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Modelling and Mapping of Microrefugial Areas

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Abstract: Since historical climate change, the Mediterranean Region of Anatolia is an area that preserves biodiversity, supports endemism and has the character of refugia. Refugia can be expected to maintain the same protection and support in the face of anthropogenic climate change. However, rapid warming and a decrease in precipitation may break down the refugia areas into smaller areas. This situation necessitated the investigation of microrefugia, which accommodated climates suitable for organisms amid unsuitable climatic conditions, without waiting for the end of the century. We aimed to estimate the distribution of the important species constituting the biological diversity of the region under the influence of climate change scenarios and to determine the microrefugial areas at the intersection of these distributions. In this study, we performed climatic habitat suitability modelling of 6 species (three of them endemic), which has been assumed to represent refugia. With the help of MaxEnt, we estimated the distribution of species according to current and climate scenarios. We have suggested that microrefugia may occur at the intersection of the distribution in potential climatic maps in the HadGEM2-ES model-based RCP 2.6, RCP 4.5 and RCP 8.5 scenarios. The results of the model showed that the appropriate habitats of the species would decrease from the good scenario to the bad scenario under the influence of future climate change. The models also showed areas that provide favourable climatic conditions even in the worst climatic conditions. We have identified microrefugia as the mutual areas that provide suitable climatic conditions for the 6 species which have been selected as representatives. Climate change can lead to the extinction of organisms, such as narrowly distributed endemic species with specific climate requirements. Identifying and preserving microrefugial areas is the most effective way to protect species against climate change and anthropogenic habitat destruction. During anthropogenic climate change, microrefugial areas will preserve biodiversity and support endemism. Therefore, microrefugia is critical, and these areas should be included in conservation plans.

Keywords: Microrefugia, Climate change, MaxEnt, Biodiversity, Mediterranean, Anatolia.

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1. INTRODUCTION

Anthropogenic climate change has been emerged as a threat to the sustainability of biodiversity and ecosystems (Weiskopf et al., 2020). According to the IPCC's (Intergovernmental Panel on Climate Change) fifth report, changes in CO_2 concentrations from 490 ppm to 1370 ppm are foreseen by the end of the century for four different scenarios RCP (Representative Concentration Pathways) (IPCC, 2013). One of the main reasons for the extinction and decrease in the number of species (such as reptiles) belonging to some living groups is climate change (Sinervo et al., 2017; Telemeco et al., 2017).

Especially modelling-based research in the recent studies are important for predicting the future status of species and their habitats under the influence of climate change because global climate change is predicted to have an impact on ecosystems faster than historical climate change and far beyond our experience. Conservation and resource management plans will be successful if they are based on such research because species distribution models are currently the most effective way to transform climate change projections into ecological results (Wiens et al., 2009). In recent years, many studies have predicted how species will respond to climate change and contributed to conservation plans (Fordham et al., 2012; Mert et al., 2016; Qin et al., 2017).

When examining the processes and ecological consequences from historical climate change it is necessary to consider the terms of refugia, climate change velocity relationship between these terms. Refugia is the area where organisms survive when climatic conditions become unsuitable (such as glacial and interglacial period), maintain the continuity of biodiversity components for many years, can shrink or expand in response to climate changes (Dobrowski, 2011; Keppel et al., 2012). Since the historical climate change, areas with low climate change velocity have assumed the role of refugial areas, thus enabling species to survive. So refugial areas very rich biodiversity and endemism (Sandel et al., 2011; Keppel et al., 2012). For example, one of these refugial areas which are critical for the continuation of species is considered to be the Mediterranean basin for Europe (Birks and Willis, 2008). Since refugial areas preserved biodiversity, endemism and low climate change velocity for thousands of years, it is thought to they will provide the same protection during possible at the end of the 21st century (Carnaval et al., 2009; Sandel et al., 2011; Keppel et al., 2012).

Refugial areas that have undergone low-speed climate change in the past may face rapid climate change soon. Because anthropogenic climate change may occur in a shorter time and faster than historical climate change. As a result of this rapid warming can break down and destroy even the most stable refugia (Sandel et al., 2011; Harrison and Noss, 2017). For this reason, during anthropogenic climate change microrefugial areas which are smaller than refugial areas, will be very important by providing the persistence of species both inside and outside the refugia and supporting local climates. (Dobrowski, 2011; Harrison and Noss, 2017). Investigating the locations of microrefugia is important to determine the potential distribution areas of species in response to climate change (Dobrowski, 2011). These investigations can be completed because of modelling future distributions of the species according to climate projections (Wiens et al., 2009).

Our aim is to estimate the microrefugial areas in the Mediterranean region of Anatolia, which we consider being an important refugial area for current and future with a high rate of endemism and biodiversity. In other words, we defined microrefugia areas where species can survive during anthropogenic climate change, by predicting the intersection of future climatic suitable habitats of the species. In order to estimate the position of microrefugia, we suggest focussing on the intersection of endemic species, that indicate the ecosystem is healthy, and species representing the climate of the refuge in future climate change scenarios. In this study, an endemic reptile Danford's Lizard (*Anatololacerta danfordi*), endemic plant species Turkish Oregano (*Origanum minutiflorum*) and Kasnak Oak (*Quercus vulcanica*), ecosystem health indicator Griffon Vulture (*Gyps fulvus*) and Brown Bear (*Ursus arctos*), and such as Calabrian Pine (*Pinus brutia*) representing regional climate are the species that help us predict microrefugial areas in Mediterranean Region of Anatolia. We think that these microrefugial areas, estimated in this study, should be subjected to priority protection, since day are thought to be least affected by climate change. In this way, many species will continue their generation by taking refuge in these areas during climatic change effect.

2. MATERIAL AND METHOD

Species Data

The species data of the study included 53 locations for *Anatololacerta danfordi* (Danford's Lizard), 76 locations for *Ursus arctos* (Brown Bear), 147 locations for *Origanum minutiflorum* (Turkish Oregano), 46 locations for *Quercus vulcanica* (Kasnak Oak) and 1357 locations for *Pinus brutia* (Calabrian Pine). Thirty-four *Gyps fulvus* (Griffon Vulture) data were obtained from Global Biodiversity Information Facility (GBIF- www.gbif.org) and from our own fieldwork. Species data were converted to excel "csv." format for each species and made ready for analysis.

Bioclimatic Data

The Worldclim dataset consists of bioclimatic data, which temperature and precipitation are represented monthly, quarterly, seasonal and annual (Table 1). Nineteen bioclimate data (current and future) were downloaded from www.worldclim.org. (30 arc-seconds (~1 km)). The climate variables of the RCP 2.6, RCP 4.5 and RCP 8.5 scenarios were downloaded from the HadGEM2-ES model. The HadGEM2-ES model helps to project long-term changes in climate and ecosystem from 2006 to 2100 and includes atmospheres, land surface and hydrology, aerosols, ocean and sea ice, terrestrial carbon cycle, atmospheric chemistry, and ocean biogeochemistry configurations (Dike et al., 2015).

Climatic Habitat Suitability Modelling

We managed the analysing procedure with the help of MaxEnt, which gives better results than other modelling methods even in small areas with minimum data (Elith et al., 2006; Hernandez et al., 2006; Wisz et al., 2008). MaxEnt estimates which environmental conditions have an impact on the distribution of organisms, referring to the presence data of organisms (Baldwin, 2009). Furthermore, with the help of MaxEnt, current climatic conditions and future climate scenarios can be analysed together, and the potential distribution of species in today's conditions and future climate change can be estimated. We used MaxEnt 3.4.1 software to determine the climatic conditions affecting the distribution of species in today's conditions and to determine their distribution during anthropogenic climate change. During the analysis process, we used 90% of the species presence data as training data and 10% as test data. The software was asked to perform ten repetitions for each model. In this way, the software analysed different training and test data for each repetition compared to the previous repetition. As a result of these analyses carried out separately for each species, the estimated climatic suitability maps (current, RCP 2.6, 4.5, 8.5) of the species were obtained in "ascii" format. These maps represent the habitat suitability, ranging from 0 to 1. When evaluating the model performance, the AUC values were considered. As the AUC value approaches from 0.5 to 1, it shows that the model is excellent and explanatory (Phillips et al., 2006).

Detection of Microrefugia

Climatic suitability maps (each takes a value between 0 (Low: blue) and 1 (High: red) of six species in ascii format were visualised using ArcMap 10.2 software. With the help of the calculator feature in ArcMap 10.2 software, the current distributions of the six species were superposed and intersection areas were obtained. Then the same procedure was performed separately for each of the HadGEM2-ES RCP 2.6, RCP 4.5, RCP 8.5 2070 scenarios. In the maps obtained as a result of this process, the red areas will show the areas where the microrefugia are most likely to be found.

3. RESULTS

As a result of the analyse we made for six species, we found that the AUC values were close to 1 (Fig.1). Therefore, we can say that the performance of the models is high. The climatic factors that limit the distribution of each species are shown in Figure 2.

According to *Anatololacerta danfordi*'s (which is an endemic reptile species in the Mediterranean Region of Anatolia) analysis results, $AUC_{\text{training data}}$ value is 0.962, and $AUC_{\text{test data}}$ value is 0.924. In the model giving these results, climatic factors limiting the distribution of *A. danfordi* were determined as Bio6, Bio8, Bio12, Bio14. When we look at the results of the region's largest bird species, *Gyps fulvus*, $AUC_{\text{training data}}$ value is 0.907, and $AUC_{\text{test data}}$ value is 0.906. Bio4, Bio8, Bio14, Bio17, Bio19 were the climatic factors limiting the distribution of this species. When the results of Brown Bear, which is the largest mammal species in the region, are investigated, the $AUC_{\text{training data}}$ and $AUC_{\text{test data}}$ values are 0.984 and 0.983, respectively. Climatic conditions that limit the distribution of Brown Bear are Bio3, Bio8, Bio13 and Bio19. $AUC_{\text{training data}}$ and $AUC_{\text{test data}}$ values of *O. minutiflorum* (endemic plant species) were 0.990 and 0.987, respectively. Bio7, Bio12, Bio13, Bio16 and Bio17 have been found to provide the climatic requirements of this species. Another endemic plant species *Quercus vulcanica* was found to have $AUC_{\text{training data}}$ value is 0.994, and $AUC_{\text{test data}}$ value is 0.981. The climatic conditions that makeup climatically suitable habitats of *Q.vulcanica* are Bio8, Bio13, Bio14, Bio15, Bio17, Bio19. Results of *Pinus brutia*, which has the largest distribution in the region, are 0.946 for $AUC_{\text{training data}}$ and 0.939 for $AUC_{\text{test data}}$. Bio3, Bio14, Bio17 and Bio19 were found to be climatic conditions limiting the distribution of *P.brutia*.

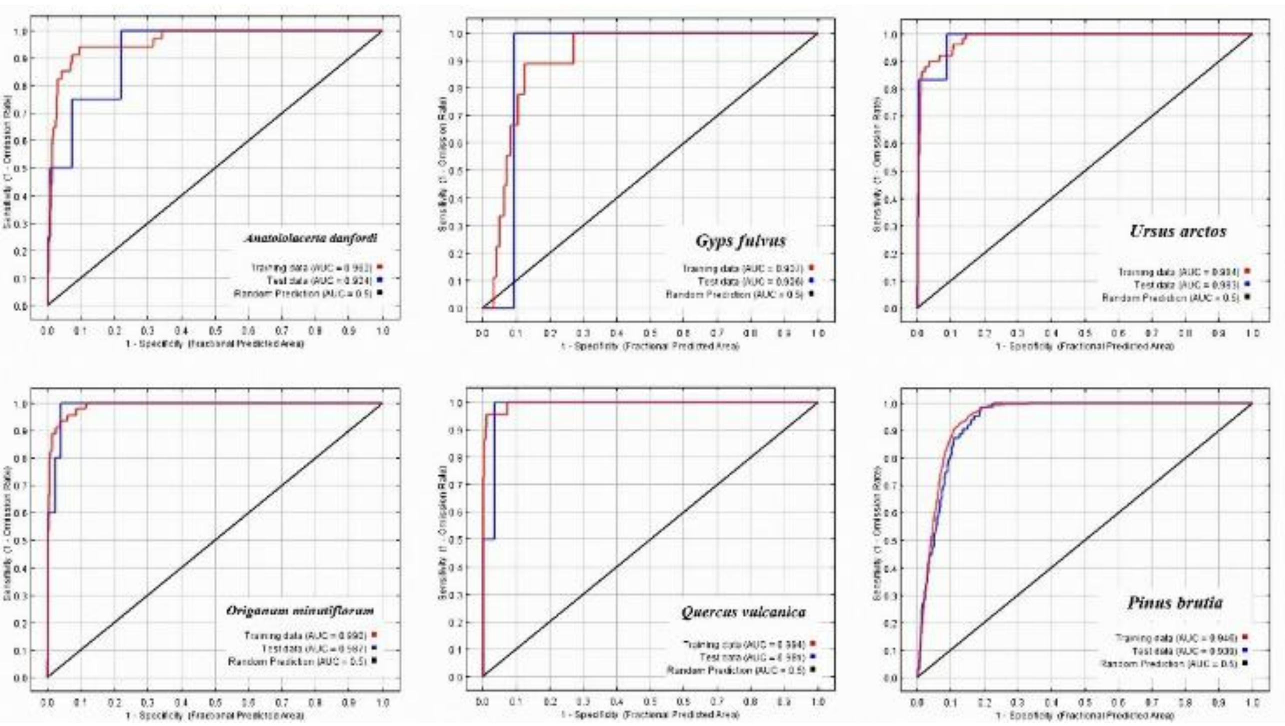

Figure 1. Sensitivity vs 1- specificity graphic and AUC values

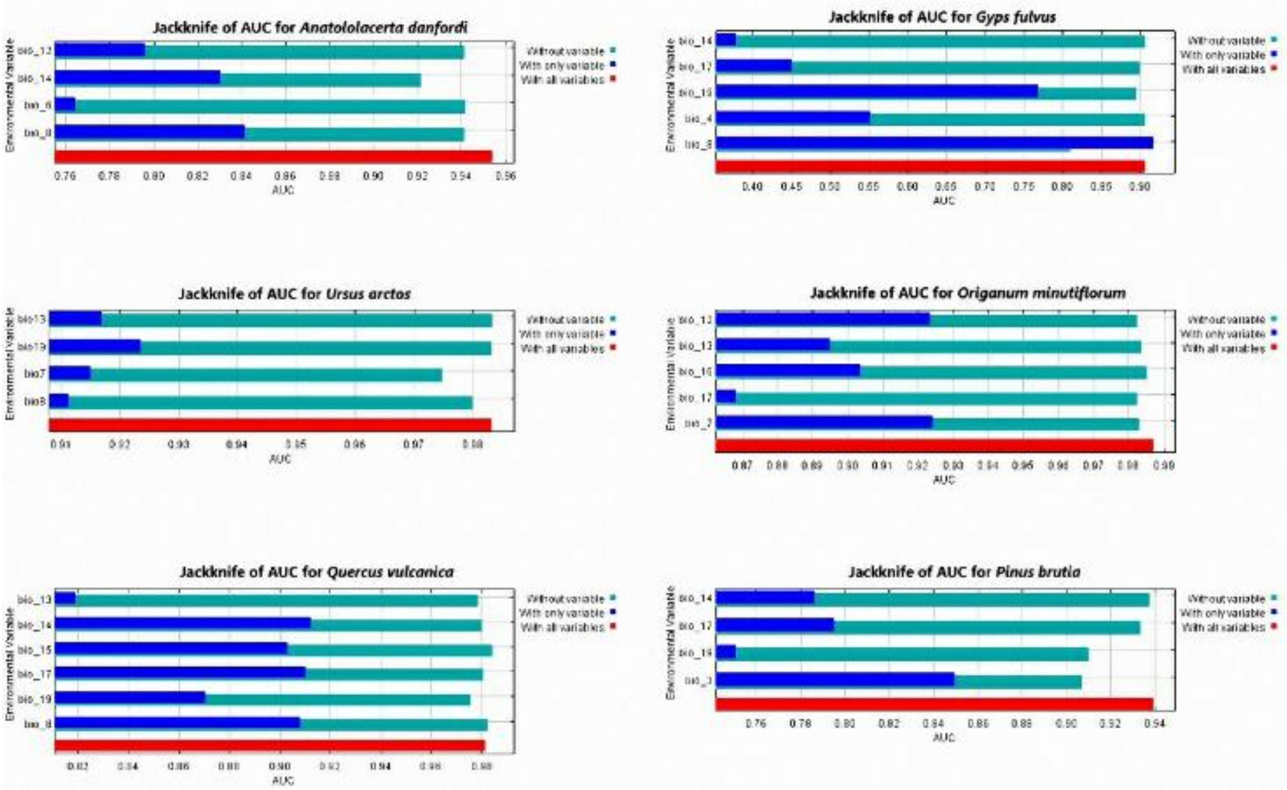

Figure 2. Results of jackknife evaluations of the relative importance of predictor variables

The map outputs of climatic habitat suitability modelling show the distribution of each species according to climatic conditions in the current, RCP 2.6, RCP 4.5 and RCP 8.5 scenarios (Fig. 3). When these maps are examined, we can say that in the scenarios RCP 2.6, RCP 4.5 and RCP 8.5, habitats providing climatic conditions suitable for these six species will decrease compared to the present day. The worst climate conditions are seen in the RCP 8.5 scenario. Again, looking at these maps, we can say that the endemic lizard species *A.danfordi* and the two endemic plant species *O.minutiflorum* and *Q. vulcanica* are the species most affected by climate change. The results show that endemic species will experience more loss of habitat than other species.

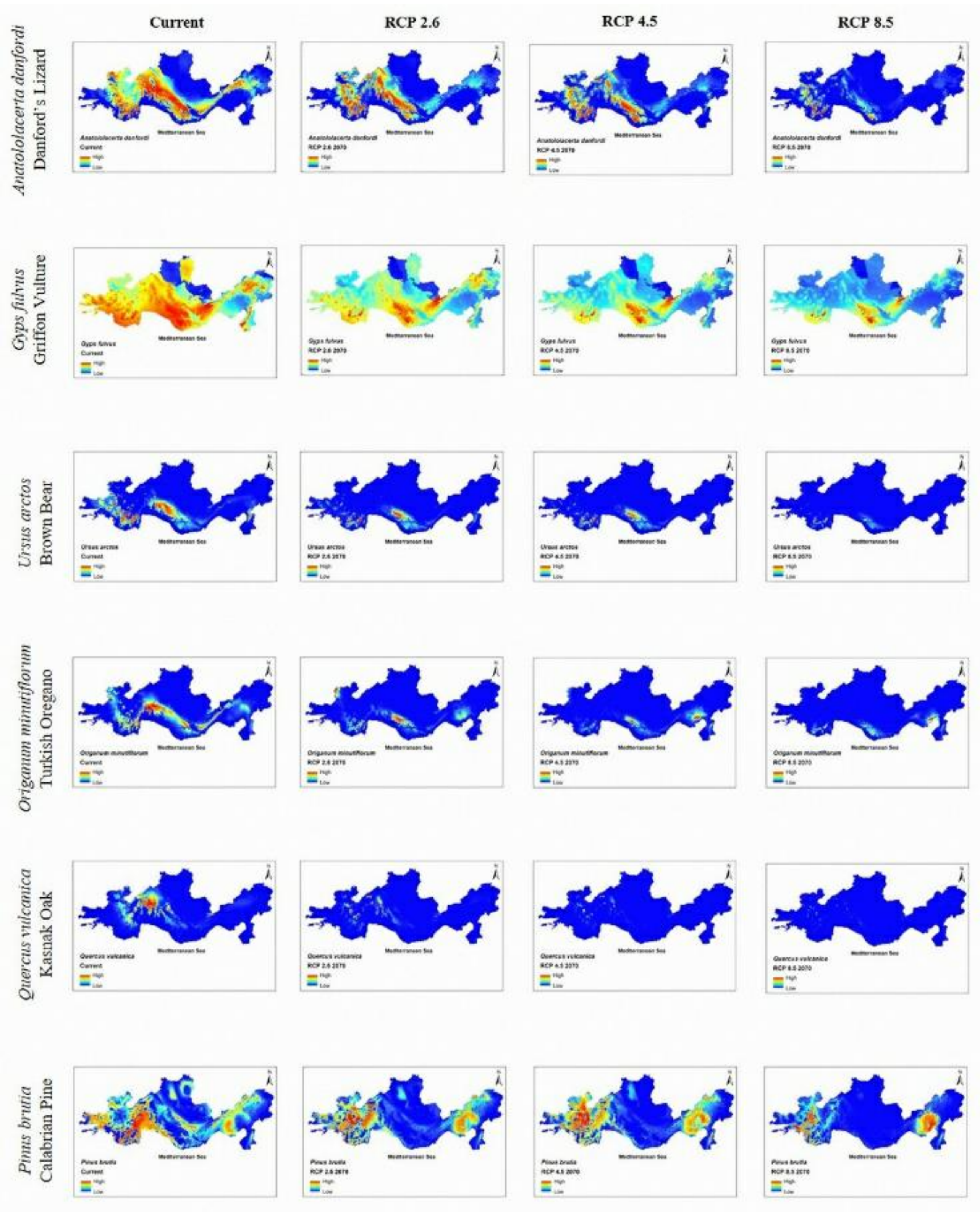

Figure 3. Climatic suitability maps

Nevertheless, some areas seem to provide suitable climatic conditions even in the worst scenario, even if they are small than current. We showed in Figure 4 (red areas), the areas where small areas that continue to provide these suitable climatic conditions intersect for these six species. These small areas of intersection are microrefugia which are not affected by climate change and continue to provide suitable climatic conditions during anthropogenic climate change. As shown in Figures 4 B, C and D, climate change velocity is high in the blue areas. We suggest that red areas may be microrefugia. These red areas will be critical habitats in which species can shelter and can sustain their generation in anthropogenic climate change.

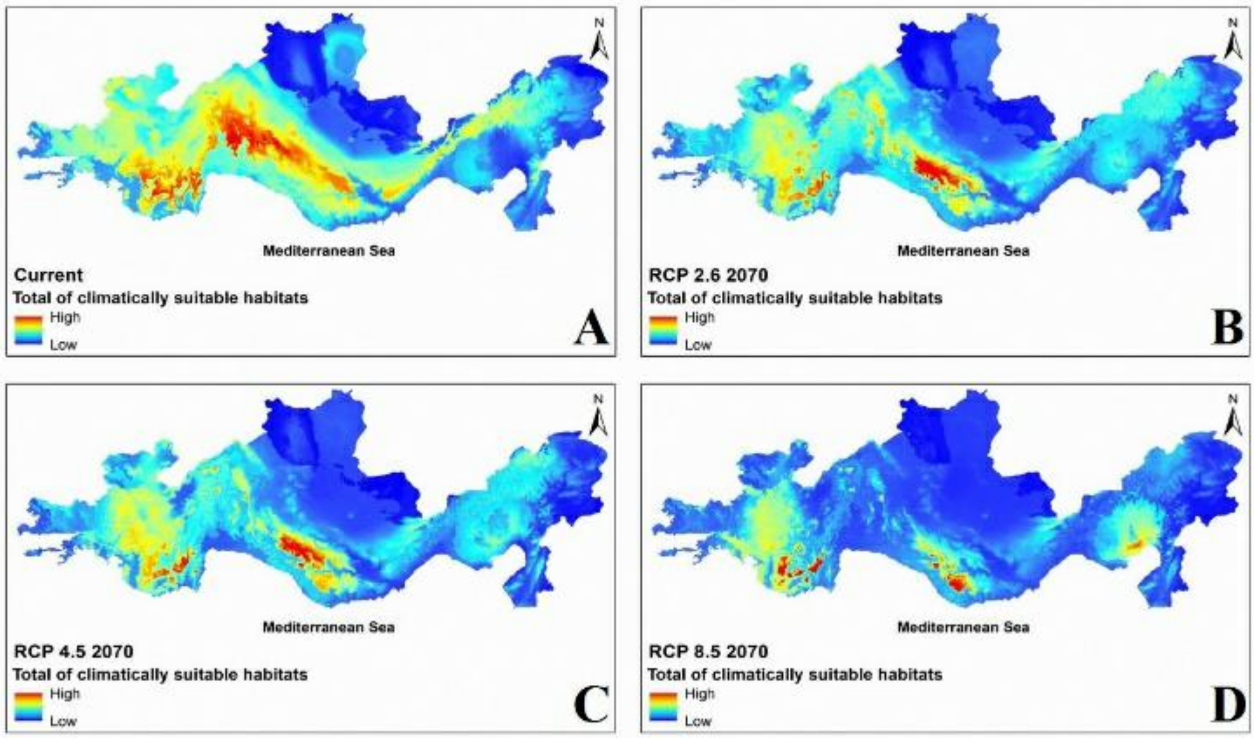

Figure 4. Intersection map of suitable climatic conditions. A) The intersection of climatically suitable habitats in the current. B) The intersection of climatically suitable habitats in the RCP 2.6 scenario. C) The intersection of climatically suitable habitats in the RCP 4.5 scenario. D) The intersection of climatically suitable habitats in the RCP 8.5 scenario.

4. DISCUSSION AND CONCLUSIONS

In order to predict the response of species to anthropogenic climate change, it is necessary first to determine which in climatic conditions the species distribute today. In many studies bioclimatic variables (bio1-19) from Current Condition version 1.4, which represent climatic conditions from 1960 to 1990 in the worldclim database were used to determine the climatic conditions necessary to maintain the continuity of a species (Hijmans et al. 2005). The next step is to predict where these climatic conditions for the target species will be found during climate change. Perhaps these climatic conditions will remain unchanged within the species' natural habitats or will disappear altogether or remain unchanged in smaller areas within or outside the area in which it is distributed. At this stage, bioclimatic variables of RCP scenarios representing changes during anthropogenic climate change are needed. To achieve the result, the species distribution model is created by using the presence data of the target species, the existing bioclimate variables and the bioclimatic variables of the RCP scenarios. As a result, areas with suitable climatic conditions for the species during anthropogenic climate change were predicted.

How a species will react during anthropogenic climate change has been investigated in many recent studies. In summary, these studies predicted that the climatic habitats of a species would be reduced and fragmented by the end of the century due to climate change. Moreover, these studies have already suggested to preserve these climatic habitats that will survive in the future (Fordham et al., 2012; Bezeng et al., 2017; Vicenzi et al., 2017; Wilson et al., 2019). Although it is crucial to do conservation planning by making predictions for the future, it is complicated to evaluate and plan for each species separately. Therefore, in the refugial areas where endemism and biodiversity are high, finding the intersection points in the maps obtained from Future Climatic Habitat Suitability Models of the species representing the ecosystem is significant for the success of conservation planning. That is, identifying and preserving microrefugia is vital to the sustainability of biodiversity. According to Harrison and Noss, 2017, it is critical to identify and protect the microrefugia that maintains the species's persistence in order to establish the link between biodiversity and stability (low climate change velocity) in the future. However, nothing is more critical than minimising global warming and habitat destruction. Because a rapid climate change and the increasing destruction of natural habitats by humans will destroy even the microrefugia.

This study was conducted using data from a total of 6 species, including an endemic reptile, an endemic woody plant, an endemic herbaceous plant, the largest bird in the region, the largest mammal in the region, and a typical plant species in the region. These three endemic species have taken refuge in this region in the past, and their distribution has been limited to this region. Also, endemic species represent specific climatic conditions and climate stability in refugial areas. Therefore, the data of these three endemic species were very important for our results. The data of Griffon Vulture and Brown Bear were also critical in predicting microrefugia, as it indicated that the ecosystem was healthy. Calabrian Pine, which has the highest population and distributes in many parts of the region, has assumed the duty of control by representing the general climate of the region from west to east. For these reasons, we think that with these six species, we make an ideal prediction for the location of microrefugia. Finally, climatic habitat suitability modelling of representative species selected from living groups such as lichen, fungus, amphibian and insect can be added to these studies, and the location of microrefugia can be estimated more accurately in the next studies.

Ethics Committee Approval
N/A

Peer-review
Externally peer-reviewed.

Conflict of Interest
The authors have no conflicts of interest to declare.

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