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Modelling the combined effects of land use and climatic changes: Coupling bioclimatic modelling with Markov-chain Cellular Automata in a case study in Cyprus

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ABSTRACT

Environmental change in terms of land use and climatic changes is posing a serious threat to species distributions and extinctions. Thus in order to predict and mitigate against the effects of environmental change both drivers should be accounted for. Two endemic plant species in the Mediterranean island of Cyprus, *Crocus cyprius* and *Ophrys kotschyi*, were used as a case study. We have coupled climate change scenarios, and land use change models with species distribution models. Future land use scenarios were modelled by initially calculating the rate of current land use changes between two time snapshots (2000 and 2006) on the island, and based on these transition probabilities Markov-chain Cellular Automata were used to generate future land use changes for 2050. Climate change scenarios A1B, A2, B1 and B2A were derived from the IPCC reports. Species' climatic preferences were derived from their current distributions using classification trees while habitat preferences were derived from the Red Data Book of the Flora of Cyprus. A bioclimatic model for *Crocus cyprius* was built using mean temperature of wettest quarter, max temperature of warmest month and precipitation seasonality, while for *Ophrys kotschyi* the bioclimatic model was built using precipitation of wettest month, mean temperature of warmest quarter, isothermality, precipitation of coldest quarter, and annual precipitation. Sequentially, simulation scenarios were performed regarding future species distributions by accounting climate alone and both climate and land use changes. The distribution of the two species resulting from the bioclimatic models was then filtered by future land use changes, providing the species' projected potential distribution. The species' projected potential distribution varies depending on the type and scenario used, but many of both species' current sites/locations are projected to be outside their future potential distribution. Our results demonstrate the importance of including both land use and climatic changes in predictive species modelling.

1. Introduction

Climate and land use changes are two of the main causes for biodiversity loss worldwide, while their combined effects may be greater than either of these factors acting alone (de Chazal and Rounsevell, 2009). Climate change has already affected species distribution, abundance, phenology and interactions, while even greater impacts are expected in the future (Rosenzweig et al., 2007) with three major options for threatened species: (a) extinction, (b) evolution and subsequent adaptation and (c) shifting its geographic range to more favourable conditions (Moustakas and Evans, 2013). However, the rate at which climate change is happening today is often faster than the ability of some species to disperse or adapt, while other factors such as land use change and habitat fragmentation impede their ability to move to suitable areas (Thuiller et al., 2005).

Climate change models simulate the change in climate due to the accumulation of greenhouse gases, based on the current understanding of atmospheric physics and chemistry (Hannah, 2010). The Intergovernmental Panel on Climate Change (IPCC) has produced a range of emission scenarios for use in global climate models that predict future climate (IPCC, 2013). The latest IPCC report is based on alternative concentrations of greenhouse gases without being associated with any socio-economic scenario, but instead could result from different combinations of economic, technological, demographic, policy, and institutional futures (IPCC, 2013). This change facilitates better integration of socio-economic factors, such as land use changes into future projections.

Species distribution models (SDMs) use information on the locations of species and their corresponding environmental covariates, creating statistical functions to be projected in areas or time periods where environmental parameters are known but species distribution is unknown, providing inference for potentially suitable sites (Brotons et al., 2004).

In addition to climate change, the destruction, fragmentation and degradation of habitats due to changes in land use are among the strongest pressures on biodiversity (EEA, 2010). In analogy to climate modelling, land use change models use a variety of approaches

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to assess and project the future role of land use change on biodiversity, soil degradation, the ability of biological systems to support human needs and the vulnerability of places and people to climatic, economic, or sociopolitical perturbations (Zhang et al., 2015). The development of land use change scenarios allows their integration into SDMs alongside dynamic climatic variables which can significantly improve a model's explanatory and predictive ability at fine scales (Martin et al., 2013). Land use can be incorporated into the model as static variables that do not change over time (Iverson and Prasad, 2002), or as dynamic variables that change under different scenarios (Schweiger et al., 2012).

Despite the fact that the combined effects of climate and land use change affect species distributions (Martin et al., 2013), only a small number of SDMs predict species distribution based on both of these factors (e.g. Esteve-Selma, et al., 2012; Heubes, et al., 2013; Schweiger, et al., 2012), while most SDMs that combine climatic variables with land use variables only use dynamic variables for climate, while land use is considered stable (Martin et al., 2013). Dynamic model coupling (Verdin et al., 2015) of climate models and land use models can be employed to account for the interaction between both effects in projected future conditions (Evans et al., 2013a).

Cyprus is a biodiversity hotspot (Myers et al., 2000) which is expected to become warmer and dryer (Hadjinicolaou et al., 2011). At the same time, the increased pressure for urban and tourism development in Cyprus is leading to significant changes in land uses (Eurostat, 2012). Thus, the island of Cyprus is an ideal study area because of the major climate and land use changes expected in the near future, the presence of a multitude of threatened endemic species and the absence of similar studies in the region to date. We sought to quantify the combined effects of climatic and land use changes on two plant endemic species.

2. Materials and methods

2.1. Study area

Cyprus is the third largest Mediterranean island, with an area of 9251 km^2. The climate is Mediterranean, with hot and dry summers from June to September (little or no rainfall, average maximum temperatures up to 36 °C), rainy but mild winters from November to March and two short transitional seasons, autumn and spring. For detailed information regarding the geomorphology and biogeography of the island see Supp. 1A.

2.2. Target species

The target species are *Crocus cyprius* Boiss. & Kotschy and *Ophrys kotschyi* H. Fleischm. & Sofi, both endemic to Cyprus, and categorised as vulnerable under the IUCN classification (Tsintides et al., 2007). The criteria considered to target these two species were: (i) high risk of extinction, (ii) endemism, (iii) high number of data occurrences/location relative to other available species and (iv) significant differences between their distributions, as *C. cyprius* only occurs in the Troodos Mountains, while *O. kotschyi* occurs almost everywhere in Cyprus except the Troodos Mountains. For additional information regarding the target species see Table S1 in Supp. 1A.

2.3. Data

Species distribution data were obtained from the Red Data Book of the Flora of Cyprus (Tsintides et al., 2007), in the form of true presence points. The data were collected during a systematic extensive survey between 2002 and 2006 (Tsintides at al., 2007).

There were 102 true presences for *C. cyprius* and 117 for *O. kotschyi*. From these, a set of "theoretical" presences were derived for each species; these comprised centres of cells of the potential habitat, i.e. the entire area with a suitable altitude, soil and land use, within which at least one true presence had been recorded. The absence data were created artificially, from background data of the entire potential habitat of each species; these comprised the centres of cells of the potential habitat where no true presence had been recorded. This was done in order to provide a sample of the set of conditions available to the species in the region and not to pretend that the species is absent in the selected sites (Phillips et al., 2009). The data were then weighted to simulate prevalence 0.5, i.e. the total weight of the presence is equal to the total weight of absences (Barbet-Massin et al., 2012).

Bioclimatic data were obtained from Worldclim database, version 1.4 (release 3), which is available on www.worldclim.org (Hijmans et al., 2005). The bioclimatic variables used are shown in Table S2 in Supp. 1B. Future bioclimatic data were also obtained from Worldclim for the year 2050, according to GCM HadCM3 (Hadley Centre Coupled Model, Version 3) and A1B, A2, B1 and B2A SRES emission scenarios. Each scenario is based on a different "storyline" and scenario family (A1, A2, B1 or B2), representing different demographic, social, economic, technological, and environmental developments (IPCC, 2013). The four storylines combine two sets of divergent tendencies: one set varying between strong economic values (A1 and A2 families) and strong environmental values (B1 and B2 families) and the other set between increasing globalisation (A1 and B1 families) and increasing regionalisation (A2 and B2 families) (Nakicenovic and Swart, 2000).

Land use data for 2000 and 2006 were obtained from CORINE database, available on http://www.eea.europa.eu/data-and-maps. The resolution for both the current and the future bioclimatic data was 0.71 km^2 while for the land-use data 250 m × 250 m.

Habitat preferences were determined based on the information provided in the Red Data Book of the Flora of Cyprus, which was the result of a systematic study of all available information on the threatened plants of Cyprus, in combination with field work (Tsintides et al., 2007). The combination of suitable altitude, soil and land use, as described in Tsintides et al. (2007) was defined as the species current potential habitat when using current land use and as future potential habitat when using future land use in ArcGIS (http://www.esri.com).

2.4. SDMs

The SDMs were created using classification trees (CTs), a machine learning method used to create predictive models (Figs. 2 and 3). The method predicts the value of a dependent variable with a finite set of values, from the values of a set of independent variables (Ji et al., 2013). The main advantage of this method is that it does not require a specific type of data or that they follow a specific statistical distribution. The evaluation of the predictive accuracy of the model was measured using Cohen's Kappa (Congalton, 1991) and the "area under the curve" (AUC) of receiver operating characteristic plot (ROC plot) (Fielding and Bell, 1997). The classification tree is considered to represent each species' "bioclimatic envelope" or "bioclimatic space", which is defined as the climatic component of the fundamental ecological niche, or the 'climatic niche' (Pearson and Dawson, 2003). We used SPSS version 20 for the statistical analysis (http://www-01.ibm.com/software/analytics/spss/).

2.5. Land use prediction

Future land use was predicted with an integration of Markov chain and Cellular Automata (Fig. 4). Markov chain is a technique that has been widely used to predict changes in vegetation and which predicts future changes based on the rate of previous changes (Arsanjani et al., 2011). The main disadvantage of the Markov chain is its lack of spatial dimension: it gives accurate information on the transition probabilities of each land use type to another, but provides no information on the spatial distribution of changes (Eastman, 2003).

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