Assessing impacts of climate change on *Campanula yaltirikii* H.Duman (Campanulaceae), a critically endangered endemic species in Turkey

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Abstract: Ecological niche models (ENMs) provide information to assess the effects of environmental and climatic conditions on species distribution. The purpose of this study was to predict the impact of climate change on a critically endangered species, *Campanula yaltirikii* H.Duman. It is a local endemic chasmophyte from Mt Çığlıkara (Antalya, Turkey), restricted to cracks in calcareous rocks and threatened by goat overgrazing. Current and future ENMs of *C. yaltirikii* were predicted with a maximum entropy (Maxent) algorithm. The MIROC5 (Model for Interdisciplinary Research on Climate) climate change scenario for the year 2070 was used for projecting the future ENM of the species. A total of 38 GPS records of the species' localities were obtained from fieldwork. Fifteen environmental variables, including edaphic and topographic factors, and 19 climatic variables were used as predictors. The jackknife evaluation results indicated that geological formation, soil groups, and elevation are the main factors influencing *C. yaltirikii*'s distribution for current and future models. To conclude, climate change will shift some parts of the suitable habitats of *C. yaltirikii*. While there will be an expansion to higher altitudes and further north, there also will be habitat loss in the northeast of the current suitable habitat.

Key words: Conservation, biodiversity, endemic species, ecological niche modeling, Maxent

1. Introduction

For the conservation of biodiversity, the ecology of species should be investigated in various aspects, such as abiotic factors, biological interactions, ecosystem processes, temporal and spatial variability of the environment, regional processes, historical contingency, and evolutionary processes (Heywood and Iriondo, 2003). It is projected that future extinction rates will rely on species–area relations combined with estimates of habitat loss (May et al., 1995). Therefore, understanding the species–area relations and habitat suitability of species is essential for the conservation of endangered species.

Climate change is an important driver of exponentially increasing biodiversity loss, since it may affect species' natural distribution, cause temporal reproductive isolation, change the length of the growing season for plants, and increase pest and disease outbreak frequencies (Pimm et al., 1995; Millennium Ecosystem Assessment, 2005). Climate change could be seen as the greatest global threat to biodiversity over the next few decades (Leadley et al., 2010) The Intergovernmental Panel on Climate Change (IPCC) in the fifth assessment report estimates a 2 °C increase in temperature for each future decade, whereas it was 0.2 °C in the previous assessment report

(IPCC, 2007, 2013). Such implications of climate change are critical for biodiversity as species extinctions are an irreversible form of fitness decrease (Bellard et al., 2012). To reduce the impacts of climate change on ecosystems, biodiversity conservation is of great importance and will require both measuring biodiversity and monitoring the loss of biodiversity (Balmford and Bond, 2005).

Ecological niche models (ENMs) are widely used tools for conservation studies (Peterson, 2006). They enable understanding and predicting of spatial patterns of biodiversity, which are essential in terms of conservation biology (Pradervand et al., 2014). ENMs associate known species occurrence records with environmental variables that can affect the species' distributions and provide information about suitable environments for the species (Pearson, 2007). These models are used for estimating potential species' distributions (Gülsoy et al., 2017; Jazwa et al., 2018), predicting species' invasion (Vetter et al., 2018), projecting potential impacts of climate change (Bellard et al., 2018), exploring speciation mechanisms (Gutierrez et al., 2014), etc. However, comparatively few ENMs have been used for rare and endangered plant species with small population sizes (de Siqueira et al., 2009).

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The genus *Campanula* L. (Campanulaceae) comprises approximately 420 species (Lammers, 2007). Turkey is one of the endemism hotspots for the genus. There are 138 taxa (66 endemics) of *Campanula* in Turkey (İkinci, 2012; Yıldırım, 2018). *Campanula yaltirikii* H.Duman is a critically endangered local endemic species and belongs to the section *Tracheliopsis* (Buser) Damboldt of the subgenus *Campanula* (Figure 1). It occurs exclusively in cracks of calcareous block rocks on Mt Çığlıkara (Antalya, Turkey) at altitudes of 1900–1950 m (Duman, 1999). This chasmophytic species is threatened by overgrazing and therefore protection measures must be taken. The objectives of the present study were (1) to predict *C. yaltirikii*'s current potential distribution in fine resolution, (2) to understand environmental constraints in its habitat preferences, and (3) to determine the impact of climate change on this critically endangered, Turkish local endemic species, as an example in mountain regions of the Mediterranean Basin.

2. Materials and methods

2.1. Study area

The study area is located in the Çığlıkara Nature Conservation Area (ÇNCA) in Elmalı District, Antalya Province, Turkey (Figure 2). The ÇNCA is a mountainous region that lies within 36.45–36.59 N and 29.69–29.98 E coordinates with an area of 158,890 km². Field surveys were conducted in 2016–2017 covering the species' known distribution area (only ca. 0.8 km²) during its flowering period (July–August). The region receives a mean annual rainfall of 725.4 mm. The average temperature ranges from –2.3 °C in winter to 18 °C in summer (Başaran et al., 2011). It is a protected area with high biodiversity; however, as seasonal goat breeding by the local people cannot be
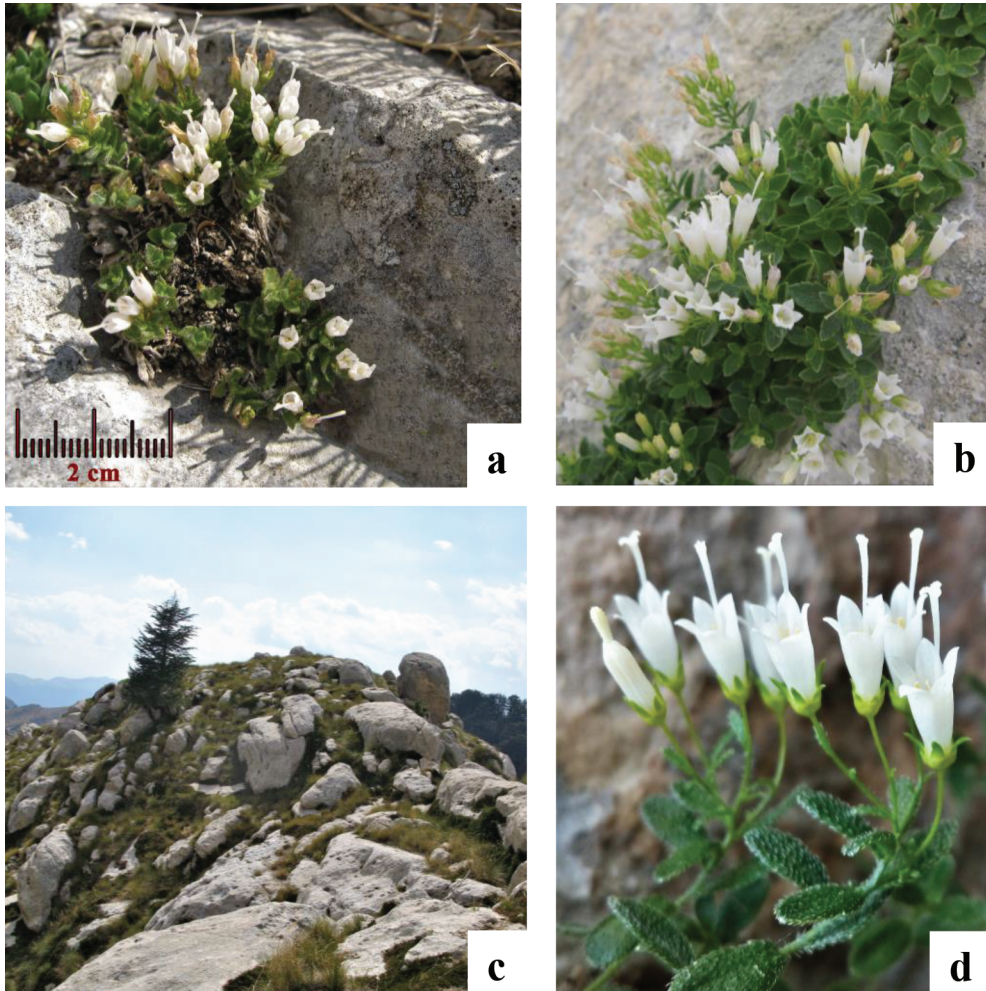
Figure 1. *Campanula yaltirikii* (Campanulaceae). a: size and habit of the plant, b: general view of a flowering individual in its habitat, c: general view of the area with typical species' habitat, d: close-up of flowers and leaves (shade form).

Figure 2. Study area in Çığlıkara region (Antalya, Turkey) and locality (GPS) records used in the ENM of *Campanula yaltirikii* (Campanulaceae).

prevented, the plant species in the area are threatened by overgrazing.

2.2. Environmental variables and species occurrence data
A total of 38 occurrences were recorded randomly in the study area during the flowering season of *C. yaltirikii* in July and August, 2016–2018 (Figure 2). A handheld Garmin Global Positioning System (GPS) receiver with ±3-m positional accuracy was used to acquire the species occurrence geocoordinates.

Fourteen environmental variables and 19 climatic variables, including edaphic and topographic factors, were used as predictors (Table 1). The Shuttle Radar Topography Mission (SRTM) digital elevation model with 30-m resolution was used to create topographic variables (solar position index, hill shade, solar illumination index, slope (percent and degree), area solar radiation, topographic position index, Beer's aspect, landform classification, topographic convergence index, heat load index, and

Table 1. Environmental variables used in modeling the distribution of *Campanula yaltirikii* and the percentage of their contributions. Variables without any values were removed because of high cross-correlations.

Code	Environmental variables	Percent contribution (%)	
		Current	Future
jeo	Geological formation	28.6	30.1
soil	Soil groups	27.9	29.8
spi	Solar position index	12.1	-
hillshade	Hill shade	-	-
sii	Solar illumination index	-	-
slope_p	Slope (percent)	3.2	-
slope_d	Slope (degree)	-	-
asr	Area solar radiation	1.5	-
tpi	Topographic position index	1.4	9.9
b_aspect	Beer's aspect	-	-
dem	Digital elevation model	25.4	2.3
lc	Landform classification	-	-
tci	Topographic convergence index	-	-
hli	Heat load index	-	-
aspect	Aspect	-	-
b1/mc1	Annual mean temperature (°C)	-	-
b2/mc2	Mean diurnal temperature range (°C)	-	26
b3/mc3	Isothermality (b2 ÷ b7)	-	-
b4/mc4	Temperature seasonality (C of V)	-	1.9
b5/mc5	Max temperature of warmest week (°C)	-	-
b6/mc6	Min temperature of coldest week (°C)	-	-
b7/mc7	Temperature annual range (b5–b6) (°C)	-	-
b8/mc8	Mean temperature of wettest quarter (°C)	-	-
b9/mc9	Mean temperature of driest quarter (°C)	-	-
b10/mc10	Mean temperature of warmest quarter (°C)	-	-
b11/mc11	Mean temperature of coldest quarter (°C)	-	-
b12/mc12	Annual precipitation (mm)	-	-
b13/mc13	Precipitation of wettest week (mm)	-	-
b14/mc14	Precipitation of driest week (mm)	-	-
b15/mc15	Precipitation seasonality (C of V)	-	-
b16/mc16	Precipitation of wettest quarter (mm)	-	-
b17/mc17	Precipitation of driest quarter (mm)	-	-
b18/mc18	Precipitation of warmest quarter (mm)	-	-
b19/mc19	Precipitation of coldest quarter (mm)	-	-

aspect) (Farr et al., 2007). Slope (percent and degree), area solar radiation, hill shade, and aspect were created using spatial analyst tools provided by ArcMap (ESRI, 2011). The Topography Toolbox was added to ArcMap in order to create solar position index, solar illumination index, topographic position index, Beer's aspect, landform classification, topographic convergence index, and heat load index (Weiss, 2001). The soil groups map was provided

by the OGM (General Directory of Forestry). The SRTM data were downloaded from the website http://dwtkns.com/srtm30m/ and the lithological data were obtained from Geoscience Map Viewer and Drawing Editor of General Directorate of Mineral Research and Exploration (Akbaş et al., 2016).

The climatic data were obtained from the website http://www.worldclim.org/bioclim with 30-s spatial resolution (approximately 800 m). The dataset includes precipitation, temperature, and their derivatives created using climatic data for the years 1950–2000 (Hijmans et al., 2005). For the future model prediction, the same set of bioclimatic variables pertaining to the year 2070 was downloaded from the WorldClim website. The Model for Interdisciplinary Research on Climate (MIROC5) climate change scenario was used, which was part of the fifth phase of the Coupled Model Intercomparison Project (CMIP5). In addition, high CO_2 emission foreseeing climate change scenario (8.5) projections were considered for this study (Watanabe et al., 2010).

In order to avoid cross-correlation within the selected environmental variables, the highly correlated ones were removed using Pearson's correlation coefficient, and the representative variables were selected using factor analyses. Variables with cross-correlation values > 0.80 were eliminated. All variables were extracted from the study area and converted to ASCII files with the WGS84 datum using ArcMap 10.3. The "create fishnet" tool in ArcMap was used in order to make all the environmental variables the same cell size and 30 m × 30 m grids were created (same spatial resolution as the SRTM data).

2.3. Spatial modeling
The species distribution model was created with the maximum entropy algorithm, Maxent v. 3.3.3 (http://biodiversityinformatics.amnh.org/open_source/maxent/) (Phillips et al., 2004, 2006). This software was chosen because of its successful discrimination performance for presence-only data and small sample sizes (Wisz et al., 2008; Piri Sahragard and Ajorlo, 2018). The Maxent algorithm fundamentally builds species distribution models by quantifying the unknown likelihood distribution, determining the occurrence of a species across a study area without any inferring groundless information about the observed distribution (Salter and Michael, 2012). Maxent was run with the following settings: logistic output format, random test percentage = 25, and auto features (feature types are automatically selected depending on the training sample size), while other settings were maintained as default (Philips et al., 2004).

Maxent uses a threshold-dependent 'omission and predicted area curve' and threshold-independent 'receiver operating characteristic (ROC) curve' for the model evaluation. The area under the ROC curve (AUC) was used to assess the model performance. AUC is a measure of model performance and varies from 0 to 1 (Fielding and Bell, 1997). An AUC value of 0.5 shows that the model did not perform better than a random prediction, whereas a value of 1.0 indicates perfect discrimination (Swets, 1988). The jackknife procedure and percent variable contributions were used to estimate the relative influence of different environmental variables. The final potential species distribution maps are categorized into four classes of potential habitats: 'high potential' (>0.6), 'good potential' (0.4–0.6), 'moderate potential' (0.4–0.2), and 'least potential' (<0.2) (Yang et al., 2013).

3. Results and discussion
The model output gave satisfactory results with the set of training and test data used. The final model for the current and future potential distribution model had high accuracy with an AUC value of 0.998 for both models (Figure 3). The models performed better than a random prediction. The results indicated that AUC values were high for *C. yaltirikii*, because of the restricted study area described by the environmental data. According to Philips (2010), this does not necessarily mean that such models are better; instead, this behavior is an artifact of the AUC statistic. Cross-correlations in the model were eliminated in order to prevent AUC artifacts. The current ENM explained the distribution of *C. yaltirikii* perfectly. Current suitable habitats for *C. yaltirikii* were predicted in the north and northeast of the occupied niche of the species in the ÇNCA (Figure 4). The area of the current potential distribution is significantly larger than the known present occurrence of *C. yaltirikii*.

The Maxent model predicts the fundamental niche (potential distribution), which is different from the realized niche (present occurrence), of the species according to environmental conditions (Pearson, 2007). The result maps of the potential distribution area of the species may be overpredicted in some areas for *C. yaltirikii*; still, the maps included the realized niche. For the current model, the jackknife evaluations and percent contributions indicated that geological formation (jeo), soil groups (soil), and elevation (dem) are the main factors influencing the species' current distribution (Figures 5 and 6; Table 1). Edaphic factors are emphasized by many studies for their important contribution to the ENM of plant species (Pir Sahragard and Ajorlo, 2018). Moreover, there are a number of studies that show that altitude affects the distribution of plant species (Maltez-Mouro et al., 2005; Baudraz et al., 2017).

The future prediction for 2070 showed both gain and loss of habitat for *C. yaltirikii*. The future ENM map showed a decrease in the northeastern and eastern parts of the current suitable habitat and an expansion to the northern
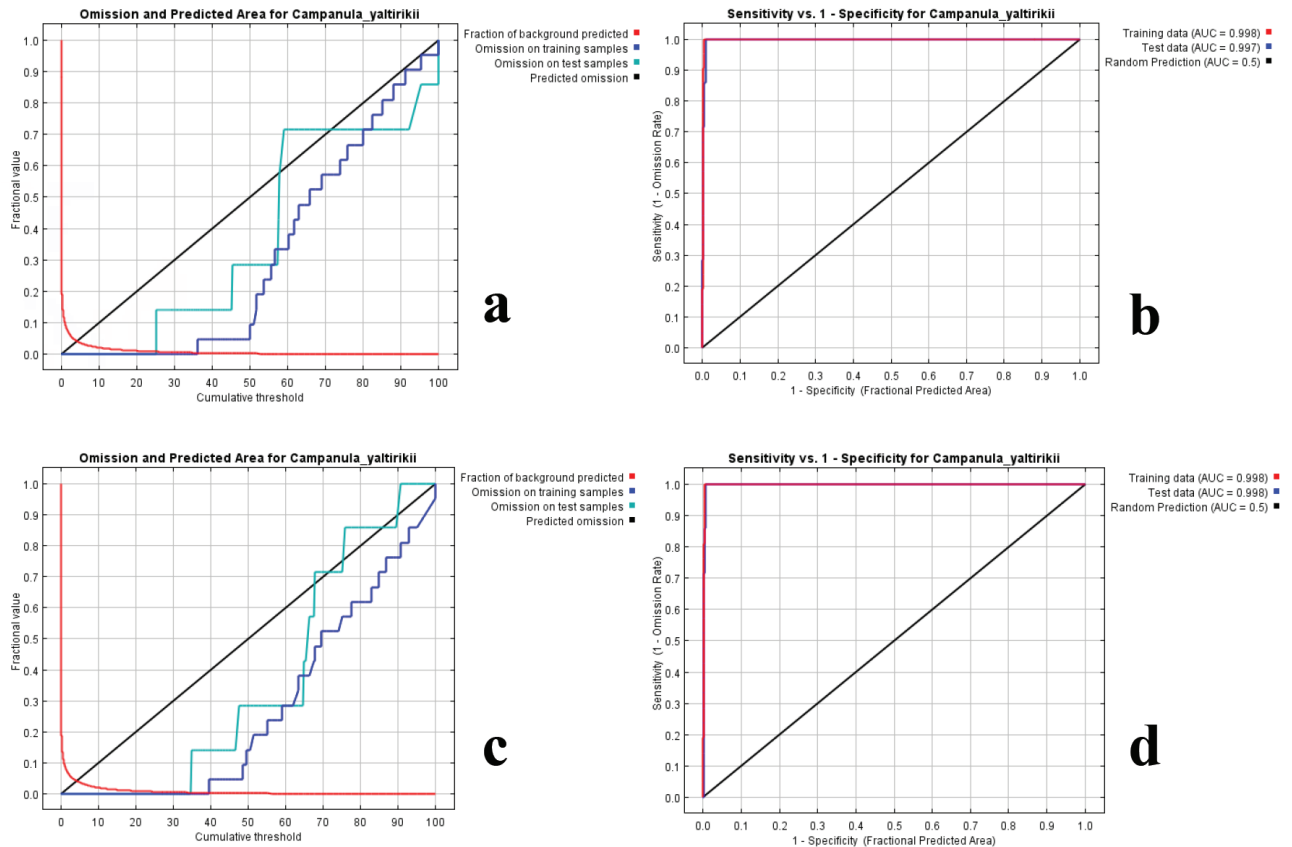
Figure 3. The omission rate and predicted area of *Campanula yaltirikii* as a function of the cumulative threshold for current (a) and future (c) model and the receiver operating characteristic (ROC) curve for current (b) and future (d) model.

and southern parts of the current suitable habitat (Figures 4b and 4c). The south of the suitable habitat is at higher altitude, indicating that the species may shift its habitat towards higher altitudes. The jackknife evaluations and percent contributions indicated that geological formation (jeo), soil groups (soil), and mean diurnal temperature range (mc2) are the main factors influencing the species' future distribution (Figures 5b and 6; Table 1). The temperature constraint of the distribution of *C. yaltirikii* indicates that this species will be adversely affected by temperature anomalies caused by climate change.

The environmental variables used as predictors in the models are of great importance (Austin and Van Niel, 2011) and finer-scale predictors significantly improve the predictive ability of any model (Pradervand et al., 2014). Additionally, using high resolution digital elevation models remarkably promotes the predictive ability of the topographic parameters derived from the digital elevation model (Lassueur et al., 2006). Due to these reasons, a 30-m resolution digital elevation model was used for creating topographic variables in our study. In addition, the resolution of all variables used for modeling was also the same as that of the digital elevation model. High resolution

variables were one of the reasons for the high accuracy of the ENMs of *C. yaltirikii*.

Topographic variables have strong predictive potential due to the predictive weakness of available macroclimate variables in the case of the existing local microclimate (Lassueur et al., 2006; Baudraz et al., 2017). Incorporating edaphic factors into the model significantly boosts the quality of the projections of the ENM (Dubuis et al., 2013; Buri et al., 2017). Using topographic and edaphic factors together with bioclimatic variables, as is the case in this study, is another reason for the high accuracy of the models.

The distribution of a species might have been constrained by different ecological factors such as competition with other species, anthropogenic effects, geographic barriers, or special habitat needs. The rocky habitat of the target species (rock-dweller) constrains the distribution of *C. yaltirikii*. Additionally, the species currently face overgrazing by the goats of local shepherds. Therefore, it is likely to lose its entire habitat in the near future.

As a result of the studies conducted to determine the effect of climate change on plants, it has been reported
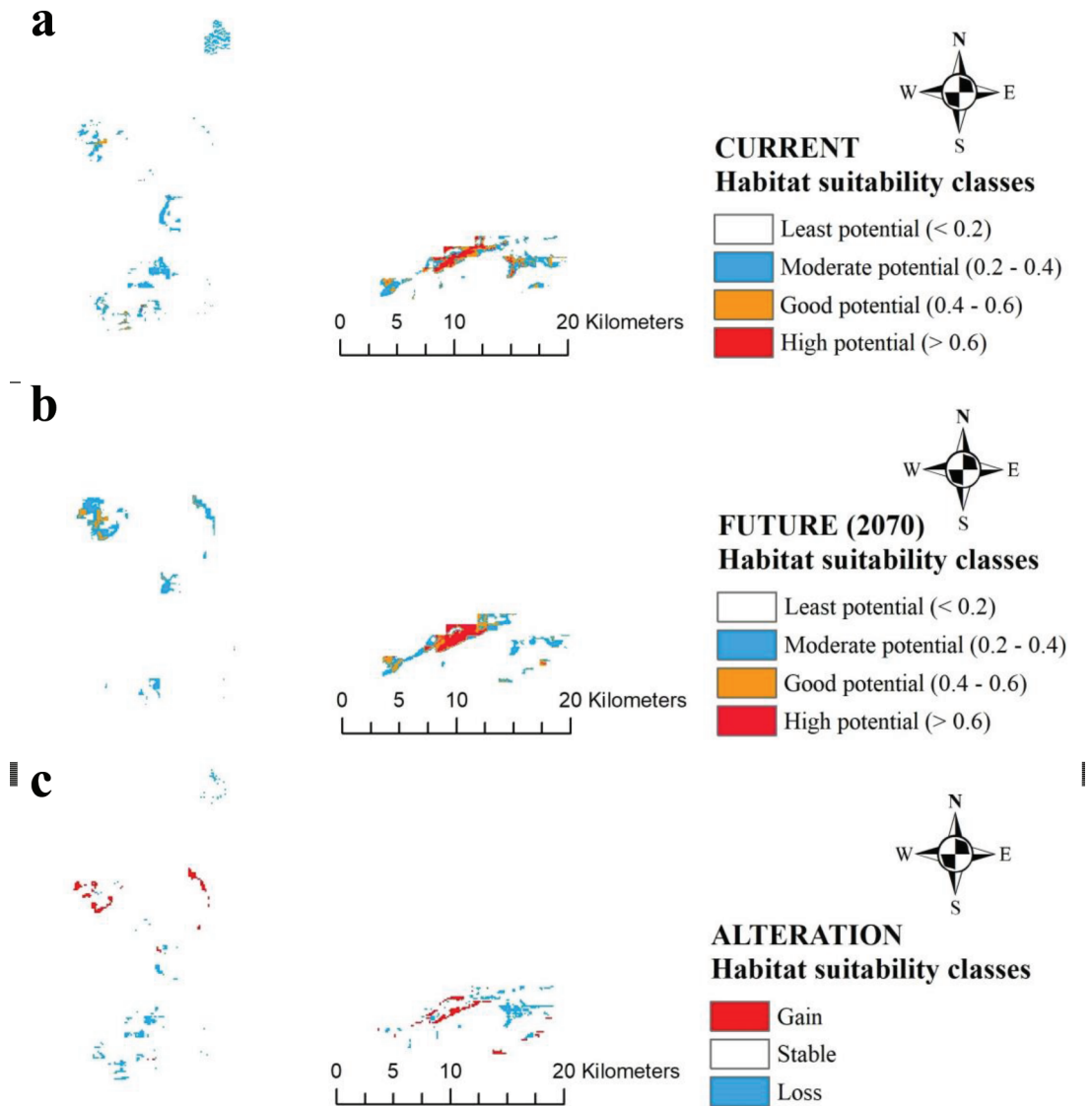
Figure 4. Projected potential distribution of *Campanula yaltirikii* (Campanulaceae): (a) current, (b) future (2070), and (c) differences between current and future distributions.

that plants will change their distribution area from current habitats to higher altitudes or further north (Walther et al., 2002; Moiseev and Shiyatov, 2003). Our results offer support to such claims. If plants located in the Mediterranean Basin—the region where global climate change is being experienced the fastest—do not adapt to climate change, the danger of extinction will be inevitable (Lynch and Lande, 1993; IPCC, 2013). Mittermeier et al. (1998) reported that endemics are the most vulnerable elements in a community under high threat circumstances because they have a narrow distribution area and are the first components to disappear in the ecosystem. However, according to Medail and Verlaque (1997), endemic species in the Mediterranean Basin are less affected by natural and anthropogenic factors as they are stress tolerant and adapted to extreme habitats. *C. yaltirikii* is an East Mediterranean element confined to a small geographic area in southwest Turkey (local endemic). Therefore, it is threatened due to its very narrow distribution range and its special habitat needs (rock-dweller), although it is stress-tolerant and adapted to extreme habitats.

To conclude, modeling species distributions is a useful tool for deciding on priority areas for conservation planning. The ENM of current conditions indicated that *C. yaltirikii* has a very restricted suitable habitat. Edaphic factors and elevation mainly constrain the habitat preferences of the species. Climate change is expected to shift some parts of the suitable habitats of *C. yaltirikii*. While there will be an
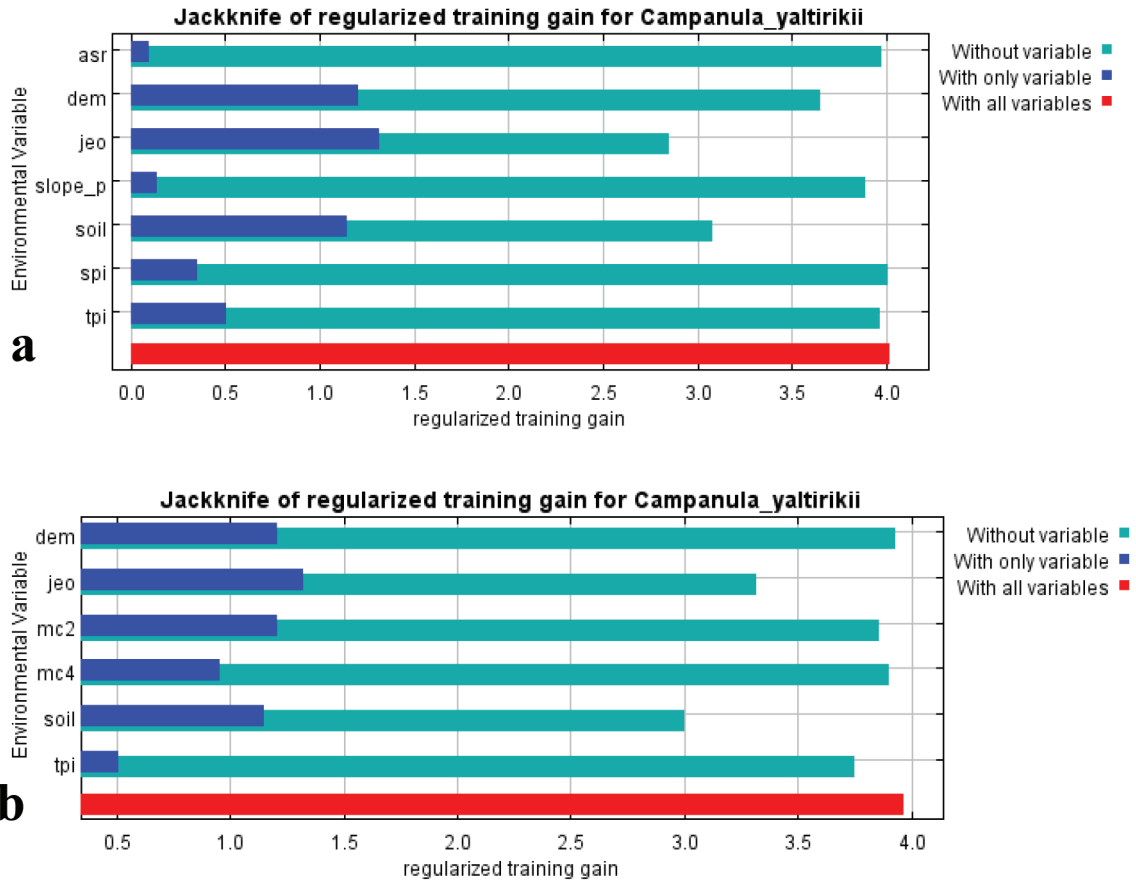
Figure 5. Current (a) and future (b) jackknife test results of evaluating the relative importance of environmental variables used in the ecological niche modeling for *Campanula yaltirikii* (Campanulaceae).
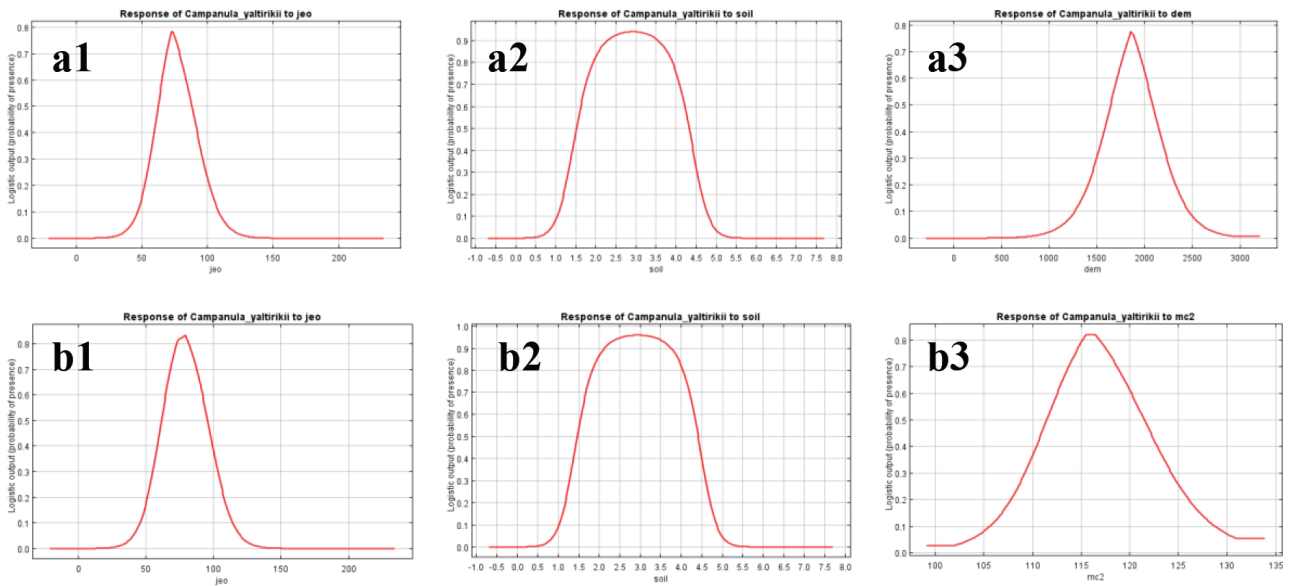
Figure 6. Response curves of most effective variables for current (a1: jeo, a2: soil and a3: dem), and future (b1: jeo, b2: soil and b3: mc2) model for *Campanula yaltirikii* (Campanulaceae).

expansion to higher altitudes and further north, there also will be habitat loss in the northeast of the current suitable habitat. Elevation limits the distribution of the species; thus in the future the species may not be able to expand its habitat to higher altitudes. Therefore, the species needs rapid in situ and ex situ conservation measures in order to protect its genetic diversity. Even though some parts of the distribution area of the species fall within a protected area, conservation at the population level should also be emphasized for the studied endemic plant species.

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