Ecological Modelling 313 (2015) 201–211

Contents lists available at ScienceDirect

Ecological Modelling

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

Winners and losers of climate change for the genus *Merodon* (Diptera: Syrphidae) across the Balkan Peninsula

Aggeliki Kaloveloni[a,*], Thomas Tscheulin[a], Ante Vujić[b], Snežana Radenković[b], Theodora Petanidou[a]

[a] *Laboratory of Biogeography & Ecology, Department of Geography, University of the Aegean, 81100 Mytilene, Greece*
[b] *Department of Biology and Ecology, University of Novi Sad, Trg Dositeja Obradovića 2, Novi Sad 21000, Serbia*

ARTICLE INFO

Article history:
Received 27 October 2014
Received in revised form 19 June 2015
Accepted 22 June 2015

Keywords:
Biogeography
Ensemble modelling
Hoverflies
Mediterranean species
Mountainous species
Plant–pollinator mismatch

ABSTRACT

The implementation of species distribution models on the research of species response to climate change has increased due to the growing vulnerability and extinction rates of various taxa. Reported declines of pollinator population sizes and diversity due to global changes may negatively affect the services they provide. Considering the importance of hoverflies as pollinators, we predict the climate change effect on the potential distribution range of selected species of the genus *Merodon* Meigen, 1803. We used two climate models (ECHAM5, HadCM3) and three climate change scenarios (optimistic, modest, pessimistic), under two time frames (2050 and 2080). We predicted the species spatial distribution as well as the species richness and the percentage turnover for two extreme dispersal hypotheses (limited, unlimited). The analysis was implemented using an ensemble forecasting modelling approach. Species adapted to higher altitudes (i.e. with lower temperature requirements) and/or latitudes were predicted to be more vulnerable to climate change vs. species able to tolerate a wider range of temperatures, by losing a higher percentage of climatically suitable area. Significant differences in distribution ranges were found between mountainous and the remaining species groups each one considered separately (viz. climate-generalists, Mediterranean, and east Mediterranean). Southern Balkans were predicted to experience a preservation of species assemblage across all climate change models, scenarios and dispersal assumptions, while the central and northwestern parts were predicted to be subject to an increased change of their species composition. We emphasize the importance of forecasting distribution shifts of a high number of species for the development of conservation strategies. Furthermore, due to the dependence of *Merodon* fly larvae on geophytes, we highlight the necessity of incorporating biotic interactions to model the potential distribution range shifts of these hoverfly species.

1. Introduction

Global warming has become an important issue during recent years due to the associated changes in ecological processes and environmental elements, posing an increased threat to global biodiversity (Pereira et al., 2010; Thomas et al., 2004). A rapid temperature rise has significant impacts on species populations and thus constitutes a matter of high concern for ecologists. In particular, climate change has been linked to shifts in species' ranges (Chen et al., 2011; Walther et al., 2005), changes in their phenological traits (Parmesan, 2007; Visser and Both, 2005) and temporal and spatial mismatches of interacting species (Burkle and Alarcón, 2011; Schweiger et al., 2008). Extinction risk is predicted to increase for a large number of taxa in the future (Bellard et al., 2012; Pereira et al., 2010), highlighting the vulnerability of many species, as most known species have small geographic ranges and the number of species with restricted distribution range is predicted to increase rapidly even in well-studied taxa (Pimm et al., 2014).

The catastrophic consequence of climate change on terrestrial species is a subject of increased interest during recent years. One of the most widely applied tools to study the effects of climate change on organisms are Species Distribution Models (SDMs), which relate species observations to environmental estimates to predict distribution across landscapes (Elith and Leathwick, 2009). SDMs have been widely used in pollination studies and applied on diverse pollinator species (Giannini et al., 2012; Kuhlmann et al., 2012; Luoto et al., 2006). Pollination is a keystone process with a fundamental role for primary production (Klein et al., 2007), the reproduction of

* Corresponding author. Tel.: +30 2251036406.
E-mail address: akal@geo.aegean.gr (A. Kaloveloni).

http://dx.doi.org/10.1016/j.ecolmodel.2015.06.032
0304-3800/

large numbers of flowering plant species (Ollerton et al., 2011) and the maintenance of organisms depending on them; besides, the economic value of this ecosystem service is of great significance (Gallai et al., 2009). Increasing declines of pollinator diversity and populations, which are partly associated with the climate change effects (Burkle et al., 2013; Potts et al., 2010), could affect the distribution range of pollinators. Because an increased restriction of pollinators' spatial ranges is associated with high risk of reduction in pollination services, the implementation of SDMs is invaluable to assess the future health of pollination systems.

Most hoverflies feed regularly on pollen and nectar, and thus function as pollinators considered as second in importance after bees (Petanidou et al., 2011). Approximately 6000 hoverfly species have been described worldwide, of which 1200 occur in Europe (Rotheray, 1993). With more than 100 described species, the genus *Merodon* Meigen, 1803 is the second richest in species number on the European continent (Speight, 2013). Especially, the Balkan Peninsula is considered one of the centres of endemism and diversity of *Merodon* (Vujić et al., 2007; Ståhls et al., 2009) with a minimum of 78 recorded species (unpublished data). The high diversity could be a result of the diverse climatic conditions in the Balkans, from Mediterranean to continental, or even an evolutionary result of the high richness and diversity of geophytes in the Mediterranean flora, as *Merodon* species are closely associated with the pollination of, and the larval development in, bulbous plants. Such kinds of interactions are particularly important on small scales, such as at community level, but SDMs are often fitted at larger extents, such as regional to continental. The inclusion of these kinds of interactions into the modelling process for the assessment of climate change effects on species distribution and co-existence is considered essential at every geographical extent, even at the broader scales (Wisz et al., 2013) and, thus, important efforts have been made for the development of ways to account for biotic interactions into the predictive modelling mechanism (Kissling et al., 2012; Wisz et al., 2013).

Our study objectives are to (i) forecast the current distribution of *Merodon* species under a bioclimatic modelling framework, (ii) evaluate the potential range change of *Merodon* species due to climate change effects and (iii) determine the species most threatened by climate change. Regarding the latter aim, we expect that the species encountered in the colder range of the genus' distribution area will be more vulnerable to climate change effects than those occurring in the warmer or in a wide range of the climate gradient. These objectives were assessed by implementing an ensemble modelling approach, in which models with different algorithms are combined to produce more accurate forecasts of species distribution, and hence the use of multi-model ensemble projections has been proposed by several authors (e.g. Araújo and New, 2007; Grenouillet et al., 2011; Marmion et al., 2009).

2. Material and methods

2.1. Species data set

Current distribution data regarding *Merodon* species were extracted from two databases: the database of the Department of Biology and Ecology of the University of Novi Sad, i.e. the largest hoverfly database of the Balkan Peninsula, with 73 *Merodon* species from a total of 1452 sites; and the database of the Laboratory of Biogeography and Ecology of the Department of Geography of the University of the Aegean (*Melissotheque of the Aegean* cf. Petanidou et al., 2013), with 18 *Merodon* species from 44 sites. Both databases contain long-term observation data, which were checked for their spatial accuracy. We chose species for which a minimum of 30 occurrence points were available to avoid potential modelling errors associated with small sample sizes (Stockwell and Peterson, 2002; Wisz et al., 2008). In total we applied SDMs to 12 hoverflies (Table 1), classified into four categories: (1) generalist species (*Merodon aberrans* Egger, 1860, *Merodon armipes* Rondani, 1843, *Merodon clavipes* Fabricius, 1781 and *Merodon nigritarsis* Rondani, 1845), (2) mountainous species (*Merodon cinereus* Fabricius, 1794 and *Merodon moenium* Wiedemann, 1822, (3) Mediterranean species (*Merodon albifrons* Meigen, 1822, *Merodon avidus* Rossi, 1790, *Merodon erivanicus* Paramonov, 1925 and *Merodon funestus* Fabricius, 1794) and 4) east Mediterranean/Aegean species (*Merodon spinitarsis* Paramonov, 1929 and *Merodon velox* Loew, 1869). Duplicate records, as well as records before 1950, were removed from the analyses and only one occurrence point per pixel at 2.5 arcmin (ca. ∼5 km) resolution was taken into account.

2.2. Predictors used for modelling

We assume that at the small spatial scale there is a variety of ecological factors determining a species' absence or presence, such as soil composition, micro-climate, and land cover, while at larger scales we expect the climatic parameters to be more meaningful. The bioclimatic variables (Table 2) for the current conditions (1950–2000) were obtained from the WorldClim database (Hijmans et al., 2005) at 2.5 arcmin resolution. Future bioclimatic variables are generated from Global Climate Models (GCM, also called General Circulation Models), which are provided by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS, http://ccafs-climate.org). There are no objective criteria to rank the performance of climate models (McAvaney et al., 2001). Thus, two climate models, ECHAM5 (Roeckner et al., 2003) and HadCM3 (Pope et al., 2000) were used to predict species distributions. For each model we ran three different SRES (Special Report on Emission Scenarios) storylines for the time frames 2050 (averaged across 2040–2069) and 2080 (averaged across 2070–2099). We chose these time frames to represent the near and far future climates, respectively. The A1B is a moderate scenario within the A1 scenario family, assuming a balanced use of fossil and non-fossil energy sources (IPCC, 2007). The A1 scenario family assumes a global population that peaks mid-century and subsequently decreases with a coupled rapid growth of the economy and technology. The A2 scenario describes a strong heterogeneity of the world's economic development and technological change. Finally, the B1 scenario describes a convergent world with the same global population as the A1 scenario but with rapid change in economic structures and the introduction of clean and resource-efficient technology (IPCC, 2007).

The selection of bioclimatic variables to define the habitat suitability for the selected *Merodon* species was based on a multicollinearity assessment using pairwise Pearson correlations coefficient. For each pair of highly correlated variables ($r \geq \pm 0.75$) only the biologically relevant was selected (Appendix A, Table A.1). This resulted in a set of nine bioclimatic variables (see bold variables in Table 2) we used consequently for modelling.

2.3. Species distribution modelling process

A number of modelling algorithms has been developed and proposed to identify the relationship between species occurrence and environmental data. We used seven different SDMs within the biomod library (Thuiller et al., 2009) implemented in the R platform (R Development Core Team, 2013). These models have been shown to give accurate results for different samples sizes (Elith et al., 2006; Hernandez et al., 2006). In particular, we ran with default settings (see Thuiller et al., 2013) the: (i) Generalized Linear Model (GLM), (ii) Multivariate Adaptive Regression Splines (MARS),