https://doi.org/10.31298/sl.148.7-8.5

Izvorni znanstveni članci – Original scientific papers Šumarski list, 7–8 (2024): 375-387

WILL CINEREOUS VULTURE (*Aegypius monachus* L.) BECOME EXTINCT IN THE FORESTS OF TÜRKIYE IN THE FUTURE?

IZUMIRE LI CRNI STRVINAR (*Aegypius monachus* L.) U BUDUĆNOSTI U ŠUMAMA TURSKE?

Ahmet ACARER[1]*

SUMMARY

Changing climate conditions and different climate scenarios on a global scale are associated with the shrinkage, fragmentation and even extinction of habitats of important bird species. Based on this, the aim is to conduct habitat suitability modelling and mapping of the cinereous vulture (*Aegypius monachus*), which has the largest body among the four different vulture species in the world, under the circumstances of climate change in Türkiye. MaxEnt method was performed to reveal the current habitat suitability model of the cinereous vulture, which is an indicator of old and high-quality black pine forests in terms of biological diversity in Türkiye. It was determined that the variables contributing to the current habitat suitability model of the cinereous vulture were bedrock, isothermality, landform classification and seasonal precipitation. Chelsa climate scenarios (SSP126-SSP370-SSP585) for the year 2100 were used to reveal the effects of changing climate conditions on the cinereous vulture. Mapping results according to different scenarios were classified as 0.5 – unsuitable, 0.51-0.8 – suitable and 0.81-1.0 – the most suitable habitat. According to the mapping results based on different year and scenarios, cinereous vulture has suitable habitat in a minimum of 16.13% of the study area in the present state, 13.95% in the year 2100 in the SPP126 climate scenario, 10.11% in the SPP370 climate scenario and 7.36% in the SPP585climate scenario. As a result, when the 2100 SSP585 climate scenario mapping was compared to the current habitat suitability mapping, it was determined that habitat suitability for the cinereous vulture decreased by approximately 55%. Therefore, these results will be a source of information to prevent the extinction of the cinereous vulture, in order to protect its current and potential distributions in advance, and to reduce the impact of changing climate conditions.

KEY WORDS: *Aegypius monachus*, climate change, wildlife conservation, modelling and mapping, maximum entropy

INTRODUCTION
UVOD

Türkiye shelters different habitats for bird species thanks to its location and geographical features (Karakaş, 2010; Kirwan et al., 2010). In other words, two of the four important migration routes in the Western Palearctic Region pass through Türkiye (Bilgin et al., 2016), which has very favourable ecological conditions for birds (Leshem and Yom-Tov 1998). Therefore, Türkiye has a rich ornithological fauna in terms of bird diversity and richness (Özay and Özkazanç, 2022). Türkiye hosts 491 bird species in total, 452 of which have been documented and 39 of which have not been seen for a long time, but their existence has been recorded (Dizdaroğlu, 2015; Elvan et al., 2022). Some of these include cinereous vulture (*Aegypius monachus)* and imperial eagle *(Aquila heliaca)*, which are among the world's rarest vertebrate species (Collar et al., 1994; Donázar et al., 2002; Demerdzhiev et al., 2011). Furthermore, the fact that four vul-

[1] Assist. prof. Ahmet Acarer, PhD, Isparta University of Applied Sciences, Faculty of Forestry, Department of Wildlife Ecology and Management, Türkiye
* Coresponding adress: aacarer32@gmail.com

ture species belonging to the *Accipitridae* family have been found, namely bearded vulture (*Gypaetus barbatus*), Egyptian vulture (*Neophron percnopterus*), griffon vulture (*Gyps fulvus*) and cinereous vulture (*Aegypius monachus)*, their distribution in Türkiye supports the indicator of bird species diversity and richness (Göktürk et al., 2008; Doğa, 2015; Doğa, 2021).

Cinereous vulture, which has the bulkiest body among the vulture species belonging to the *Accipitridae* family, is known to be among the largest bird of prey species in Europe (Ogada et al., 2012; Van Dooren, 2012). Although it has a bulky body, cinereous vulture can fly or glide silently in the air with its wide and long wings (Dunne and Karlson, 2017). Like all carrion eaters, they also feed on the carcasses of dead animals, snatch the prey of other predators and the like (García-Barón et al., 2018). In addition, cinereous vultures have an important ecological role since they are birds that can tear the skin of carrion, thanks to their strong and thick beaks (Ferguson-Lees et al., 2001; Chander, 2013). Thanks to the durable structure of their beaks, they can make their nesting sites both on trees and in rocky areas. Nesting sites in rocky areas can usually be found in Asia. In Europe, it has been recorded that the species prefers tree species such as juniper and oak (Reading et al., 2005; Moreno-Opo et al., 2012). In Türkiye, black pine (*Pinus nigra*), and rarely other species from the *Pinaceae* family and oak species, may be used as nesting sites (Yamaç and Bilgin 2012).

However, adverse effects such as developing industry, increasing population rate and climate change brought about by advancing technology in the 19th century have endangered some bird species (Carey, 2009; Upadhyay, 2020). This situation can be explained by the fact that in the last hundred years, the habitats of approximately 200 bird species in the world have been fragmented, shrunk, and even faced with the danger of extinction (Tabur and Ayvaz, 2010). These negative effects are still increasing even at the beginning of the 21st century. For example, the habitats and distribution of cinereous vulture, which is thought to be around 50-100 pairs in Türkiye, has been adversely affected (Özçelik, 2009). This species, which has become extinct in countries such as Cyprus, Italy, Moldova, Romania, and Slovenia, is being rereleased into nature in France (Kirazli, 2013) in order to maintain its existence within the country.

The habitat preference and distribution of cinereous vulture has changed regarding the geography and landform where it is distributed (Gavashelishvili et al., 2012; Guerrero-Casado et al., 2013). In general, the regions with continental climate in the West Palearctic region are suitable habitats (Arslan and Kirazli, 2022). It shows a potential distribution from the temperate zone to the boreal zone vertically. In these regions it prefers high hillsides, upper slopes containing clearings and old trees as nesting sites. However, cinereous vulture does not prefer seacoasts, wetlands, and closed basins which are extremely preferred by humans as habitats (Carrete and Donázar, 2005). It also does not prefer areas where there are no suitable nesting trees or cliffs, and where harsh climatic conditions prevail. Therefore, changing climatic conditions pose a threat to the cinereous vulture and its potential distribution, which is also the case with other wild animals (Cramp and Simmons, 1980; Mert et al., 2016; Suel et al., 2018; Kıraç and Mert, 2019; Özdemir et al., 2020; Kıraç, 2021; Kıraç et al., 2022).

Different numerical and model-based methods, such as generalized additive model (GAM) or random forest (RF), may be used to perform endangered wild animal habitat suitability modelling and mapping (Hastie and Tibshirani, 1990; Miller, 2010; Rigatti, 2017). One such method is the maximum entropy (MaxEnt) software, which is a probability calculation method. In habitat suitability modelling and mapping studies of wildlife and bird species, the models produced by MaxEnt software provide more reliable and accurate results than other methods (Phillips et al., 2006). MaxEnt software comes to the fore for the protection, development, and sustainability of habitats when past, present and future climate models are considered, with minimal existing data on the target species that are endangered or at risk of extinction (Elith et al., 2011).

Global climate models make predictions for the future with the help of statistical analyses (Winsberg, 2012), considering current climatic conditions. Evaluating these models and obtaining the results covers a long and complex process. However, it has been stated that determining appropriate habitats for the target species using future climate scenarios is the most effective for taking protection measures (Hartmann, 2015; Pottier et al., 2017). In summary, while there are many global climate scenarios that may display an impact on birds, in general, Chelsa V2.1 climate scenarios are preferred (Ramesh et al., 2022).

This study aimed to reveal the current and future habitat suitability maps of the endangered cinereous vulture, which is distributed in Türkiye. For this purpose, Chelsa climate scenarios (IPSL-CM6A-LR SSP126-SSP370-SSP585) were used for current (2010) and future (2100) modelling and mapping projections of cinereous vulture. As a result, areas that must be protected for the protection, development and sustainability of the cinereous vulture were determined.

MATERIALS AND METHODS
MATERIJALI I METODE

Study area and species data collection – *Područje istraživanja i prikupljanje podataka o vrsti*

The geographical location of Türkiye, forming the study area, is located between 26°-45° east longitude and 36°-42° north latitude. Thanks to its geographical location, Türkiye

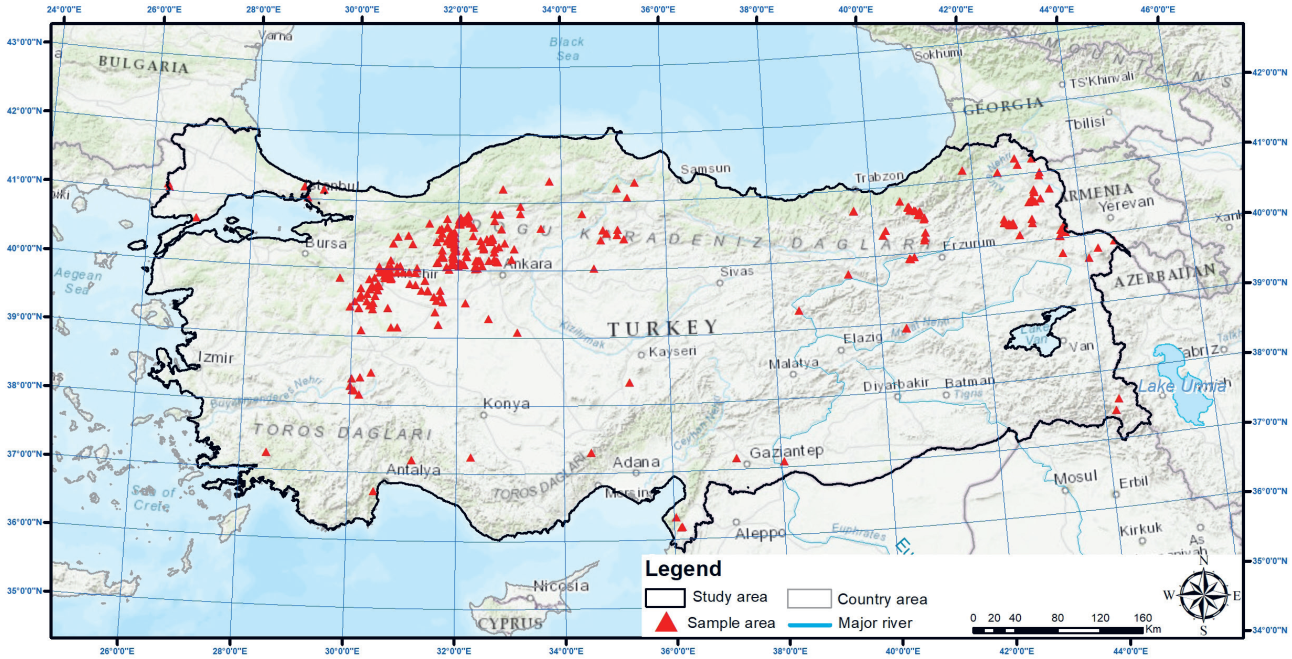

Figure 1. Location mapping of cinereous vulture *(Aegypius monachus)* presence data
Slika 1. Mapiranje podataka o prisutnosti crnog strvinara (*Aegypius monachus*)

is home to many bird species. According to the inventory classification of the World Union for Conservation of Nature and Natural Resources, the endangered cinereous vulture is distributed in Türkiye (IUCN, 2023). Numerically based sample locations (62 895) of the cinereous vulture, the target species of the study, were obtained from the international Global Biodiversity Information Facility (GBIF, 2022). The present data of cinereous vulture obtained at the world scale were repositioned based on the study area boundary and coordinates "Lambert conformal conic ED50". As a result, only 352 sample areas from the present data are included in the study area. Presence data for the target species are shown in red on the map. (Figure 1).

Production of digital base maps – *Izrada digitalnih baznih karata*

To produce the digital base maps, the digital elevation model (~**1 km*1 km**) of the study area was downloaded from the internet (www.usgs.gov/). Based on the digital elevation model of the study area, base maps were created using different indices, formulas, Arc toolboxes or they were obtained from various institutions. In this context, Elevation, Aspect, Slope, Landform classification, Roughness3, Roughness5, Topographic Position Index, Roughness Index, Solar Radiation Index, Topographic Humidity Index, Solar Illuminate Index (06am, 8am, 10am, noon, 2pm, 4pm, 6pm, 8pm, Solar illuminate) base maps were produced with the help of ArcMap 10.8 software. Environmental variables such as Stand type, Area (ha), Age classes, Cover, Bedrock, which may be effective on cinereous vulture distribution, were obtained from the General Directorate of Mineral Research and Exploration and Forest General Directorate. Base maps of the current (**30 arc-second ~1 km**) climate scenario of the Chelsa 2.1V (www.chelsa-climate.org) (Table 1) were created to reveal how the changing climatic conditions will affect the distribution of cinereous vulture. To reveal the impact of changing climate conditions on the species, Chelsa climate variables were obtained from future climate scenarios for the year 2100 (SSP126-SSP370-SSP585) (Karger et al., 2017). As a result, a total of 38 different base maps of the study area were created, including 19 environmental and 19 Chelsa climate variables.

Variable selection and statistical analysis – *Odabir varijabli i statistička analiza*

The fact that independent variables have similar values in numerical and model-based habitat suitability mapping causes a high correlation among them. Switching to modelling with highly correlated variables creates the multicollinearity problem. To eliminate this problem, variables showing high correlation with each other are subjected to Correlation Analysis with the R software code. Principal Component Analysis (PCA $p<0.05$) is performed with the R software code to determine the best representative variable among the variables that emerged after the correlation analysis results. Therefore, as stated in some habitat suitability mapping studies, it is stated that Chelsa shows a high correlation between current climate variables (Brambilla et

Table 1. Chelsa climate variables
Tablica 1. Klimatske varijable Chelsa

Name/Ime	Full name/Puno ime	Unit/Jedinica
Bio1	Mean diurnal air temperature range	°C
Bio2	Mean annual air temperature	°C
Bio3	Isothermality	°C
Bio4	Temperature seasonality	°C
Bio5	Mean daily maximum air temperature of the warmest month	°C
Bio6	Mean daily minimum air temperature of the coldest month	°C
Bio7	Annual range of air temperature	°C
Bio8	Mean daily mean air temperatures of the wettest quarter	°C
Bio9	Mean daily mean air temperatures of the driest quarter	°C
Bio10	Mean daily mean air temperatures of the warmest quarter	°C
Bio11	Mean daily mean air temperatures of the coldest quarter	°C
Bio12	Annual precipitation amount	Kg m^{-2} $year^{-1}$
Bio13	Precipitation amount of the wettest month	Kg m^{-2} $month^{-1}$
Bio14	Precipitation amount of the driest month	Kg m^{-2} $month^{-1}$
Bio15	Precipitation seasonality	Kg m^{-2}
Bio16	Mean monthly precipitation amount of the wettest quarter	Kg m^{-2} $month^{-1}$
Bio17	Mean monthly precipitation amount of the driest quarter	Kg m^{-2} $month^{-1}$
Bio18	Mean monthly precipitation amount of the warmest quarter	Kg m^{-2} $month^{-1}$
Bio19	Mean monthly precipitation amount of the coldest quarter	mm m^{-2} $month^{-1}$

al., 2021). Consequently, the most significant variables were determined by performing the above-mentioned statistical analyses before the numerical and model-based modelling process (Özdemir et al., 2020; Zhang et al., 2021).

Numerical and model-based mapping method (Maximum Entropy) – *Metoda numeričkog mapiranja i mapiranja temeljena na modelu (maksimalna entropija)*

Maximum Entropy (MaxEnt) software, which enables analysis with presence data, is a probability calculation method. In habitat suitability mapping studies, models produced by MaxEnt provide more reliable and accurate results than other methods. Although it gives accurate and reliable results, two different methods are followed in the evaluation of the Area Under the Receiver Operating Characteristic Curve (AUC) values of the model obtained by MaxEnt (Phillips et al., 2006; Elith et al., 2011). The first of the replications of the model, the AUC training value, is the highest. The other, which is the difference between the AUC training and test values between the replications of the model, is the lowest. Regarding the AUC results of the model, the test data value should not be higher than the training data value. In addition, if the AUC value of the curve is less than 0.7, it is classified as "informative", between 0.7-0.9 as "good", and if it is greater than 0.9 it is classified as "very good" (Baldwin, 2009). As a result, the specified criteria were taken as basis in revealing the current habitat suitability model of cinereous vulture on a numerical basis. After the climate variables that are effective on cinereous vulture distribution are determined, future habitat suitability mapping was produced by subjecting them to the same analysis and processes according to the Chelsa climate scenarios in 2100 (SPP126-SPP370-SPP585). The resulting mapping process has been classified as unsuitable if the values were <0.5, suitable if they were 0.51-0.8, and the most suitable if they were 0.81-1.

RESULTS
REZULTATI

Chelsa climate variables selection – *Odabir klimatskih varijabli Chelsa*

Before proceeding with habitat suitability modelling, correlation analysis was applied in the R package program since Chelsa climate variables show a high relationship between each other. Principal Component Analysis (PCA) was applied to determine the best representative variables among the Chelsa climate variables that due to the same reason. As a result of the principal component analysis, it was revealed that 4 out of 19 climate variables explained the model by 7.624% variance and 89.742% cumulative (Tab. 2). The contributions of these variables were found to be Bio15 (0.918), Bio3 (0.911), Bio1 (0.814) and Bio12 (0.806), respectively (Tab. 3). Therefore, it was decided that 4 climate variables would be representative variables in the current habitat suitability mapping of cinereous vulture, which will be created with the maximum entropy method.

Table 2. Principal component analysis results applied to Chelsa climate variables
Tablica 2. Rezultati analize glavnih komponenti primijenjeni na klimatske varijable Chelsa

Component *Komponenta*	**Initial Eigenvalues** ***Početne vrijednosti***			**Extraction Sums of Squared Loadings** ***Ekstrakcija zbroja kvadratnih opterećenja***		
	Total *Ukupno*	% of Variance *Varijance (%)*	Cumulative *Kumulativno*	Total *Ukupno*	% of Variance *Varijance (%)*	Cumulative *Kumulativno*
1	8.49719	44.72205	44.72205	8.49719	44.72205	44.72205
2	4.435619	23.34536	68.06742	4.435619	23.34536	68.06742
3	2.669661	14.05085	82.11826	2.669661	14.05085	82.11826
4	1.448601	7.624214	89.74248	1.448601	7.624214	89.74248
5	0.80471	4.235316	93.97779			
6	0.616649	3.245523	97.22332			
7	0.339211	1.785324	99.00864			
8	0.07198	0.378842	99.38748			
9	0.057146	0.30077	99.68825			
10	0.01931	0.101629	99.78988			
11	0.017334	0.091234	99.88112			
12	0.007293	0.038387	99.9195			
13	0.006622	0.034854	99.95436			
14	0.004565	0.024026	99.97838			
15	0.002124	0.011177	99.98956			
16	0.001564	0.008232	99.99779			
17	0.000323	0.001701	99.99949			
18	9.66E-05	0.000508	100			
19	-1.9E-15	-1E-14	100			

Table 3. Component matrix results (r^2) applied to Chelsa climate variables
Tablica 3. Rezultati matrice komponenti (r^2) primijenjeni na klimatske varijable Chelsa

Variable *Varijabla*	Component/*Komponenta*			
	1	2	3	4
bio1	0.795	0.526	0.814	–0.095
bio10	0.812	0.373	0.377	–0.043
bio11	0.71	0.681	0.025	–0.112
bio12	–0.877	0.395	0.806	0.15
bio13	–0.778	0.39	0.398	0.245
bio14	–0.808	0.169	–0.113	–0.112
bio15	0.918	0.015	0.73	0.373
bio16	–0.767	0.398	0.413	0.232
bio17	–0.613	0.219	–0.066	–0.1
bio18	–0.893	0.019	0.122	–0.24
bio19	–0.539	0.68	0.049	0.436
bio2	0.395	–0.685	–0.24	0.371
bio3	0.366	0.911	–0.754	0.256
bio4	0.085	–0.664	0.647	0.16
bio5	0.877	0.238	0.318	0.047
bio6	0.643	0.746	0.014	–0.114
bio7	0.153	–0.839	0.394	0.237
bio8	0.081	–0.199	0.453	–0.703
bio9	0.565	0.524	–0.236	0.293

To eliminate the multicollinearity problem between the representative climate variables and other environmental variables, the correlation between 4 different climate variables and 19 other environmental variables was examined. According to the results of the correlation analysis, a positive relationship ($r=0.972$, $p<0.05$) was found between Bio1 and elevation. Among these highly correlated variables, the elevation variable was chosen for the modelling because it defines the land surface more clearly. As a result of these analyses, it was decided that 22 of the 38 independent variables (19 Chelsa climate variables and 19 environmental variables) produced for the study area could be used in the modelling stage.

Climatic and environmental habitat suitability modelling results for cinereous vulture – *Rezultati modeliranja klimatske i ekološke prikladnosti staništa za crnoga strvinara*

Current modelling and mapping – *Trenutno modeliranje i mapiranje*

For the habitat suitability modelling and mapping for cinereous vulture, 32 different models were created with 22 independent variables. When the models were evaluated according to accuracy criteria, it was determined that there was no deviation in the omission graph of the 30th model (Fig 2a). AUC value of the training data of the 30th model was 0.852, and its test data AUC value was 0.840, which is the most suitable habitat suitability model (Figure 2b). According to the jackknife training graph, the environmental and climate variables that make up the model were determined to be Bedrock (Anakaya), Isothermalty (Bio3), Landform classification (lpi5_11) and Precipitation of sea-

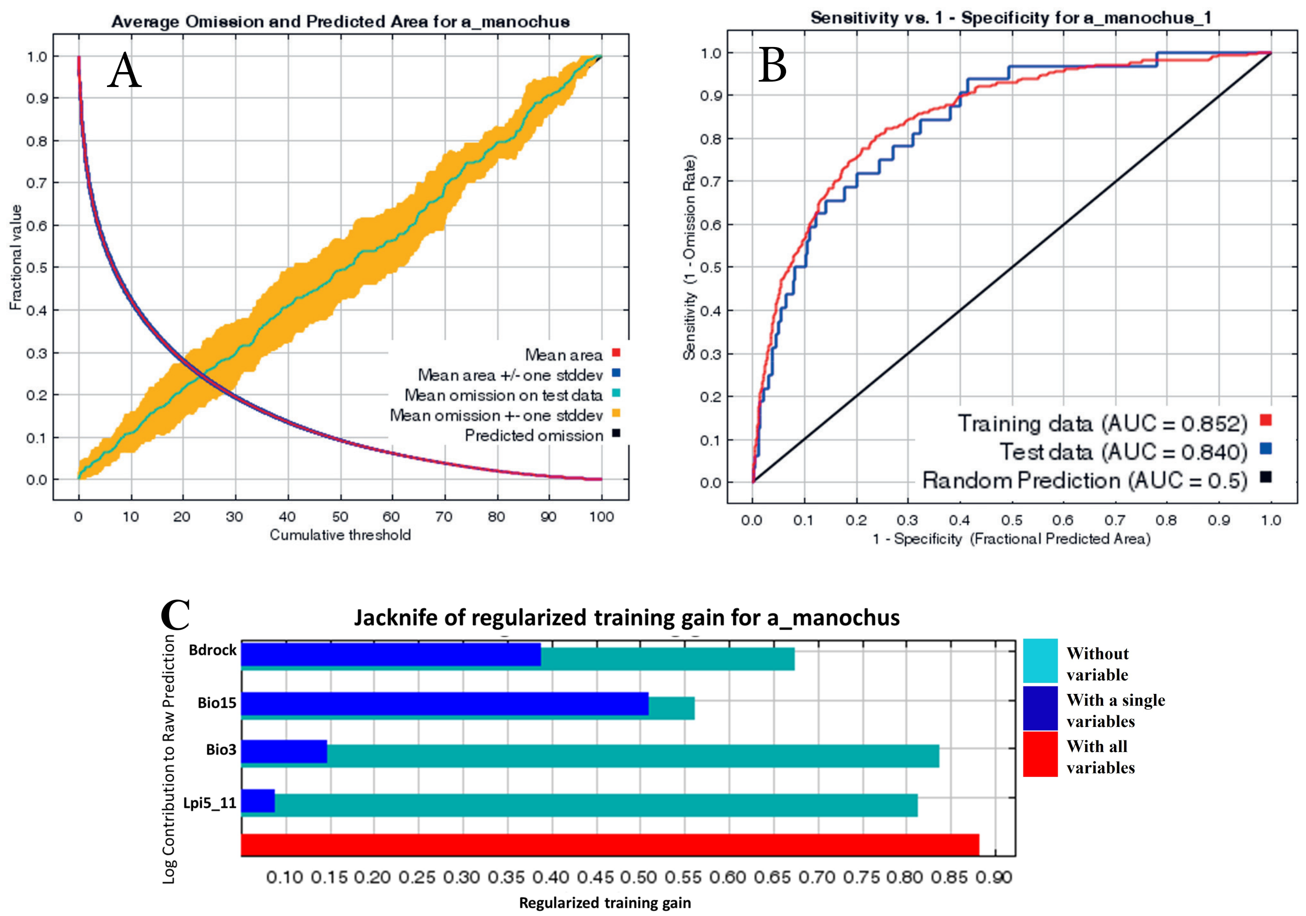

Figure 2. Current habitat suitability model of cinereous vulture: a) omission graph, b) AUC training data and AUC test data graph, c) jackknife training graph

Slika 2. Trenutačni model prikladnosti staništa za crnoga strvinara a) grafikon izostavljanja, b) grafikon AUC podataka o treningu i AUC podataka testa, c) grafikon treninga jackknife

sonality (Bio15). It was determined the variables contributing to the model are Bio15, Bedrock, Bio3, and lpi5_11, respectively (Figure 2c).

When the marginal responder graphs of the environmental variables presented were examined, it was found the species probability of existence was high in areas where the precipitation seasonality value, which contributed the most to the model, was around 380 mm. It was revealed the probability of the species to exist in areas where the precipitation seasonality is between 380 mm and 600 mm is present but decreased. According to the seasonality of precipitation, areas with precipitation above 600 mm have a negative impact on species distribution (Figure 3a). When the bedrock graph is examined, unseparated volcanic rocks (74), pyroclastic rocks (77) and evaporite sedimentary rocks (63) have shown a positive relationship on the species distribution (Fig 3b). Isothermality, which contributes to the model, is expressed as the ratio of diurnal variation to annual variation in temperatures, according to the Chelsa V.2 Technical Specification (Karger et al., 2017). Therefore, according to the model results, the probability of the species existence in areas where the daily and the annual temperature difference is up to 1.8°C, has a high relationship. It can be said the probability of existence in areas higher than this value is low (Figure 3c). When the graph of landform classification that contributes the least to the habitat suitability model was examined, it was found that 1=canyons, 3=upland drainages, headwaters, and 7=upper slopes, had a positive relationship with mesas, while 5=plains and 10=mountain tops, and high ridges had a negative relationship (Figure 3d).

Numerical and model-based habitat suitability mapping of cinereous vulture species was presented based on the variable values that were effective in the formation of the model (Figure 4). When the current potential habitat suitability map was examined, it was found that cinereous vulture stayed away from warm seas such as the Mediterranean and Aegean Seas in the study area. Similarly, it did not prefer very high elevation and areas with excessive precipitation. Therefore, it was revealed that the areas in the inner parts of Anatolia where the continental climate is dominant, where precipitation is low and temperatures are high, are suitable habitats for cinereous vulture.

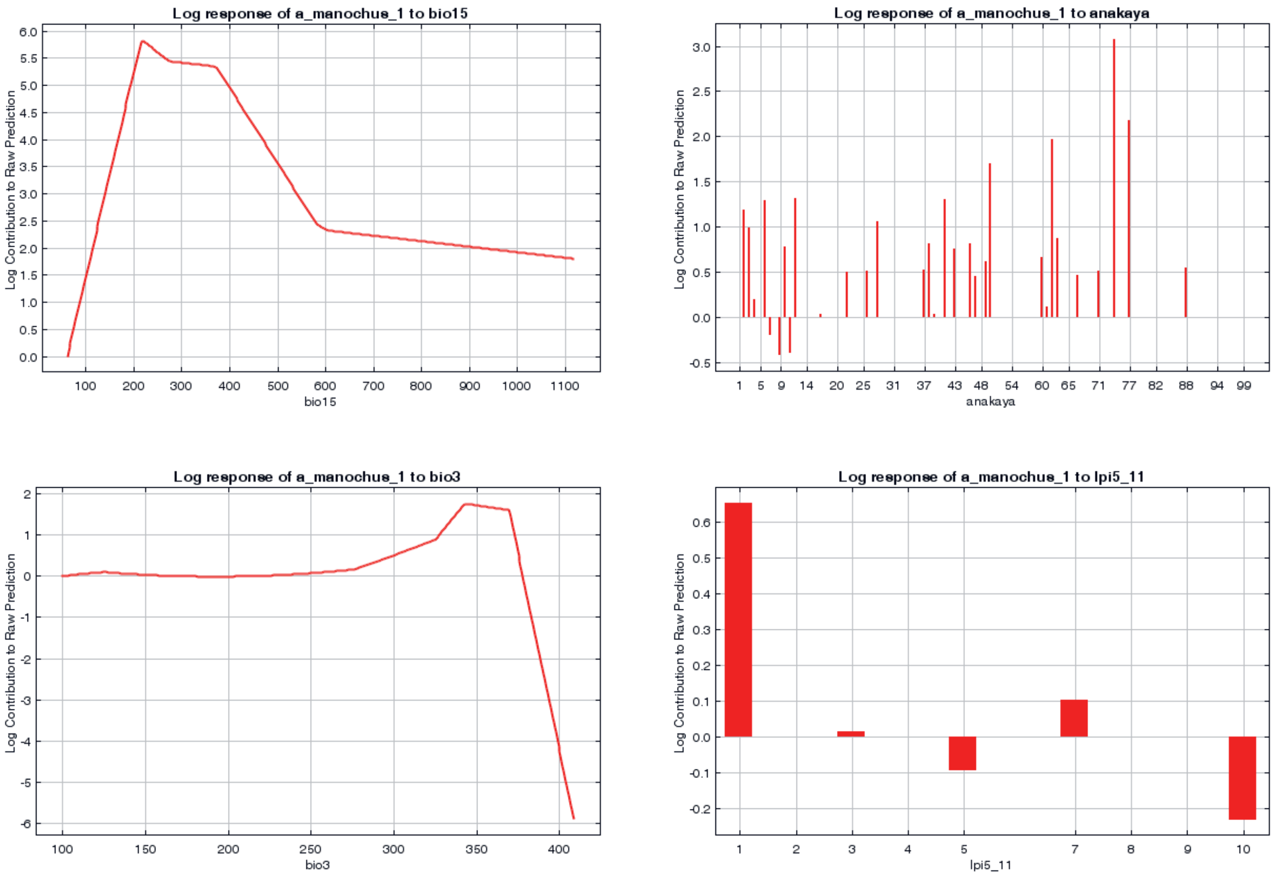

Figure 3. Cinereous vulture contributing to current habitat suitability model: a) precipitation seasonality graph, b) bedrock graph, c) isothermality graph, d) landform classification

Slika 3. Crni strvinar doprinosi trenutnom modelu prikladnosti staništa: a) grafikon sezonalnosti padalina, b) grafikon stjenovitog tla, c) grafikon izotermnosti, d) klasifikacija oblika reljefa

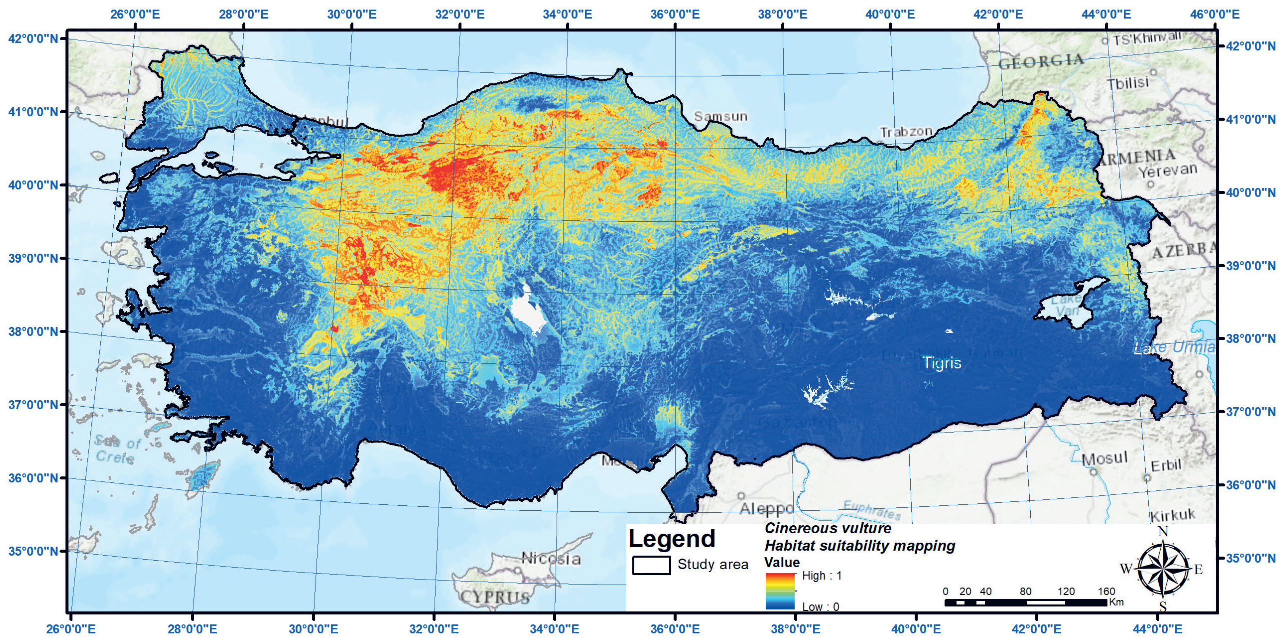

Figure 4. Cinereous vulture current habitat suitability mapping

Slika 4. Mapiranje prikladnosti trenutnog staništa crnog strvinara

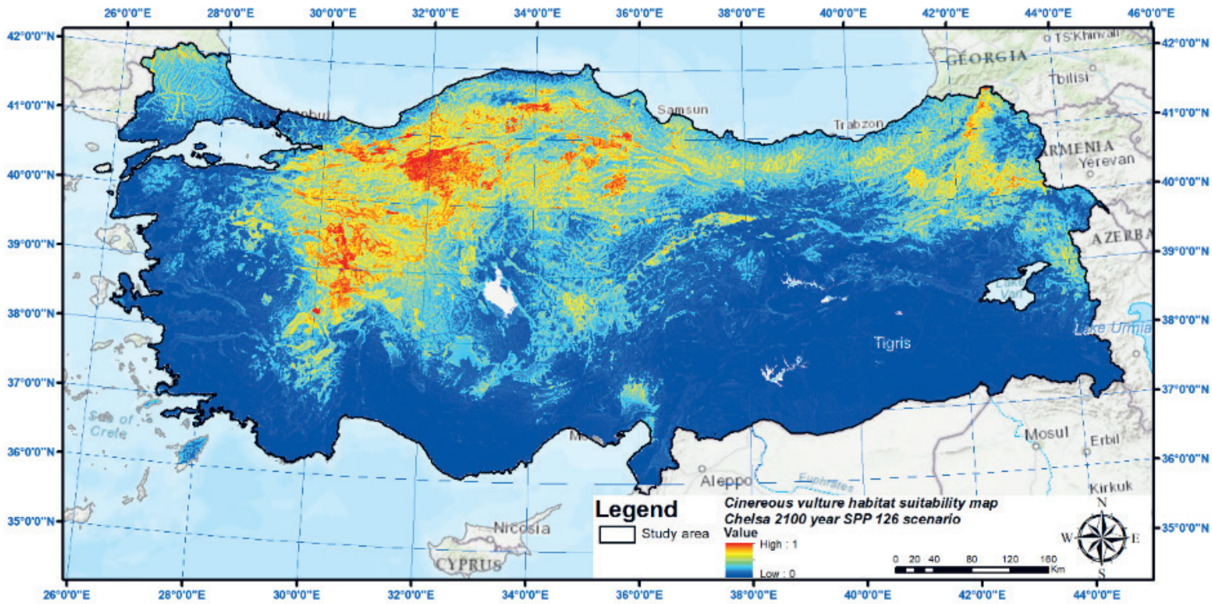

Figure 5. Cinereous vulture habitat suitability mapping for Chelsa year 2100 SPP 126 scenarios
Slika 5. Mapiranje prikladnosti staništa crnog stvinara za 2100. godinu za scenarije Chelsea SPP 126

Future modelling and mapping – *Buduće modeliranje i mapiranje*

Based on the environmental and climate variable values in the current potential distribution map of cinereous vulture, mapping was carried out with the Chelsa SSP126-SSP370-SSP585 climate envelope models for the year 2100. As a result of the mapping, shrinkages in suitable habitats for the species were detected according to the 2100 SSP126 climate envelope models (Figure 5). Similarly, according to the 2100 SSP370 climate envelope model, it is shown on the map that suitable habitats for the species are not only shrinking but also becoming fragmented (Figure 6). Finally, according to the 2100 SSP585 climate envelope model map, it was revealed that species habitats are under threat or even facing extinction (Figure 7).

The results were classified based on values of unsuitable habitat (0.5), suitable habitat (0.51-0.8), and the most suitable habitat (0.81-1.00). By evaluating the classification re-

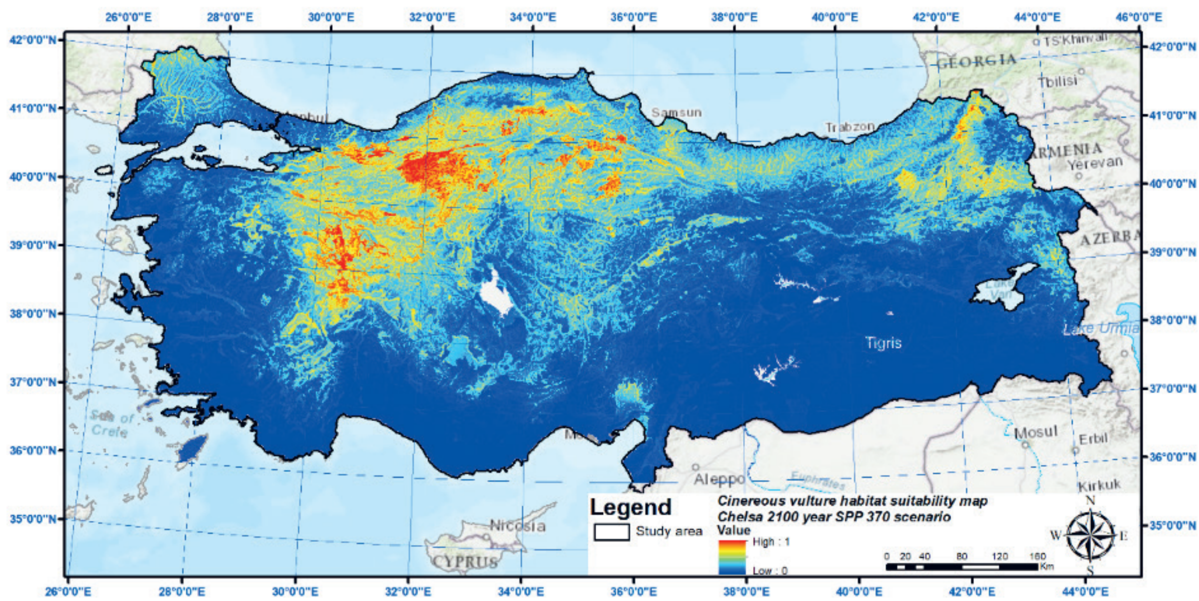

Figure 6. Cinereous vulture habitat suitability mapping for Chelsa year 2100 SPP 370 scenarios
Slika 6. Mapirenje prikladnosti staništa crnog stvinara za 2100. godinu za scenarije Chelsea SPP 370

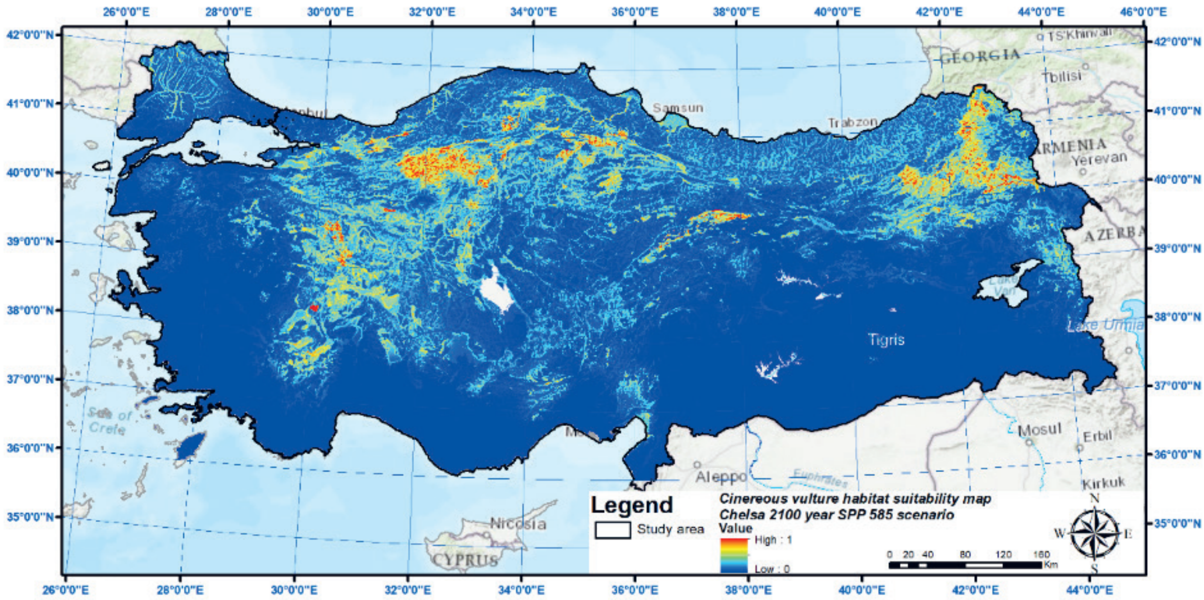

Figure 7. Cinereous vulture habitat suitability mapping for Chelsa year 2100 SPP 585 scenarios
Slika 7. Mapiranje prikladnosti staništa crnog strvinara za 2100. godinu za scenarije Chelsea SPP 585

sults, unsuitable habitats, suitable habitats, and most suitable habitats for the species were determined in % (Table 4).

When the current habitat suitability mapping of the cinereous vulture was evaluated, it was determined that the total of the suitable and most suitable areas for the species was 16.13%. According to the SSP126 Chelsa climate scenario in year 2100, the total of suitable and most suitable habitats for the species were 13.95%. In the SSP 370 scenario, this value was 10.11%. Finally, according to the SSP 585 climate scenario, the total of the suitable and most suitable areas for the cinereous vulture was 7.36%. When the 2100 SSP585 climate scenario was evaluated according to current habitat suitability mapping, it was revealed that approximately 55% of the total suitable habitat for the cinereous vulture will decrease. As a result, it was determined that while suitable habitats for the cinereous vulture will decrease according to all scenarios created for the year 2100, they will decrease by approximately 55% in the coming years according to the SPP 585 envelope model. When these values are evaluated on a study area (783.562 km^2) basis, it can be seen that the cinereous vulture study area is currently 126.388 km^2, 109.306 km^2 according to the SSP126 scenario, 79.218 km^2 according to the SSP370 scenario and 57.670 km^2 according to the ssp585 scenario. This value obtained is proof that cinereous vulture habitats are in danger of extinction.

DISCUSSION
RASPRAVA

In this study, habitat suitability modelling and mapping of the cinereous vulture distributed in Türkiye was created. In addition, suitable habitats were mapped with Chelsa climate scenarios for the future, which demonstrated significant changes that have vital effects on the potential distribution of wild animal species. This mapping process demonstrates the importance of climate envelope models to obtain a representative understanding of long-term cinereous vulture habitat preference (Gavashelishvili, 2012). Therefore, it is very important to integrate climate change into numerical and model-based methods compared to old classical methods in wild animal habitat preferences (LeDee et al., 2021).

Table 4. Cinereous vulture habitat suitability modelling rate
Tablica 4. Stopa modeliranja prikladnosti staništa crnog strvinara

Habitat suitability rate *Stopa prikladnosti staništa*	**Current** *Trenutno*	**Future**/*Buduće* **SSP (year**/*godina* **2100)**		
		126	370	585
0.0-0.50	83.87%	88.30%	89.89%	92.64%
0.51-0.80	13.11%	11.70%	8.04%	5.83%
0.81-1.00	3.02%	2.52%	2.07%	1.53%
Total suitable habitat *Ukupno prikladno stanište*	16.13%	13.95%	10.11%	7.36%

MaxEnt method was preferred due to various reasons. This is because MaxEnt method 1) gives the most accurate and reliable results with the least amount of data, 2) provides the opportunity to work with both categorical and continuous data, and 3) demonstrates the effects of climate, vegetation, and environmental effects (Phillips et al., 2004; Elith and Leathwick, 2009; Elith et al., 2011). According to model results, it was determined that there was no significant deviation in the average deficiency curve graph of cinereous vulture habitat suitability model. AUC values revealed that the selected replication was in the reliable and good model category (Baldwin, 2009). The standard deviation of the model was determined to be 0.031 and the variables contributing to the model were precipitation of seasonality, bedrock, isothermality and landform classification.

When the seasonality of precipitation is evaluated, which contributes most to the model created by the MaxEnt method, the importance of the amount of precipitation in taking off from the areas where cinereous vulture shelters and flying in the air is emphasized (Hiraldo and Donázar, 1990; Moreno-Opo et al., 2010). It has been determined that in the areas which receive heavy and long-term precipitation, the flying activity of cinereous vulture decreases and is practically almost zero (McGrady and Gavashelishvili, 2006; Morán-López et al., 2006). In addition, a study in the Sündiken mountains revealed that there are differences in the behaviour of cinereous vultures in December, which is the month with the heaviest precipitation in the area (Kirazli, 2015). This difference supports the great importance of the amount of seasonal precipitation for cinereous vulture. Finally, although the low reproductive success of cinereous vulture is generally thought to be caused by humans, excessive precipitation can negatively affect the reproductive success as well (Gavashelishvili et al., 2006; Gavashelishvili et al., 2012). Therefore, whether precipitation seasonality is too high or low affects the distribution, habitat preference and foraging activity of cinereous vulture.

When the bedrock graph is examined, unseparated volcanic rocks, pyroclastic rocks and evaporite sedimentary rocks show a positive relationship on the species distribution. Unseparated volcanic rocks generally have different degrees of weathering at different temperatures or cooling. They have cracks in their structure due to their ability to decompose upon heating or cooling. Pyroclastic rocks refer to all the fragments thrown out of the vents by the eruption of a volcanic mountain structure. Evaporite sedimentary rocks are generally formed by the evaporation of sea and lake water and are common in arid climate zones. Studies on cinereous vulture have found that they generally build their nests in cracked rocky areas in arid regions. It has also been stated that the species prefers trees and crump rocks in the high parts of the mountains as nesting areas (Cramp and Simmons 1980, Zhatkanbayev, 2011; Campbell, 2015). Even though some studies explain bedrock type choice, no study on bedrock characteristics that could have an impact on the habitat preference of cinereous vulture could be found. However, according to the bedrock map presented, bedrock areas in habitat preference are generally of great importance in nesting area preference. Therefore, the bedrock variable results presented are compatible with the literature.

The isothermality variable that contributes to the model emerges by dividing the difference between daily evening temperature and daytime temperature by the difference between annual evening temperature and daytime temperature (Karger et al., 2017). The study revealed that daily and annual temperature is important in the distribution of cinereous vulture. In literature analysis, it was found that this species prefers nesting areas where there is a warm air flow and there are no climatic conditions such as extreme heat or extreme cold (Morán-López et al., 2006). In addition, it was stated that daytime temperature is more important than night temperature in determining the seasonal movements of cinereous vulture. Also, it was revealed that cinereous vultures shelter at higher latitudes and altitudes (i.e., where the air is relatively cooler) during high daytime temperatures (Tarkhnishvili et al., 2012). Considering different climate warming scenarios (IPCC 2007), which assume that surface temperature will increase by 1.4–5.4°C over the next 100 years, they predicted that the distribution of cinereous vulture will move to higher latitudes and altitudes, especially in summer. More specifically, under these scenarios that predict climate warming, temperatures will increase, and precipitation will remain unchanged. It has been determined that the vegetation density within the area will decrease significantly according to NDVI (Normalized difference vegetation index) and there will be a change in species habitats (Gavashelishvili et al., 2012) As a result, as stated in literature, daily and annual temperature changes will have influence on cinereous vultures, and the increase in temperatures will cause the shrinkage or fragmentation of their habitats.

Landform classification that contributes the least to the model shows that canyons, upper slopes, upland drainages, and headwaters in the study area have a positive relationship in the species distribution. In this context, cinereous vulture prefers upper slopes rather than mountain peaks to dominate the area. Another reason why it prefers the upper slopes is to protect itself from predatory species on the mountain peaks or to easily reach its habitats (Moreno-Opo et al., 2013). In addition, it was revealed that it feeds by throwing the animals it hunts down from mountain structures such as canyons to meet its nutritional needs. Generally, upland drainages and headwaters with puddles that have lost their flow rate are described as areas preferred by the cinereous vulture in extreme and high temperatures (Yamaç and Bilgin, 2012; Erdoğdu, 2014; Chung et al., 2015; Kirazli, 2016; Yamaç et al., 2019). In conclusion, it was determined that the cinereous vulture prefers canyons, upper slopes, and dry streams where it can use the air flow more easily, instead of mountain peaks and flat areas, to feed, shelter, protect and survive.

In short, precipitation seasonality, bedrock, isothermality and landform classification results for the habitat suitability mapping of cinereous vulture are compatible with the literature. Climate variables such as precipitation seasonality or isothermality will affect cinereous vulture's nutrition, shelter, or habitat preference. Changing precipitation seasonality within the study area will cause the species to leave the areas where they shelter and change their habitat preference. At the same time, the change in temperature will have an influence on the distribution of cinereous vulture, which has a large body, and whose body temperature will increase and cause a change in the food chain. Since its habitat preference, which has a wide distribution area, is sensitive to seasonal precipitation and isothermality, these factors will limit the current and future distribution of the species. If the increase in seasonal precipitation and isothermality continues due to changing climatic conditions, the species will face extinction in the year 2100 according to the SSP 585 scenario.

CONCLUSIONS
ZAKLJUČCI

This study is the first numerical and model habitat suitability mapping of the cinereous vulture in Türkiye under climate change. In this study, areas that need to be protected for the cinereous vulture to survive the changing climate conditions and for the sustainable management of its generation were determined. Climatic and environmental factors can be used for vulture species distribution modelling or habitat suitability maps. The habitat suitability maps of cinereous vulture have the potential for guiding managers when undertaking forest and agricultural management practices and determining the initiatives for biodiversity conservation. In addition, the habitat suitability mapping of the cinereous vulture under changing climatic conditions will help to obtain information on how and in what way it will be protected. Finally, this study will contribute to researchers who will investigate the cinereous vulture-climate change relationship.

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SAŽETAK

Promjenjivi klimatski uvjeti i različiti klimatski scenariji na globalnoj razini povezani su sa smanjivanjem, fragmentacijom pa čak i izumiranjem staništa važnih vrsta ptica. Na temelju toga, cilj je provesti modeliranje prikladnosti staništa i mapiranje rasprostranjenosti crnoga strvinara (*Aegypius monachus*) pod utjecajem klimatskih promjena u Turskoj, najveće od četiri vrste supova na svijetu. Metoda MaxEnt odabrana je za otkrivanje trenutnog modela prikladnosti staništa crnoga strvinara, koji je pokazatelj starih i visokokvalitetnih šuma crnoga bora u smislu biološke raznolikosti u Turskoj. Utvrđeno je da su varijable koje pridonose trenutnom modelu prikladnosti staništa strme stijene, izotermnost, klasifikacija oblika reljefa i sezonske oborine. Klimatski scenariji Chelsa (SSP126-SSP370-SSP585) za 2100. godinu korišteni su za otkrivanje učinaka promjene klimatskih uvjeta. Rezultati mapiranja prema različitim scenarijima klasificirani su kao 0,5 – neprikladno, 0,51-0,8 – prikladno i 0,81-1,0 – najprikladnije stanište. Prema rezultatima mapiranja otkrivenim na temelju različitih godina i scenarija, crni strvinar ima prikladno stanište u najmanje 16,13 % područja istraživanja u trenutnoj situaciji, a broj će se smanjiti na 13,95 % u 2100. godini u klimatskom scenariju SPP126, 10,11 % u klimatskom scenariju SPP370 i 7,36 % u klimatskom scenariju SPP585. Kao rezultat, kada se mapiranje klimatskog scenarija SSP585 iz 2100. usporedilo s trenutnim mapiranjem prikladnosti staništa, utvrđeno je da se prikladnost staništa za istraživanu vrstu supa smanjila za približno 55 %. Stoga će ovi rezultati poslužiti kao izvor informacija kako bi se spriječilo izumiranje crnoga strvinara, kako bi se unaprijed zaštitila njegova sadašnja i buduća rasprostranjenost te smanjio utjecaj promjenjivih klimatskih uvjeta.

KLJUČNE RIJEČI: *Aegypius monachus*, klimatske promjene, očuvanje divljih životinja, modeliranje i mapiranje, maksimalna entropija