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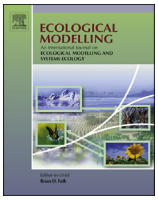

Effects of alternative sets of climatic predictors on species distribution models and associated estimates of extinction risk: A test with plants in an arid environment

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ABSTRACT

The effects of using alternative sets of climatic predictor variables on the performance, spatial predictions and future projections of species distribution models (SDMs) and its consequences on extinction risk estimates have remained insufficiently studied.

Here, we modelled the present and future potential distributions of 13 species of *Heliotropium* sect. *Cochranea*, a plant group with a centre of diversity in the Atacama Desert. We developed and applied a sequential procedure, starting from climate monthly variables, to derive six alternative sets of climatic predictor variables. We used them to fit models with eight modelling techniques within an ensemble forecasting framework, and derived climate change projections for each of them. We evaluated the effects of using these alternative sets of predictor variables on performance, spatial predictions and projections of SDMs using Generalised Linear Mixed Models (GLMM). Our Results show that the use of different sets of climatic predictor variables did not have a significant effect on overall metrics of model performance, but had significant effects on present and future spatial predictions and extinction risk estimates. This form of uncertainty in model-based estimates of extinction risk may need to be better acknowledged and quantified in future SDM studies.

1. Introduction

The identification of the important climatic factors involved in controlling the present distribution of plant species is a key step in assessing extinction risks and making predictions about the potential effects of climate change on species distributions (Guisan and Thuiller, 2005). Species distribution models (SDMs, Guisan and Thuiller, 2005; Franklin, 2009; Peterson et al., 2011) represent an important class of tools in this regard, by allowing to quantify species-environment relationships and using these to predict spatial distributions. As a result, SDMs have been and are still used massively to derive climate change projections of species distributions (e.g., Engler et al., 2011; Thuiller et al., 2011). However, by being correlative, SDMs cannot formally be used to identify causal species-environmental relationships; they can only provide supporting evidence for pre-established hypotheses on factors controlling species distributions (Austin, 2007; Araújo and Townsend Peterson, 2012). How, then, can we provide guidelines on which climatic factors should be preferentially used to build models, predictions and future projections?

As a first approach, Austin (2007) suggested that previous knowledge about the physiological responses of plants to their environments and general ecological theory (e.g., the law of the minimum) should be used a priori to identify suitable environmental variables for modelling species distributions (from recent past to present). SDMs can then be used to quantify the respective importance of pre-selected environmental factors, or sets of factors, in influencing the distribution of plant species. For instance, a recent study has shown that the use of monthly variables rather than annual means or totals, and the inclusion of variables capturing environmental variations (e.g., extremes), improved SDM

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predictions of tree species (Zimmermann et al., 2009). More generally, Araújo and Guisan (2006), Austin and Van Niel (2011a) and Peterson et al. (2011), in their reviews, identified the selection of environmental predictors as one of the major challenges in SDM research, and recent studies have shown that the selection of predictor variables can significantly affect the performance of and predictions from SDMs (Dormann et al., 2008; Peterson and Nakazawa, 2008; Syphard and Franklin, 2009; Ashcroft et al., 2011; Austin and Van Niel, 2011b; Synes and Osborne, 2011; Triviño et al., 2011; Watling et al., 2012; Williams et al., 2012; Braunisch et al., 2013; Sheppard, 2013).

In practice, however, the choice of predictor variables to be used is often limited by both the availability of information and the scale at which phenomena are studied (Austin and Van Niel, 2011a). Furthermore, it remains difficult to determine a priori which specific variables primarily influence the distribution of a species, unless there is deep knowledge of its ecophysiology. One easy solution would be to include as many variables as are available. However, the inclusion of too many variables in a model can cause serious overfitting problems (Araújo and Guisan, 2006; Thuiller et al., 2008a), generating models too centred on the dataset used to train them, and consequently of limited transferability to other conditions such as future climates (Randin et al., 2006).

A more parsimonious approach is to select alternative subsets of variables with potential ecological relevance to the species under study, with each subset corresponding to a different hypothesis or set of hypotheses on how the environment may control the species' distribution. This type of approach was for instance used by Vicente et al. (2010) to test hypotheses on the factors controlling patterns of alien invasive plant species richness, but it has so far rarely been used for individual species. Another way of defining subsets of factors is to keep as separate sets, variables generated through different published approaches, such as the use of raw monthly values (e.g., Hijmans & Graham, 2006), of more advanced bioclimatic indices (e.g., Broennimann et al., 2007). The effect of the different preparative treatment of climatic and other environmental variables on SDM performance and predictions has so far remained largely untested (Ashcroft et al., 2011; Synes and Osborne, 2011; Bedia et al., 2013; Fernandez et al., 2013).

SDMs have been used for more than a decade to derive climate change scenarios (e.g., Guisan and Theurillat, 2000), but they were only more recently identified as useful tools for determining species status in terms of vulnerabilities and extinction risks (Thuiller et al., 2005; Rödder et al., 2009; IUCN, 2010; Fordham et al., 2012; Crimmins et al., 2013; Fordham et al., 2013; but see Akçakaya et al., 2006), in particular through providing an alternative approach to calculating IUCN's AOO criterion (area of occupancy; IUCN, 2001). However, it is unclear whether the choice of environmental variables can have an effect on the resulting SDM-based extinction risk estimates.

Arid ecosystems have been identified as being among the most sensitive to climate change (Kefi et al., 2007) and climate change ultimately affect the modelled estimates of extinction risks (IUCN, 2001; Fordham et al., 2013). They thus provide appropriate systems to assess the use of SDMs to estimate climate change threat on plants.

Here, we use data on the distribution of rare plant species in an arid landscape in Chile and Perú to address the following questions:

(1) Are there differences in performance and accuracy among SDMs fitted with different alternative sets of climatic predictor variables?
(2) Are there differences in the estimates of climate change effects among different sets of climatic predictor variables?

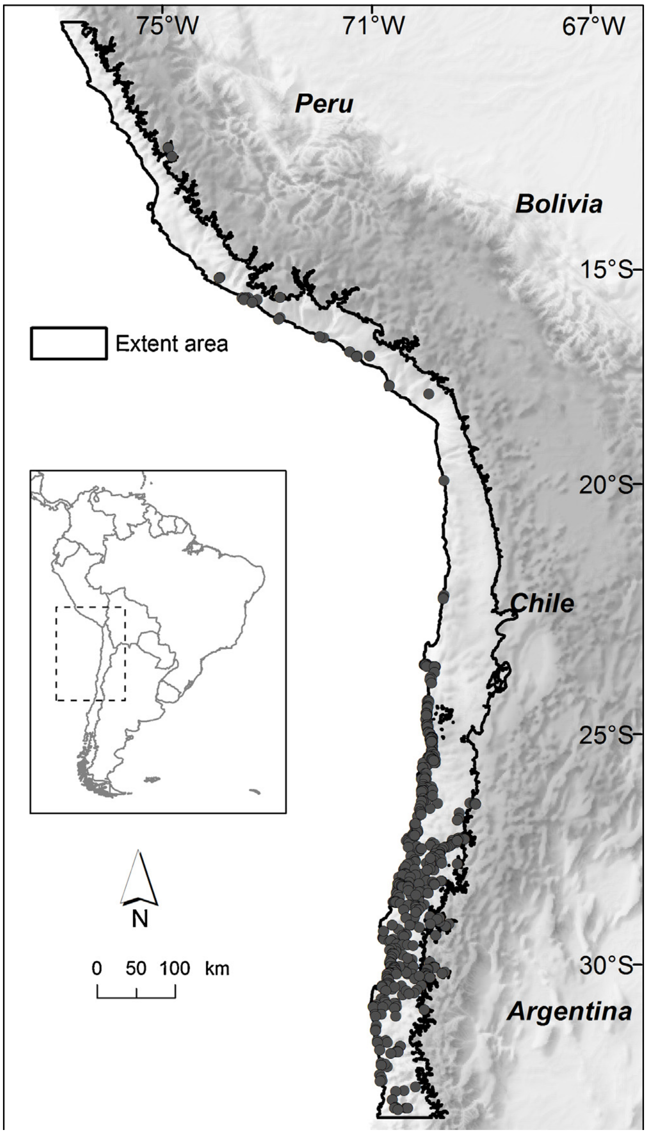

Fig. 1. Extent area indicating the distribution of *Heliotropium* sect. *Cochranea* (circles).

(3) Do those differences affect model-based estimates of extinction risk for rare species?

To address these questions, we derived six sets of present and future predictors from the same initial monthly climatic variables we previously developed for the area, and applied a sequential procedure to compare the results of using them for fitting SDMs with different modelling techniques.

2. Materials and methods

2.1. Study system

Heliotropium L. sect. *Cochranea* (Miers) Kuntze (Heliotropiaceae, Boraginales) is a group of shrubby and microphyllous plants. Sixteen out of 17 species have a geographical range centred in the Atacama Desert (18°30′ S–31°30′ S, 0–3 000 a.s.l; Table 1; Fig. 1). Only one species has its centre of distribution in the Peruvian Desert (*H. krauseanum*), and one species extends its distribution to the Mediterranean woodland zone of central Chile (*H. stenophyllum*). Most species have narrow geographic ranges along the coast