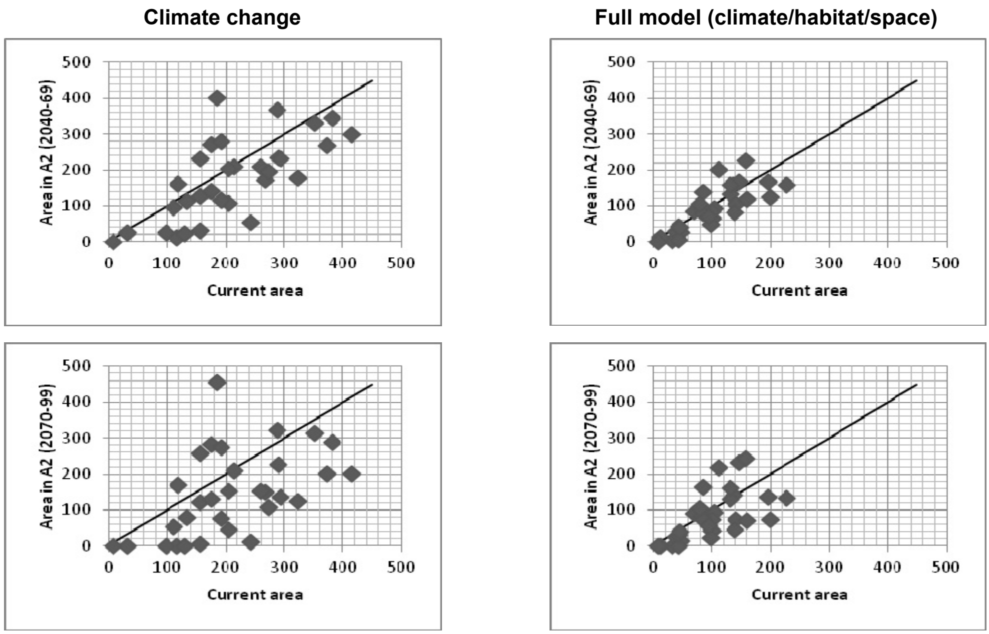

Fig. 3: Changes in habitat area (number of grids cells) between present and future (A2 scenario, and periods 2040-69 and 2070-99). On the left side, models under climate change are presented; on the right, models under climate and vegetation change. Each dot represents a species. The diagonal lines represent a hypothetical situation of no change, where present and future areas are similar. Dots above and below the line represent species where an increase or decrease in area is expected, respectively.

Within Madeira Island, species with narrow distributions, such as *Actinella armitageana,* may be more affected by climate change than more widespread *taxa*, as a result of habitat reduction and the nonexistence of suitable habitat elsewhere on the island. For example, both the climate and habitat model identified suitable areas for *A. armitageana* in the surroundings of the known current distribution, and in the western plateau of the island at lower altitudes; however, predictions under A2 and B2 scenarios indicate a considerable reduction of species range, up to 100% (A2 scenario; see figure 4). Although our full model has identified suitable areas for the species distribution at lower altitudes, future predictions indicate a notable decrease in species range (with the possible extinction of both scenarios).

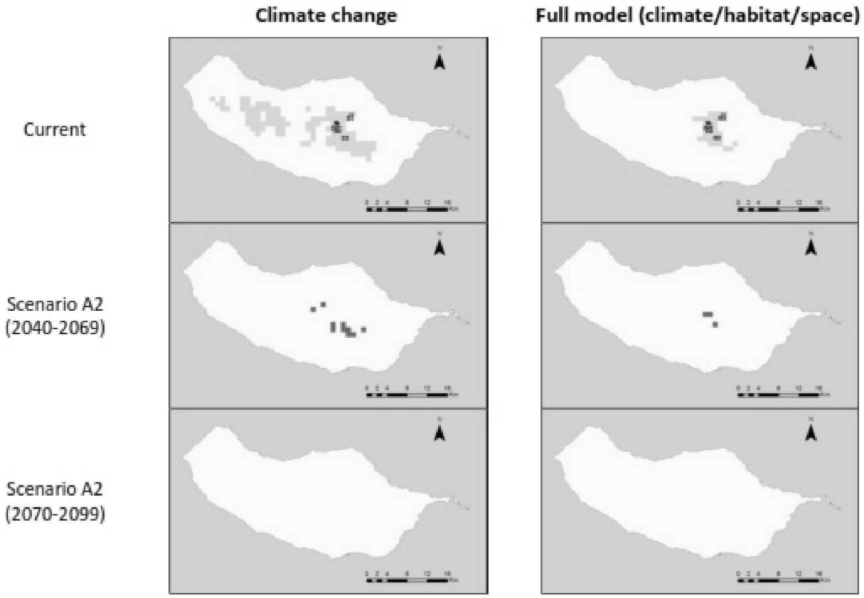

Fig. 4: Predictive distribution maps for *Actinella armitageana*. In the first row, black points represent occurrence data, and green patches correspond to the predicted distribution in the present. The following rows present the modelled distribution of the species under future climatic and habitat change for the A2 scenario.

In both sets of models, there is a great variability among species to projected climate or climate/habitat change. And it is worth mentioning that, for both low and high emissions scenarios, some endangered species (listed by the International Union for Conservation of Nature) may lose all suitable area by the end of the century. The reduction of potential distribution area, especially for slow-moving animals with poor dispersal capacity, arises as a big conservation problem, as natural barriers to dispersal may hamper the colonization of new places in relatively short time-frames.

4 Conclusion and Outlook

Conservation efforts and biodiversity monitoring are required to assess the real impacts of climate changes on terrestrial molluscs. The maximum entropy model identified potential distribution areas for thirty-one species, and was able to project future suitable areas for endemic and threatened land snail species of Madeira Island. Species distribution models, which are widely used in monitoring and conservation policies, can be used to evaluate the potential impacts of climate change in species' range size, community patterns, and representation within protected areas. The use of SDMs in the determination of species' suitable areas has limitations, and the outputs should be interpreted carefully. According to our results, species' suitable areas might shift under climate and habitat change, in every analysed IPCC scenario; and, with all the inherently associated errors, our model suggests that a significant percentage of species is predicted to decrease their suitable areas by the end of the century. Nonetheless, it is important to note that many other variables might influence land snails' distribution, such as vegetation, land use, dispersion barriers, and perturbation variables. The low dispersal ability, the orography of Madeira's landscape, the presence of exotic vegetation and disturbed areas, and also internal population dynamics will certainly limit terrestrial mollusc turnover to favourable areas.

The successful mitigation of the impact of climate change on biodiversity depends on a very specific set of tools related to the analysis of the distribution of species. Many measures have been suggested in order to identify and understand the underlying causes of climate impacts, and its influence on species trends. Predictive models of species distribution coupled with the use of GIS and climate change scenarios have become crucial to identify threats and determine biodiversity vulnerability, resulting in an "Adaptive management" framework, contributing to species conservation and definition of management strategies.

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