POTENTIAL DISTRIBUTION OF THE CARACAL (*CARACAL CARACAL* SCHREBER, 1776) UNDER CLIMATE CHANGE

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Abstract. The Intergovernmental Panel on Climate Change (IPCC) predicts an increase in global temperatures of between 1.48 °C and 5.88 °C during the 21st century. Using climatic habitat suitability (climate envelope) models, we assessed the potential influence of climate change on the range of the caracal (Caracal caracal Schreber) based on the IPCC's future climatic scenarios. According to our model, the caracal faces probable local extinction risks in future warming scenarios. The results of this study indicated that the caracal's response to climate change was dependent on its adaptive likelihood and the present and future probability of climate change. The caracal's suitability exhibited trends toward local extinction in the future. We suggested that its placement on the IUCN Red List be reassessed. The caracal abundance is predicted to become dramatically reduced in the Mediterranean region but to increase towards the east and south of Africa due to climatic conditions in the future. Bioclimatic envelope models do not account for non-climatic factors such as land use, biotic interactions, human interference, and dispersal or history, and results should therefore be seen as first approximations of the potential magnitude of effect of future climatic change for the caracal species.
Keywords: *carnivora, Mediterranean region, camera trap, climatic habitat suitability, Turkey*

Introduction

Climate change and its impacts are one of the greatest dangers to biodiversity and ecological functions. The pressure on biodiversity exceeds, by a wide margin, the amounts imposed by natural global climate changes that occurred in the evolutionary past. It consists of temperature rises, climate zone shifts, snow and ice melting, sea level rise, droughts, and other extreme weather phenomena. Due to their limited adaptability, natural systems are susceptible to such alterations (Sintayehu, 2018). The effects of climate change on populations and range distributions of wildlife are expected to be species specific and highly variable, with some effects considered negative and others considered positive (Kıraç, 2021). Some of the negative responses are distributional shifts, phenology changes, anthropogenic factors, habitat fragmentation and habitat loss, increased disease transmission, and diminished resource availability (Root et al., 2021; Mawdsley et al., 2009). The ranges of habitats and fauna in Turkey are anticipated to shift northward as temperatures rise (Gül et al., 2018). Variations in this overall trend will rely on individual local conditions, altering precipitation patterns, and the responses of various species to various components of climate change. Consequently, the organization of plant–animal communities will shift. Ignoring climate change is likely to result in increasingly ineffective wildlife management (Inkley, 2004).

Natural habitats will be split up and lost in the next century, according to IPCC climate change scenarios. Currently, the 6th period climate change scenarios and those, namely SSPs (Socio-Economic Scenarios), are accessible in the Worldclim database for researchers to simulate. The difference between these new period climate change

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scenarios from the previous period is that anthropogenic forces are taken into account (Almazroui et al., 2020; Harris et al., 2006).

It is expected that global climate change will cause land cover change, which will lead to narrowing and subdivision of species distributions (Do Linh San et al., 2022; Khosravi et al., 2021). In fact, land cover changes are currently one of the most important major threats to felines (Zanin et al., 2015, 2021). This has increased the risk of feline extinction by reducing and isolating populations through habitat loss and fragmentation. Therefore, the current critical conservation status of felines caused by land cover changes is expected to worsen, possibly non-linearly, due to climate change (Feddema et al., 2005). Ashrafzadeh et al. (2019) predicted that global climate change could lead to the extinction of up to 10% of all European mammals within the next 100 years, with up to 25% of the species becoming critically endangered. Kıraç (2021) indicated that this rapid change in climate might affect *Lynx pardinus* and *Lynx lynx* cat species indirectly.

Climate change may endanger felid survival by causing range shifts, changing the biogeographical aspects of their current range, and reducing range overlap with protected areas (Monroy et al., 2019; Henle et al., 2004). Because of their low numbers, limited dispersion abilities, and decreased reproductive potential, large carnivores are susceptible to changes in their habitats and environments (Sergio et al., 2008; Marneweck et al., 2022). *Leopardus* and *Felis* species have the highest conservation priority and the greatest conservation gaps. These taxa are also among those with the most uncertainty about species taxonomy and distribution limitation, which may hinder the efficiency of conservation efforts owing to the difficulties in determining conservation status (Kitchener et al., 2017).

The caracal (*Caracal caracal*) is a significant cat species in West Asia, Middle East Africa, and the Turkish Mediterranean (Gros et al., 1996). The caracal is the third biggest of the five felids present in Turkey, after the leopard and the *lynx*. It is a slender, medium-sized cat (5.8–22 kg) characterized by a short tail and long ear tufts. Caracal populations have a wide distribution and are found throughout the African continent, north of the Arabian Peninsula, the Middle East, and Turkey, eastwards to central India and northwards of Kazakhstan and Turkmenistan (Sunquist, 2002; Mengüllüoğlu, 2019). In Turkey, it is present in the southwest of the country, specifically in the Datça and Bozburun peninsulas (İlemin and Gürkan, 2010; Hepcan et al., 2013). Caracal's habitat includes arid woodlands, savanna, scrublands, hilly steppes, and arid mountainous regions (Monao, 2016; Veals et al., 2020). It has a key role in the control of rodent populations. Its diet consists primarily of brown hare (*Lepus europaeus*), birds, reptiles, and insects. Sometimes it hunts wild goat (*Capra aegagrus*), fallow deer (*Damadama*) (Hassan, 2015; Gritsina, 2019). The conservation status of caracal populations is not clear across most of the range. According to the IUCN Red List, although in Europe it is in the LC (Least concern) category, the Asiatic population is threatened and listed in CITES appendix I (Avgan et al., 2016; Ünal et al., 2022). The main threats to the caracal are habitat loss and human conflict due to frequent livestock attacks. Lack of knowledge about the caracal and the unknown impacts of the conflict on its population may drive the species to an endangered situation (Ünal et al., 2020; Macdonald et al., 2010).

Large carnivores are sensitive markers of ecological stability since they can only exist if lower trophic levels are largely unaffected (Fabiano et al., 2020). For instance: Turkey, although the distribution areas of the caracal are mostly in the north, it is known that it spreads only in the Aegean region, Mediterranean region and Anatolia, Turkey's hottest and driest habitats. This distribution can be accepted as evidence showing that

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the species spread its habitats in areas with hot climates in Turkey and that it is stuck in this area and not to the north. Especially in the previous literature, it is known that this species spread to Eastern Anatolia and Southeastern Anatolia (İlemin, 2017).

Species Distribution Models (SDMs) are frequently used to forecast a species' geographic range based on presence-only occurrence data exist and environmental variables hypothesized to affect the species' distribution (Václavík and Meentemeyer, 2009; Peterson et al., 2011). There is rising concern about how SDMs are being used to predict the impact of climate change on biodiversity (Jones and Cheung, 2015; Austin, 2011). The assumptions criticized include the expectation of equilibrium conditions (Schröder and Seppelt, 2006), ignoring the effects of evolutionary adaptation and limitations on dispersal (Jeschke and Strayer, 2008), and ignoring the acclimatization and persistence ability of species (Willis, 2009). The other concerns are the disregard of appropriate scales for plant–environment and biotic interactions (Randin et al., 2009), the lack of modern analogues of future climates (Heikkinen et al., 2006), and the absence of ecophysiological and experimental confirmation of models (Dormannet al., 2007). However, the most effective way to predict the effects of climate change on living things is to predict where the climatic conditions favored by the species in the past may be achieved in the future. This is achieved by determination of species distribution' based on climatic conditions" (Phillips et al., 2017).

In recent years, MaxEnt (Maximum Entropy) has shown the potential to predict biodiversity loss under future climate scenarios (Bertrand, 2012) and also significantly contributed to the prediction of threats to species by upcoming climate change (Wang et al., 2014; Hu et al., 2015), based on machine learning techniques and a python-based GIS toolkit and SDM projection (Brown, 2014). MaxEnt has been shown to be particularly effective for modeling rare species with small ranges and scarce presence-only occurrence data (Wisz et al., 2008; Rebelo and Jones, 2010; Sardà-Palomera et al., 2012). Many studies have been undertaken on the distribution of wild animal species, but some of them forecasted probable distribution ranges based on current climate conditions, rather than taking the paleoclimatic context into account (Ma, 2014). This complicates the assessment of changes in a species' distribution region as a result of past, current, and future climate swings. Additionally, few research focused on animal species with extremely limited distribution zones and a dearth of data on occurrences based just on presence (Engler et al., 2004; Austin, 2007). In this study, we utilized MaxEnt to predict the distribution of the caracal in the world.

As it has become clear that climate change requires adaptive conservation planning, species distribution models offer the chance to predict the future distribution of species and communities as well as assess their future representation in existing protected areas (Zimbres et al., 2012). The main aim of this study is to use species distribution models (SDMs) to identify the key climatical variables which determine Caracal (*Caracal caracal*) distribution, and to map the environmental suitability for this species under current conditions and future climate scenarios. The outputs of the study are expected to lead and assist planning and conservation attempts for the species.

Materials and methods

Camera trapping

Animal behavior can limit the effectiveness of inventory methods (Ogutu and Dublin, 1998; Windell et al., 2019). Felines are generally considered to be shy animals,

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and it is often recommended that these animals be detected by using camera trap methods (Pettorelli et al., 2010; Burto et al., 2007). Camera trapping is a widespread tool used to study carnivorous terrestrial mammals and to derive abundance and density estimates, as well as behavior and, habitat preferences of wild populations (Kafley et al., 2019; Ünal and Eryılmaz, 2020). One of the biggest advantages of camera traps is that they can monitor species diversity and animal behavior non-invasively, making it a good and preferred method for detecting shy animals such as felines (Jenks, 2011). For the majority of *Felidae* species, individuals are identifiable from camera trap images because of their unique strip (eg. caracal) and spot (e.g. *Lynx*) (Ridout and Linkie, 2009; Cruz et al., 2018; Amaya-Castaño and Palomares, 2018). In recent years, it has been seen that camera trap data provides sufficient information in order to investigate the potential distribution of different species sharing the same area (Linkie and Ridout, 2011; Anile and Devillard, 2016).

The presence of caracals in the research region was determined using the camera trap methodology (Chreiki, 2022). Cuddeback Black Flash E3 infrared camera traps were employed. Non-glare infrared shooting, 0.25 s trigger time, 15 m night vision, 20 megapixels, and simultaneous 1–5 photo and video capturing are all features of these camera traps. We set the cameras to record 20-second movies with a 5-second delay before becoming active again at each trigger. The random opportunist approach was used to set up camera trap stations. In total, 444 stations had 35 camera traps deployed. They were operational for 22 months, with the camera traps working for an average of 30 days throughout each period. The cameras were installed at suitable and sheltered tree trunks from a height of 0.30–1.00 m above the ground in the interior parts of forest habitats within the protected area and agricultural areas, at the appropriate station between the heights of 55 m and 572 m near villages/towns and roadsides, and at suitable and sheltered tree trunks from a height of 0.30–1.00 m above the ground. We evaluated whether the video traps continued to record actively after they were put in the research area on a regular basis. The number of days between the start date and the control dates was used to compute the day value of the camera traps that were active during the controls. If the camera trap was not operational for different reasons (full memory card, flat battery, technical difficulties, etc.) during the checks, the last photo shot by the camera trap was accepted as the camera trap’s last day (Ünal et al., 2020; Stein, 2008).

Species data

Some of the caracal presence data was obtained from our camera traps (35 records from Anatolia), while the other majority was downloaded from GBIF (379 records from Africa and Asia) (GBIF, 2022). Coordinate information was obtained by opening the “occurence.txt” file in the folder downloaded from GBIF (Global Biodiversity Information Facility) in Excel software. The presence/presence data (414) of the target species were made ready for analysis in the form of a “csv” file.

We conducted caracal camera trap study in Antalya province in the Mediterra-nean Region of Turkey from January 2015 to October 2017. During the research period, the camera traps were deployed in 444 camera trap stations using the opportunist method (Harmsen et al., 2011; Ünal et al., 2020). Google Earth, ArcMap 10.4 and Microsoft Excel pro-grams were used to display the camera trap stations on the map. A total of 17951 camera trapping days were obtained throughout the three-year sampling period. In particular, the caracal was relatively abundant among the photographed carnivores, with 35 individuals captured across a total of 19 different camera trap locations.

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Bioclimatic data

In the Worldclim database, there are 19 bioclimatic data in all climate model packages. Data on temperature from Bio 1 to Bio11, data on precipitation from Bio12 to Bio 19 (Table 1). The historical climate data (1970–2000) and future projections of SSPs126 and SSPs585 scenarios (in 20-year periods until 2021-2100) were downloaded from worldclim.org, based on the CanESM5 global climate model with a resolution of 2.5 min. In the analysis, CanESM5 was preferred because its sensitivity is higher than the other eight global climate models (http://worldclim.org) (Carbonbrief, 2019).

The SPPs126 scenario portrays a world regulated by climate policies and is the most optimistic climate change scenario, with a maximum temperature increase of 1.5 °C. The SSPs585 scenario, on the other hand, is the worst-case scenario in which the warming would be roughly 4-5 °C (Carbonbrief, 2019). The analysis did not include two scenarios that were in the middle of the spectrum between the most optimistic and the most pessimistic scenarios.

Variables selection and statistic

A total of 19 bioclimatic variables were subjected to a Pearson correlation analysis to minimize multicollinearity issues that may arise between climate variables. The variables with R^2 values exceeding 0.85 were omitted from the analysis. The bioclimatic variables selected for use in the analysis are Bio2, Bio3, Bio5, Bio6, Bio7, Bio8, Bio12, Bio14, Bio15, Bio18, and Bio19 (Table 2).

Climatic habitat suitability (climate envelope model) models

Researchers may better understand how species can react to a changing climate by using climatic envelope models, a crucial tool in vulnerability assessments. Climate “envelope” models describe the current climate of a species and then plot the location of that envelope as a result of climate change. Optimistic and pessimistic climate change scenarios are employed in these models since it is impossible to predict exactly how the climate will change in the future.

The MaxEnt 3.4.4 (Phillips et al., 2020) software was used to create the climate envelope model. MaxEnt estimates which environmental conditions affect the distribution of organisms in relation to the presence data of organisms (Baldwin, 2009). During the analysis process, 414 caracal presence datasets were sliced into 90% training data and 10% test data. Each model was performed with 10 replications. Thus, it was ensured that the samples collected in different places were included in the training and test sets in each repetition. After the model was created, the jackknife graphs were examined, and the variables that did not contribute to the model were eliminated without being taken to the next stage. The analysis was carried out until only the last two variables remained. Among the obtained models, the model with the highest AUC value was selected. AUC, or “Area Under the ROC Curve,” provides a general assessment of how effectively a categorization threshold performs. According to Phillips (Phillips et al., 2006), these AUC values are “>0.90: excellent, 0.90-0.80: good, 0.80-0.70: appropriate, 0.70-0.60: poor, <0.60”. Then, by examining the graphs obtained from the Jackknife statistics, it can be determined which bioclimate variable contributes to the model and how much. Jackknife graphs will be used to see the significance of bioclimatic variables as a result of the analysis. The model’s maps were created using the ArcMap10.4 software (Phillips et al., 2006). The model obtained up to

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this stage belonged to the recent past (1970-2000). The climate variables determined in the recent model were the variables that limited the distribution of our target species. Climate variables, which correspond to these variables in future climate scenarios, were called for analysis and analyzed together with recent climate variables. The ArcMap 10.4 software was used to make the maps of the model results so that the differences or similarities between the present and the future could be seen.

Table 1. *Bioclimatic variables obtained from the WorldClim website (http://worldclim.org)*

Code	Bioclimatic variables	Unit
Bio1	Annual mean temperature	°C
Bio2	Mean diurnal range (mean of monthly (max temp - min temp))	°C
Bio3	Isothermality ((Bio2/Bio7) * 100)	Unitless
Bio4	Temperature seasonality (standard deviation *100)	C of V
Bio5	Max temperature of warmest month	°C
Bio6	Min temperature of coldest month	°C
Bio5	Max temperature of warmest month	°C
Bio6	Min temperature of coldest month	°C
Bio9	Mean temperature of driest quarter	°C
Bio10	Mean temperature of warmest quarter	°C
Bio11	Mean temperature of coldest quarter	°C
Bio12	Annual precipitation	mm
Bio13	Precipitation of wettest month	mm
Bio14	Precipitation of driest month	mm
Bio15	Precipitation seasonality (coefficient of variation)	C of V
Bio16	Precipitation of wettest quarter	mm
Bio17	Precipitation of driest quarter	mm
Bio18	Precipitation of warmest quarter	mm
Bio19	Precipitation of coldest quarter	mm

Table 2. *Pearson correlation analysis results applied for bioclimate variables (R^2 > 0.85)*

	Bio1	Bio2	Bio3	Bio4	Bio5	Bio6	Bio7	Bio8	Bio9	Bio10	Bio11	Bio12	Bio13	Bio14	Bio15	Bio16	Bio17	Bio18	Bio19
Bio1	1	0.3988	0.6027	-0.5658	0.6953	0.872	-0.4	0.767	0.633	0.7721	0.9252	0.0026	0.1701	-0.3921	0.6144	0.1352	-0.3453	-0.0209	-0.0398
Bio2	0.3988	1	0.0834	0.0774	0.651	0.0279	0.3921	0.2752	0.2619	0.5149	0.2187	-0.4621	-0.3061	-0.5357	0.4623	-0.3117	-0.5568	-0.3991	-0.3629
Bio3	0.6027	0.0834	1	-0.9212	-0.0446	0.8236	-0.8294	0.5537	0.2074	0.0185	0.8204	0.5827	0.6363	0.0606	0.3435	0.6169	0.139	0.5408	0.2667
Bio4	-0.5658	0.0774	-0.9212	1	0.1677	-0.8563	0.9406	-0.5499	-0.1309	0.0824	-0.8347	-0.6268	-0.7017	-0.0884	-0.3722	-0.6853	-0.1527	-0.5547	-0.2828
Bio5	0.6953	0.651	-0.0446	0.1677	1	0.2875	0.3645	0.4078	0.6591	0.973	0.3894	-0.5212	-0.3658	-0.5828	0.4543	-0.3915	-0.5821	-0.5404	-0.2656
Bio6	0.872	0.0279	0.8236	-0.8563	0.2875	1	-0.7871	0.7036	0.4811	0.4055	0.9771	0.3807	0.4885	-0.1056	0.4786	0.4569	-0.0365	0.3037	0.2102
Bio7	-0.4	0.3921	-0.8294	0.9406	0.3645	-0.7871	1	-0.4215	-0.0433	0.2324	-0.6992	-0.7058	-0.7106	-0.2727	-0.1728	-0.6964	-0.3394	-0.6433	-0.3755
Bio8	0.767	0.2752	0.5537	-0.5499	0.4078	0.7036	-0.4215	1	0.1173	0.4852	0.7544	0.0647	0.1943	-0.1939	0.4981	0.1643	-0.1691	0.1614	-0.1081
Bio9	0.633	0.2619	0.2074	-0.1309	0.6591	0.4811	-0.0433	0.1173	1	0.688	0.4933	-0.1382	-0.0492	-0.3982	0.3312	-0.0698	-0.3484	-0.2715	0.0353
Bio10	0.7721	0.5149	0.0185	0.0824	0.973	0.4055	0.2324	0.4852	0.688	1	0.4797	-0.4615	-0.3171	-0.532	0.4447	-0.3473	-0.5225	-0.4582	-0.235
Bio11	0.9252	0.2187	0.8204	-0.8347	0.3894	0.9771	-0.6992	0.7544	0.4933	0.4797	1	0.295	0.4409	-0.2182	0.5735	0.4101	-0.1567	0.2352	0.1165
Bio12	0.0026	-0.4621	0.5827	-0.6268	-0.5212	0.3807	-0.7058	0.0647	-0.1382	-0.4615	0.295	1	0.9219	0.5342	-0.1155	0.9374	0.6025	0.8272	0.6337
Bio13	0.1701	-0.3061	0.6363	-0.7017	-0.3658	0.4885	-0.7106	0.1943	-0.0492	-0.3171	0.4409	0.9219	1	0.2727	0.1723	0.9915	0.3341	0.7629	0.5188
Bio14	-0.3921	-0.5357	0.0606	-0.0884	-0.5828	-0.1056	-0.2727	-0.1939	-0.3982	-0.532	-0.2182	0.5342	0.2727	1	-0.5242	0.2952	0.9846	0.5031	0.4168
Bio15	0.6144	0.4623	0.3435	-0.3722	0.4543	0.4786	-0.1728	0.4981	0.3312	0.4447	0.5735	-0.1155	0.1723	-0.5242	1	0.1299	-0.5252	-0.105	-0.2055
Bio16	0.1352	-0.3117	0.6169	-0.6853	-0.3915	0.4569	-0.6964	0.1643	-0.0698	-0.3473	0.4101	0.9374	0.9915	0.2952	0.1299	1	0.3548	0.7711	0.5415
Bio17	-0.3453	-0.5568	0.139	-0.1527	-0.5821	-0.0365	-0.3394	-0.1691	-0.3484	-0.5225	-0.1567	0.6025	0.3341	0.9846	-0.5252	0.3548	1	0.5523	0.4645
Bio18	-0.0209	-0.3991	0.5408	-0.5547	-0.5404	0.3037	-0.6433	0.1614	-0.2715	-0.4582	0.2352	0.8272	0.7629	0.5031	-0.105	0.7711	0.5523	1	0.2898
Bio19	-0.0398	-0.3629	0.2667	-0.2828	-0.2656	0.2102	-0.3755	-0.1081	0.0353	-0.235	0.1165	0.6337	0.5188	0.4168	-0.2055	0.5415	0.4645	0.2898	1

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Results

AUC values give information about the level of performance of the model. According to Phillips (Phillips et al., 2006), these AUC values are “>0.90: excellent, 0.90-0.80: good, 0.80-0.70: appropriate, 0.70-0.60: poor, <0.60”. The AUC values of the model, were 0.961 for the training data and 0.959 for the test data (*Fig. 1*). The AUC values of the climate pattern model created for the caracal showed that a perfect model was obtained.

The performance of machine learning approaches and models that predict the distribution of species has been evaluated using a metric known as AUC, which stands for “Area Under the ROC Curve” (Evcin et al., 2019; Elith, 2000). The closer the model’s AUC value is to 1, the better its performance. The AUC values of the model, were 0.961 for the training data and 0.959 for the test data (*Fig. 1*).

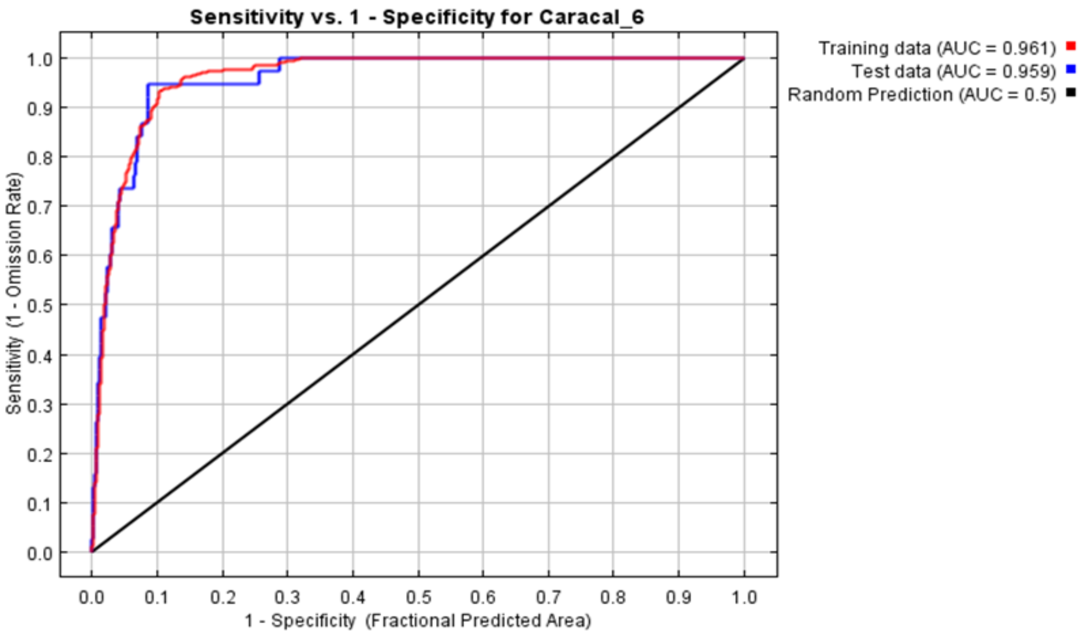

Figure 1. *AUC values of training set and test set*

Findings revealed that the following climatic factors were responsible for caracal distribution: Bio6 (Min Temperature of Coldest Month), Bio3 (Isothermality), Bio18 (Precipitation of Warmest Quarter), Bio12 (Annual Precipitation), and Bio5 (Max Temperature of Warmest Month) (*Fig. 2*). The findings of the jackknife test of variable significance are displayed in *Figure 2*. Bio6 appears to be the environmental variable that provides the most helpful information when used alone since it has the largest gain when used alone. Bio18 appears to have the most information not contained in the other variables since it is the environmental variable that reduces the gain the greatest when it is excluded.

According to the above bioclimatic variables, maps showing the distribution of the caracal were obtained. Maps showing the potential distribution of caracal according to bioclimatic variables were created. On the map (*Fig. 3*), you can see where the climatic conditions are suitable, supporting the habitats preferred by caracals. In other words, this map shows potential areas where caracals are likely to be found.

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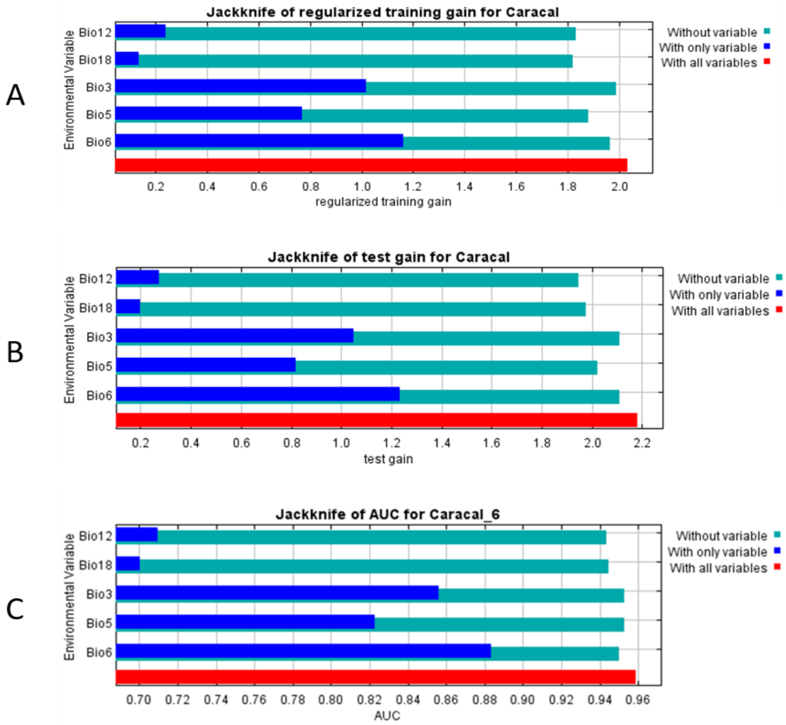

Figure 2. *Jackknife of AUC for caracal. (A) Jackknife statistic using training gain. (B) Jackknife statistic using test gain. (C) Jackknife statistic using AUC on test data*

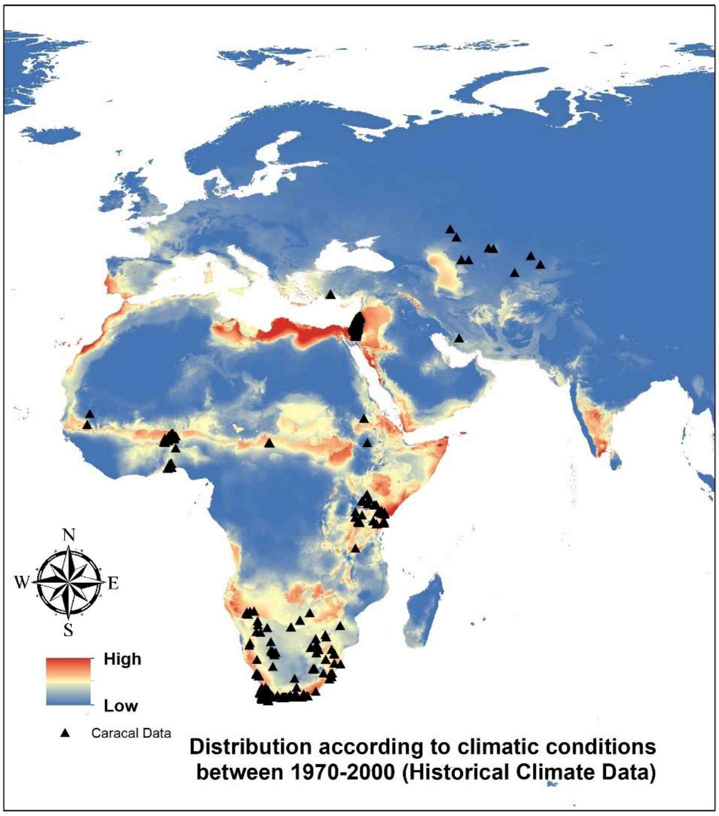

Figure 3. *Potential distribution of caracal according to current climatic conditions since the recent past*

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In the maps obtained for SSP 126, which is the most optimistic of the future climate change scenarios, it is seen that even the realization of a temperature increases of 1.5 °C would have a negative impact on the long-term sustainability of suitable climatic conditions throughout Central Africa (*Fig. 4*).

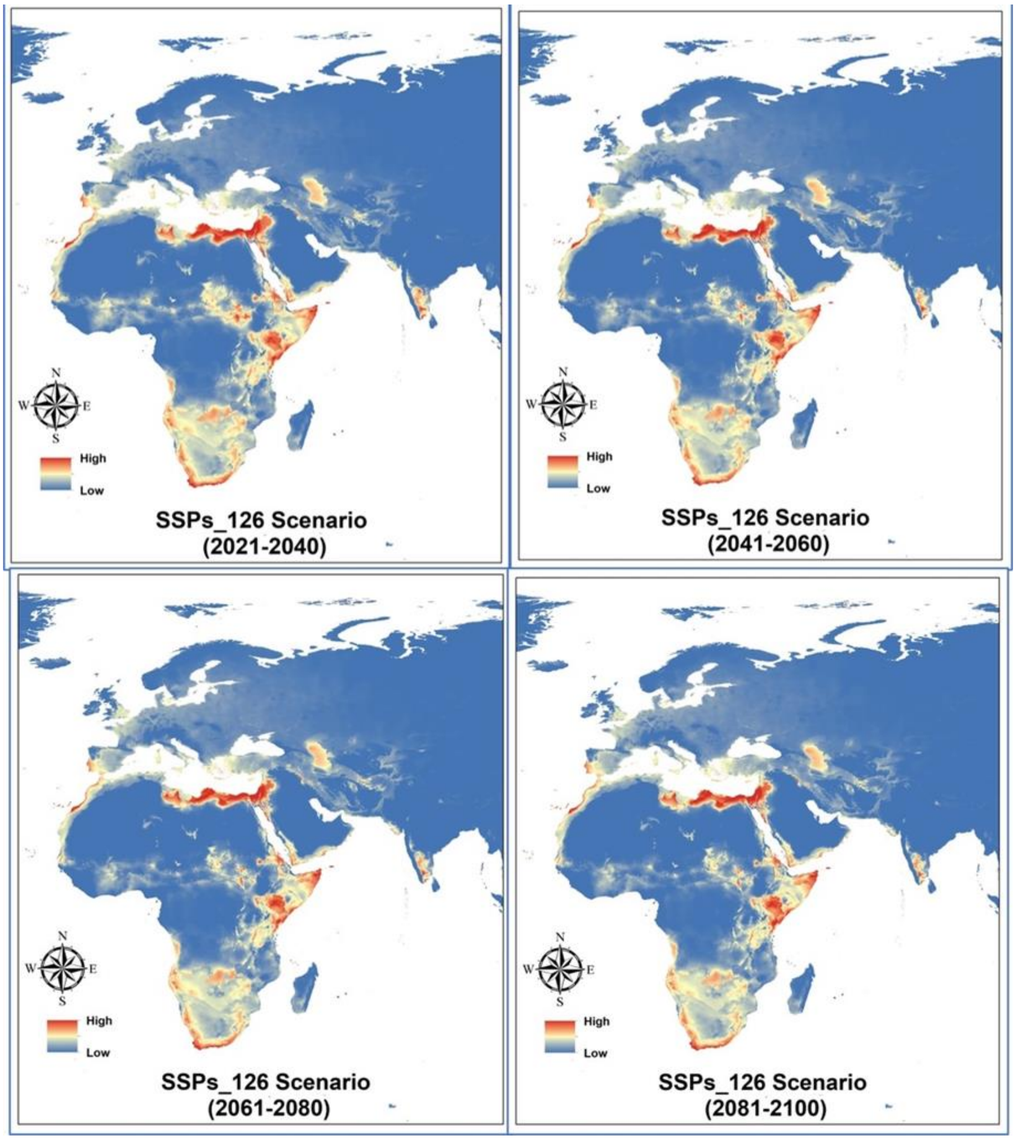

Figure 4. *Potential distribution of caracal according to SSPs 126 scenario climatic conditions*

It is seen in the simulation that favorable climatic conditions in Central Africa, where the distribution of the caracal is most intense today, would not continue in the future. In this case, it is foreseen that a few important areas on the East African coast, the coast of South Africa and the Mediterranean Basin may be climatic refuges (*Fig. 5*).

Discussion

Climate change requires adaptive conservation planning, and species distribution models are a valuable tool for predicting the future distribution of species and

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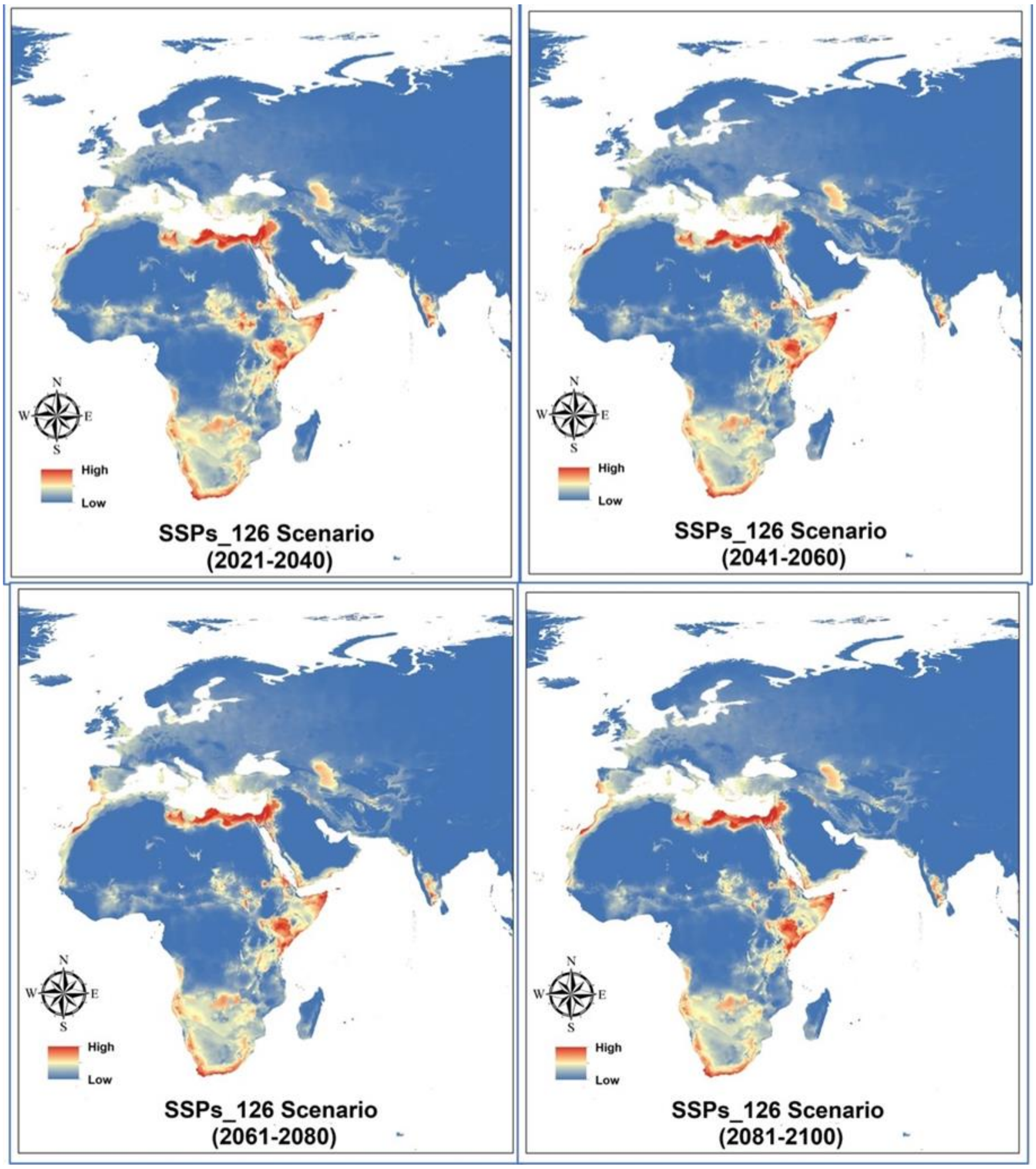
communities as well as analyzing their future representation in existing protected areas. When the results were analyzed, the model anticipated an upward shift in optimal climatic conditions for caracal in response to climate change, a phenomenon documented for other mountain specialized organisms such as plants and bird species (Lenoir et al., 2008; Buermann et al., 2011).

The findings of this study indicate that climate change would have a significant impact on caracals. Overall, there would be a significant decline in the region where caracals reside. In general, a large decrease in suitable habitats found in central Africa is expected. It is expected that the caracal population will be densified towards climatic refuges in the east and south of Africa, which are predicted to support climatic conditions in the future. In Turkey, the Mediterranean region is expected to experience the greatest decrease in caracal habitat in the 2020s. The simulations indicate that there would be a significant difference between the current and future distributions of the caracal in the Caucasus hotspot, and that the majority of the Mediterranean region would lose suitable climate areas.



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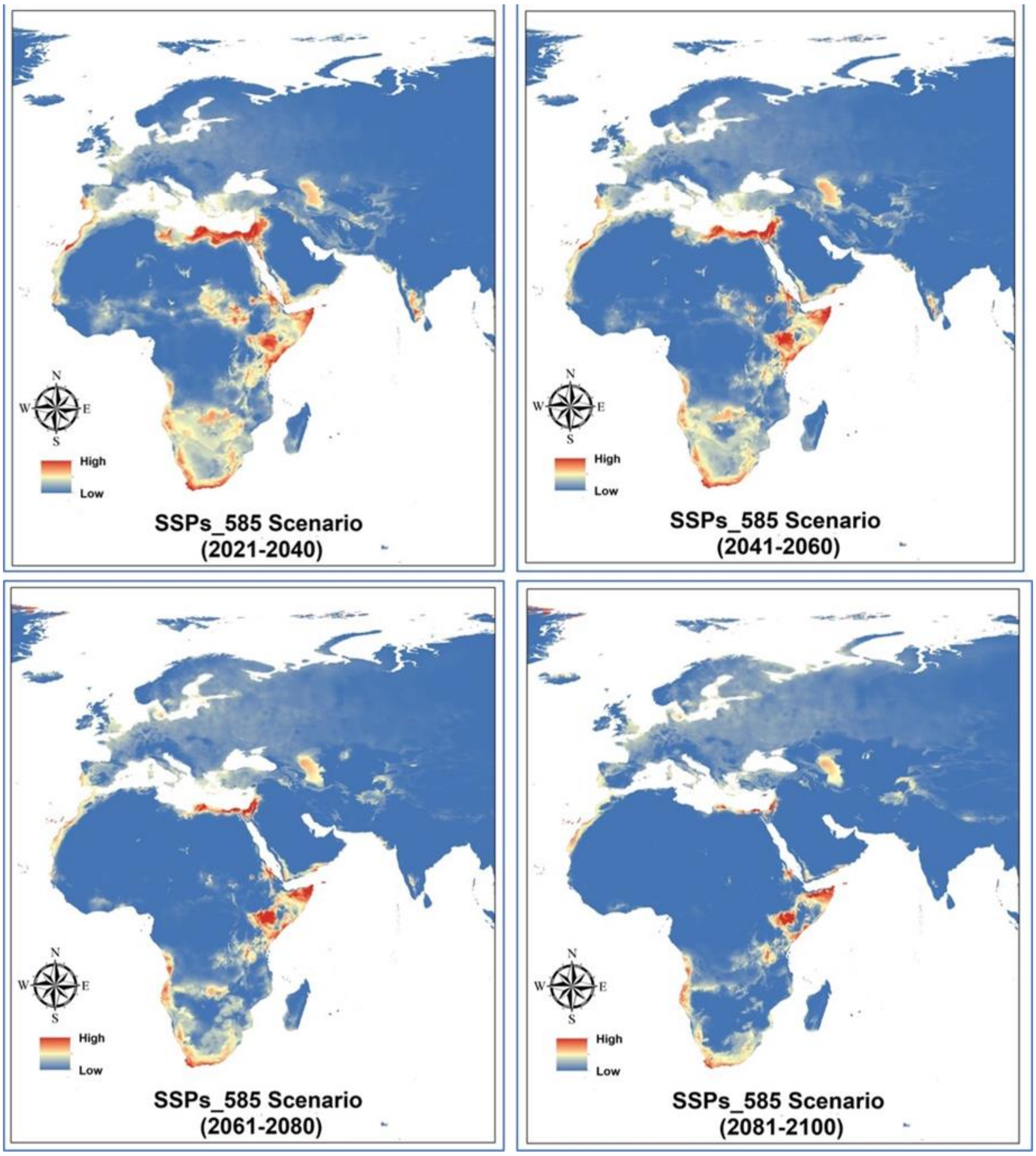

Figure 5. *Potential distribution of caracal according to SSPs 585 scenario climatic conditions*

In the case of the Caracal, its habitat is expected to show a decreasing trend. It is seen in *Figures 3, 4* and *5* that their current habitats will change in the context of future climate projections. According to SSPs126, which is the most optimistic climate change scenario, it is predicted that suitable habitats will disappear, especially in central Africa, towards the end of 100 years. The worst-case scenario is that according to SSPs585, towards the end of 100 years, habitats in northern, central and southern Africa will decrease and partially in the Mediterranean, Red Sea. It is predicted that suitable Caracal habitats on the coasts of the Yemen Sea, the Atlantic Ocean, and the Indian Ocean will survive the climate change.

Mahdavi et al. (Adibi et al., 2014) stated that climate change will have a strong impact on the distribution of caracals in the world through a habitat shrinkage from terrestrial ecosystems to coastal ecosystems and suitable habitats will decrease by the end of the 21st century. Although it is estimated that climate change may affect many

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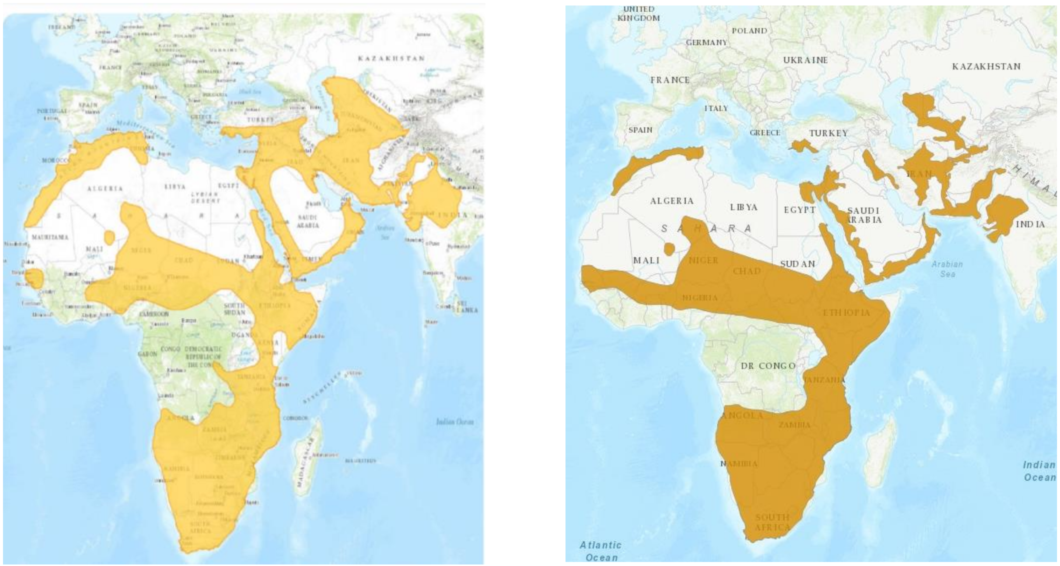
living things on earth and their habitats, it is not known to what extent this effect will trigger habitat loss over time. The model we developed using historical temperature data and the climatically appropriate habitats shown in the map (*Fig. 6*), which is an output of this model, significantly fits with the distribution map of *Caracal caracal* produced in IUCN (2022). This supports the validity of the model used in the study.



A B

Figure 6. *Distribution map of caracal according to (A) IUCN 2015 and (B) IUCN 2022*

The reason for making distribution models and predictions, such as the Climate envelope model we have used, is to have information about the fate of habitats that are likely to be lost in the future. Therefore, the purpose of these models is to make these predictions already and to form the basis for management plans for the sustainability of the habitats preferred by the species. For example, if scientists had an idea about the response of Caracal to climate-related biotic factors 20 years ago, they could predict that the species would leave these areas and not go to higher habitats due to the gradual decrease of its habitat due to drought-related agricultural activities, instead, it would move from sea level to an average of 1000 westward. They would have reached the scientific knowledge that it would move to habitats that did not exceed the altitude, and that its habitat tended to decrease gradually.

Expanding farmland is a frequently used approach to compensate for agricultural output losses caused by climate change but reduces native vegetation and causes feedback loops that accelerate climate change. As a result, the current critical conservation status of felines due to land cover changes will likely deteriorate non-linearly as a result of climate change (Jia et al., 2019).

Caracals are found in most habitat types, from dry highlands to moist coastal forests, but are usually found in forested semi-arid lands in and near aquatic ecosystems (Eid et al., 2022). Caracals are opportunistic predators that are highly skilled at hunting primarily rodents and birds (Avenant and Nel, 2002; Melville et al., 2004; Braczkowski, 2012). It is seen in the model results and the maps created that most of the habitats that are predicted to decrease due to climate change are water resources and their surroundings. It is also

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known that the caracal determines its habitat preference according to its hunting style and prey. For example, preys of the caracal species in the arid region becomes closer to water resources (Adibi, 2014).

Although the idea that climate change will not only affect arid and semi-arid ecosystem types is common, but the fact also that habitats that will lose suitable climatic conditions in the future cannot be ignored in climate change scenarios (Mahdavi et al., 2020; Yousefi, 2019). For this reason, it is more important to include areas that are expected to continue to support suitable climatic conditions for caracal in the future maps obtained with the climate envelope model, in priority protection and sustainability plans, rather than focusing on areas where the climate will change.

It has been evaluated that the areas that continue to provide suitable climatic conditions in the coastal regions will survive as a result of supporting humid and wet ecosystems due to the increase in precipitation and temperature. The most important factor in the habitat preference of the caracal is food-oriented, as in other predatory species. However, the main danger with climate changes is that the shrinkage in the habitats will cause changes in the plant species that make up the food of many herbivorous mammal and bird species, and this will indirectly affect the caracal which feeds on these species.

The results of this study clearly suggested that the reaction of the caracal to climate change relied on the present and future probability of the change in climate. Moreover, the potential future distribution of the caracal in the 2021s and 2100s according to both SSPs 126 and SSPs 585 scenarios did not overlap with the species current distribution. Since it spreads only in the southern parts of Turkey and its ability to spread is limited, this would cause significant population reductions for the caracal (Johnson, 2002). Kıraç (2021) stated that some areas that support suitable climatic conditions in the future will serve as refuge (thermal shelter) against climate change. Considering the worst-case scenario maps in this study (*Fig. 5*), it can be thought that some areas, especially in the coastal regions of Africa, will serve as refuges for the caracal, as they will provide climatic conditions in the future.

The forecasts of climate change scenarios for various time periods indicate a likely contraction of the existing potential distribution of the caracal in the Mediterranean region. The data indicate that the caracal cannot expand its range in Turkey or Europe. In contrast, they imply a contraction across Turkey/Europe between 2021 and 2100 (*Figs. 3, 4* and *5*) because increases or decreases in the region's favorable climatic conditions can produce expansions or contractions in a species' distribution range (Burton et al., 2007). Climate change may put the caracal in danger of local extinction in the near future. Can (2004) and Ünal (Ünal and Çulhaci, 2018; Ünal et al., 2020) stated that, given the magnitude and speed of climate change, the population of the species is vulnerable to decline due to adverse effects related to human activities, primarily agriculture and animal husbandry. They stated that local extinction can be prevented by moving the species to suitable habitats, otherwise local extinction of the species will be inevitable.

Conclusions

This study indicated that climate change would have a significant impact on the caracal. Overall, there would be a significant decline in the region where caracals reside. In 2100s modeling, the Mediterranean Region in Turkey was predicted to see the greatest drop in the caracal's populated territory, but the Caucasus hotspot was predicted to experience the greatest increase.

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Data availability. The data of this study can be requested from the author via email.

Conflict of interests. The author declares no conflict of interests.

REFERENCES

[1] Adibi, M. A., Karami, M., Kaboli, M. (2014): Study of seasonal changes in habitat suitability of Caracal caracalschmitzi (Maschie 1812) in the central desert of Iran. – Journal of Biodiversity and Environmental Sciences 5: 95-106.
[2] Almazroui, M., Saeed, F., Saeed, S., Nazrul Islam, M., Ismail, M., Klutse, N. A. B., Siddiqui, M. H. (2020): Projected change in temperature and precipitation over Africa from CMIP6. – Earth Systems and Environment 4(3): 455-475. https://doi.org/10.1007/s41748-020-00161-x.
[3] Amaya-Castaño, G. C., Palomares, F. (2018): Effect of human influence on carnivore presence in a Mediterranean human-modified area in the Southwestern Iberian Peninsula. – Galemys 30: 1-12. https://doi.org/10.7325/Galemys. 2018.A1.
[4] Anile, S., Devillard, S. (2016): Study design and body mass influence RAIs from camera trap studies: evidence from the Felidae. – Animal Conservation 19(1): 35-45.
[5] Ashrafzadeh, M. R., Naghipour, A. A., Haidarian, M., Khorozyan, I. (2019): Modeling the response of an endangered flagship predator to climate change in Iran. – Mammal Research 64(1): 39-51. https://doi.org/10.1007/s13364-018-0384-y.
[6] Austin, M. (2007): Species distribution models and ecological theory: a critical assessment and some possible new approaches. – Ecological Modelling 200(1-2): 1-19.
[7] Austin, M. P., Van Niel, K. P. (2011): Improving species distribution models for climate change studies: variable selection and scale. – Journal of Biogeography 38(1): 1-8. https://doi.org/10.1111/j.1365-2699.2010.02416.x.
[8] Avenant, N. L., Nel, J. A. J. (2002): Among habitat variation in prey availability and use by caracal Felis caracal. – Mammalian Biology 67(1): 18-33.
[9] Avgan, B., Henschel, P., Ghoddousi, A. (2016): Caracal caracal. – The IUCN Red List of Threatened Species: e.T3847A102424310. Downloaded on 2 August 2018. htps://doi.org/10.2305/IUCN. UK.2016-2.RLTS.T3847A50650230.en.
[10] Baldwin, R. A. (2009): Use of maximum entropy modeling in wildlife research. – Entropy 11(4): 854-866.
[11] Bertrand, R. (2012): Spatio-temporal response of the forest vegetation to climate warming - assessment of the vegetation reshuffling and characterization of the effect of ecological and geographical factors modulating this process at the species and community scales. – Ph. D. Dissertation, AgroParisTech, Nancy, France.
[12] Braczkowski, A., Watson, L., Coulson, D., Lucas, J., Peiser, B., Rossi, M. (2012): The diet of caracal, Caracal caracal, in two areas of the southern Cape, South Africa as determined by scat analysis. – South African Journal of Wildlife Research-24-month delayed open access 42(2): 111-116.
[13] Brown, J. L. (2014): SDM tool box: a python-based GIS toolkit for landscape genetic, biogeographic and species distribution model analyses. – Methods in Ecology and Evolution 5(7): 694-700. DOI: 10.1111/2041-210x.12200.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_11091128

[14] Buermann, W., Chaves, J. A., Dudley, R., McGUIRE, J. A., Smith, T. B., Altshuler, D. L. (2011): Projected changes in elevational distribution and flight performance of montane Neotropical hummingbirds in response to climate change. – Global Change Biology 17(4): 1671-1680.
[15] Burton, A. C., Sam, M. K., Balangtaa, C., Brashares, J. S. (2007): Hierarchical multi-species modeling of carnivore responses to hunting, habitat and prey in a West African protected area. – PLoS ONE 7: e38007.
[16] Can, Ö. E. (2004): Status, conservation and management of large carnivores in Turkey. – Council of Europe Convention on the Conservation of European Wildlife and Natural Habitats. Council of Europe, Strasbourg.
[17] Carbonbrief (2019): CMIP6: the next generation of climate models explained. – https://www.carbonbrief.org/cmip6-the-next-generation-of-climate-models-explained (accessed Apr 5, 2021).
[18] Chreiki, M. K. (2022): Camera trapping and occupancy model as a tool for monitoring the carnivore's guild in Wadi Wurayah Man and Biosphere Reserve. – Doctoral dissertation, Department of Applied Sciences, Faculty of Health and Applied Sciences, University of the West of England, Bristol.
[19] Cruz, P., Iezzi, M. E., De Angelo, C., Varela, D., Di Bitetti, M. S., Paviolo, A. (2018): Effects of human impacts on habitat use, activity patterns and ecological relationships among medium and small felids of the Atlantic Forest. – PLoS One 13(8): e0200806. https://doi.org/10.1371/journal.pone.0200806.
[20] Do Linh San, E., Sato, J. J., Belant, J. L., Somers, M. J. (2022): The World's Small Carnivores: Definitions, Richness, Distribution, Conservation Status, Ecological Roles, and Research Efforts. – In: San, E. D. L. et al. (eds.) Small Carnivores: Evolution, Ecology, Behaviour, and Conservation. Wiley, Hoboken, NJ, pp. 1-38. https://doi.org/10.1002/9781118943274.ch1.
[21] Dormann, C. F., McPherson, J. M., Araújo, M. B., Bivand, R., Bolliger, J., Carl, G., ... Wilson, R. (2007): Methods to account for spatial autocorrelation in the analysis of species distributional data: a review. – Ecography 30(5): 609-628. https://doi.org/10.1111/j.2007.0906-7590.05171.x.
[22] Eid, E., Soultan, A., Elalqamy, H. (2022): Habitat suitability modelling for feline species in jordan: a tool for climate-responsive conservation planning. – Journal of Wildlife and Biodiversity 6(3): 26-53.
[23] Elith, J. (2000): Quantitative Methods for Modeling Species Habitat: Comparative Performance and an Application to Australian Plants. – In: Ferson, S., Burgman, M. (eds.) Quantitative Methods for Conservation Biology. Springer, New York, pp. 39-58.
[24] Elith, J., Leathwick, J. R. (2009): Species distribution models: ecological explanation and prediction across space and time. – Annu Rev Ecol Evol Syst 40: 677-697https://doi.org/10.1146/annurev.ecolsys.110308.120159.
[25] Engler, R., Guisan, A., Rechsteiner, L. (2004): An improved approach for predicting the distribution of rare and endangered species from occurrence and pseudo-absence data. – Journal of Applied Ecology 41(2): 263-274.
[26] Evcin, O., Kucuk, O., Akturk, E. (2019): Habitat suitability model with maximum entropy approach for European roe deer (Capreolus capreolus) in the Black Sea Region. – Environmental Monitoring and Assessment 191(11): 1-13.
[27] Fabiano, E. C., Sutherland, C., Fuller, A. K., Nghikembua, M., Eizirik, E., Marker, L. (2020): Trends in cheetah Acinonyx jubatus density in north-central Namibia. – Population Ecology 62(2): 233-243. https://doi.org/10.1002/1438-390X.12045.
[28] Feddema, J. J., Oleson, K. W., Bonan, G. B., Mearns, L. O., Buja, L. E., Meehl, G. A., Washington, W. M. (2005): The importance of land-cover change in simulating future climates. – Science 310(5754): 1674-1678. https://doi.org/10.1126/science.1118160.
[29] Franklin, J., Miller, J. A. (2009): Mapping Species Distributions: Spatial Inference and Prediction. – Cambridge University Press, Cambridge.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_11091128

[30] GBIF.org (24 March 2022): GBIF Occurrence. – https://doi.org/10.15468/dl.bcv39m.
[31] Gritsina, M. A. (2019): The Caracal caracal Schreber, 1776 (Mammalia: Carnivora: Felidae) in Uzbekistan. – Journal of Threatened Taxa 11(4): 13470-13477. https://doi.org/10.11609/jott.4375.11.4.13470-13477.
[32] Gros, P. M., Kelly, M. J., Caro, M. T., (1996): Estimating carnivore densities for conservation purposes: indirect methods compared to baseline demographic data. – Oikos 77: 197-206https://doi.org/10.2307/3546058.
[33] Gül, S., Kumlutaş, Y., Ilgaz, Ç. (2018): Potential distribution under different climatic scenarios of climate change of the vulnerable Caucasian salamander (Mertensiella caucasica): A case study of the Caucasus Hotspot. – Biologia 73(2): 175-184. https://doi.org/10.2478/s11756-018-0020-y.
[34] Harmsen, B. J., Foster, R. J., Silver, S. C., Ostro, L. E., Doncaster, C. P. (2011): Jaguar and puma activity patterns in relation to their main prey. – Mammalian Biology-Zeitschrift für Säugetierkunde 76(3): 320-324. https://doi.org/10.1016/j.mambio.2010.08.007.
[35] Harris, J. A., Hobbs, R. J., Higgs, E., Aronson, J. (2006): Ecological restoration and global climate change. – Restoration Ecology 14(2): 170-176. https://doi.org/10.1111/j.1526-100X.2006.00136.x.
[36] Hassan-Beigi, Y. (2015): Conservation biology of the caracal (Caracal caracal) in Iran: action plan and conservation genetics. – Doctoral dissertation, Universidade De Lisboa, Faculdade De Ciências, Departamento De Biologia Animal.
[37] Heikkinen, R. K., Luoto, M., Araújo, M. B., Virkkala, R., Thuiller, W., Sykes, M. T. (2006): Methods and uncertainties in bioclimatic envelope modelling under climate change. – Progress in Physical Geography 30(6): 751-777. https://doi.org/10.1177/0309133306071957.
[38] Henle, K., Davies, K. F., Kleyer, M., Margules, C., Settele, J. (2004): Predictors of species sensitivity to fragmentation. – Biodiversity and Conservation 13: 207-251. https://doi.org/10.1023/B:BIOC.0000004319.91643.9e.
[39] Hepcan, Ş., Hepcan, Ç. C., Koçman, A., Özkan, M. B., Can, Ö. E. (2013): Identifying potential habitat networks; the case of caracal in Izmir province, Turkey. – Journal of Tekirdağ Agricultural Faculty, an International Journal of all Subjects of Agriculture 10(1): 29-39.
[40] Hu, X. G., Jin, Y., Wang, X. R., Mao, J. F., Li, Y. (2015): Predicting impacts of future climate change on the distribution of the widespread conifer Platycladus orientalis. – PLoS One 10(7): p.e0132326.
[41] İlemin, Y. (2017): Some ecological characteristics of caracal Caracalcaracal (Schreber, 1776) population in Marmaris and Köyceğiz region. – Muğla Sıtkı Koçman University, Muğla.
[42] İlemin, Y., Gürkan, B. (2010): Status and activity patterns of the caracal, Caracal caracal (Schreber, 1776), in Datca and Bozburun peninsulas, southwestern Turkey. – Zool Middle East 50: 3e10. https://doi. org/10.1080/09397140.2010.10638405.
[43] Inkley, D. B., Anderson, M. G., Blaustein, A. R., Burkett, V., Felzer, B., Griffith, B., ... Root, T. L. (2004): Global climate change and wildlife in North America. – Technical Review 04-2: 1-26.
[44] IUCN (2022): https://www.iucnredlist.org/species/3847/102424310.
[45] Jenks, K. E., Chanteap, P., Kanda, D., Peter, C., Cutter, P., Redford, T., Antony, J. L., Howard, J., Leimgruber, P. (2011): Using relative abundance indices from camera-trapping to test wildlife conservation hypotheses—an example from Khao Yai National Park, Thailand. – Trop. Conserv. Sci. 4: 113-131.
[46] Jeschke, J. M., Strayer, D. L. (2008): Usefulness of Bioclimatic Models for Studying Climate Change and Invasive Species. – In: Ostfeld, R. S., Schlesinger, W. H. (eds.) The Year in Ecology and Conservation 2008. Annals of the New York Academy of Sciences 1134. Blackwell. https://doi.org/10.1196/annals.1439.002.

[47] Jia, G. et al. (2019): Land–Climate Interactions. Climate Change and Land. – An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems, pp. 131-247.
[48] Johnson, K. (2002): The status of mammalian carnivores in Turkey. – Endangered Species Update 19(6): 232-239.
[49] Jones, M. C., Cheung, W. W. (2015): Multi-model ensemble projections of climate change effects on global marine biodiversity. – ICES Journal of Marine Science 72(3): 741-752. https://doi.org/10.1093/icesjms/fsu172.
[50] Kafley, H., Lamichhane, B. R., Maharjan, R., Thapaliya, B., Bhattarai, N., Khadka, M., Gompper, M. E. (2019): Estimating prey abundance and distribution from camera trap data using binomial mixture models. – European Journal of Wildlife Research 65(5): 1-14.
[51] Khosravi, R., Hemami, M. R., Malakoutikhah, S., Ashrafzadeh, M. R., Cushman, S. A. (2021): Prey availability modulates predicted range contraction of two large felids in response to changing climate. – Biological Conservation 255: 109018. https://doi.org/10.1016/j.biocon.2021.109018.
[52] Kıraç, A. (2021): Potential distribution of two Lynx species in Europe under paleo climatological scenarios and anthropogenic climate change scenarios. – Cerne 27(1). DOI: 10.1590/01047760202127012517.
[53] Kitchener, A. C., Breitenmoser-Würsten, C., Eizirik, E., Gentry, A. et al. (2017): A revised taxonomy of the Felidae. The final report of the Cat Classification Task Force of the IUCN/SSC Cat Specialist Group. – Cat News 11.
[54] Lenoir, J., Gégout, J. C., Marquet, P. A., de Ruffray, P., Brisse, H. (2008): A significant upward shift in plant species optimum elevation during the 20th century. – Science 320(5884): 1768-1771.
[55] Levinsky, I., Skov, F., Svenning, J. C., Rahbek, C. (2007): Potential impacts of climate change on the distributions and diversity patterns of European mammals. – Biodiversity and Conservation 16(13): 3803-3816.
[56] Linkie, M., Ridout, M. S. (2011): Assessing tiger-prey interactions in Sumatran rainforests. – J Zool 284(3): 224-229. https://doi.org/10. 1111/j.1469-7998.2011.00801.x.
[57] Ma, H. Y., Xie, S., Klein, S. A., Williams, K. D., Boyle, J. S., Bony, S., ... Williamson, D. (2014): On the correspondence between mean forecast errors and climate errors in CMIP5 models. – Journal of Climate 27(4): 1781-1798.
[58] Macdonald, D. W., Loveridge, A. J., Nowell, K. (2010): Dramatis Personae: An Introduction to the Wild Felids. – In: Macdonald, D., Loveridge, A. (eds.) Biology and Conservation of Wild Felids. Oxford University Press, New York, pp. 3-58,
[59] Mahdavi, T., Shams-Esfandabad, B., Toranjzar, H., Abdi, N., Ahmadi, A. (2020): Potential impact of climate change on the distribution of the Eurasian Lynx (Lynx lynx) in Iran (Mammalia: Felidae). – Zoology in the Middle East 66(2): 107-117.
[60] Marcer, A., Sáez, L., Molowny-Horas, R., Pons, X., Pino, J. (2013): Using species distribution modelling to disentangle realised versus potential distributions for rare species conservation. – Biol Conserv 166: 221-230. https://doi.org/10.1016/j.biocon.2013.07.001.
[61] Marneweck, C. J., Allen, B. L., Butler, A. R., Do Linh San, E., Harris, S. N., Jensen, A. J., Somers, M., J., Titus, K., Muthersbaugh, M., Vanak, A., Jachowski, D. S. (2022): Middle-out ecology: small carnivores as sentinels of global change. – Mammal Review. https://doi.org/10.1111/mam.12300.
[62] Mawdsley, J. R., O'Malley, R., Ojima, D. S. (2009): A review of climate change adaptation strategies for wildlife management and biodiversity conservation. – Conserv Biol. 23: 1080-1089. https://doi.org/10.1111/j.1523-1739.2009.01264.x.

[63] Melville, H. I. A. S., Bothma, J. D. P., Mills, M. G. L. (2004): Prey selection by caracal in the Kgalagadi Transfrontier Park. – South African Journal of Wildlife Research-24-month delayed open access 34(1): 67-75.
[64] Mengüllüoğlu, D., Ambarli, H. (2019): Assessing caracal-prey interactions by spatial and temporal analyses. – European Journal of Wildlife Research 65(4): 1-10. https://doi.org/10.1007/s10344-019-1294-2.
[65] Monao, D. O. (2016): Human-wildlife conflict mitigation and community well-being: evidence from predator-proof bomas. – World Scientific News 55: 101-113. EISSN 2392-2192.
[66] Monroy-Vilchis, O., Zarco-González, Z., Zarco-González, M. M. (2019): Potential distribution and areas for conservation of four wild felid species in Mexico: conservation planning. – Mammalian Biology 98(1): 128-136. https://doi.org/10.1016/j.mambio.2019.09.003.
[67] Morrison, J. C., Sechrest, W., Dinerstein, E., Wilcove, D. S., Lamoreux, J. F. (2007): Persistence of large mammal faunas as indicators of global human impacts. – J Mammal. 88: 1363-1380. https://doi.org/10.1644/06-MAMM-A-124R2.1.
[68] Ogutu, J. O., Dublin, H. T. (1998): The response of lions and spotted hyaenas to sound playbacks as a technique for estimating population size. – Afr. J. Ecol. 36: 83-95.
[69] Peterson, A. T., Soberón, J., Pearson, R. G., Anderson, R. P., Martínez-Meyer, E., Nakamura, M., Araújo, M. B. (2011): Ecological Niches and Geographic 13 Distributions. – Princeton University Press, Princeton. https://doi.org/10.1515/9781400840670.
[70] Pettorelli, N., Lobora, A. L., Msuha, M. J., Foley, C., Durant, S. M. (2010): Carnivore biodiversity in Tanzania: revealing the distribution patterns of secretive mammals using camera traps. – Anim. Conserv. 13: 131-139.
[71] Phillips, S. J., Anderson, R. P., Schapire, R. E. (2006): Maximum entropy modelling of species, geographic distributions. – Ecological Modelling 190(3-4): 231-259. DOI: 10.1016/j.ecolmodel.2005.03.026.
[72] Phillips, S. J., Anderson, R. P., Dudík, M., Schapire, R. E., Blair, M. E. (2017): Opening the black box: an open-source release of Maxent. – Ecography 40(7): 887-893. https://doi.org/10.1111/ecog.03049.
[73] Phillips, S. J., Dudík, M., Schapire, R. E. (2020): Maxent software for modeling species niches and distributions Version 3.4.1 [online]. – http://biodiversityinformatics.amnh.org/open_source/maxent/.
[74] Randin, C. F., Engler, R., Normand, S., Zappa, M., Zimmermann, N. E., Pearman, P. B., Vittoz, P., Thuiller, W., Guisan, A. (2009): Climate change and plant distribution: local models predict high-elevation persistence. – Global Change Biology 15(6): 1557-1569. https://doi.org/10.1111/j.1365-2486.2008.01766.x.
[75] Rebelo, H., Jones, G. (2010): Ground validation of presence-only modelling with rare species: a case study on barbastelles Barbastellabarbastellus (Chiroptera: Vespertilionidae). – J Appl Ecol 47: 410-420. https://doi.org/10.1111/j.1365-2664.2009.01765.x.
[76] Ridout, M. S., Linkie, M. (2009): Estimating overlap of daily activity patterns from camera trap data. – J Agric Biol Environ Stat 14: 322-337.
[77] Root, T. L., Price, J. T., Hall, K. R., Schneider, S. H., Rosenzweig, C., Pounds, J. A. (2003): Fingerprints of global warming on wild animals and plants. – Nature 421: 57-60. https://doi.org/10.1038/nature01333.
[78] Sardà-Palomera, F., Brotons, L., Villero, D., Sierdsema, H., Newson, S. E., Jiguet, F. (2012): Mapping from heterogeneous biodiversity monitoring data sources. – Biodivers Conserv 21: 2927-2948. https://doi. org/10.1007/s10531-012-0347-6.
[79] Schröder, B., Seppelt, R. (2006): Analysis of pattern–process interactions based on landscape models—overview, general concepts, and methodological issues. – Ecological Modelling 199(4): 505-516. https://doi.org/10.1016/j.ecolmodel.2006.05.036.

[80] Sergio, F., Caro, T., Brown, D., Clucas, B., Hunter, J., Ketchum, J., McHugh, K., Hiraldo, F. (2008): Top predators as conservation tools: ecological rationale, assumptions, and efficacy. – Annual Review of Ecology, Evolution, and Systematics 39: 1-19. https://doi.org/10.1146/annurev.ecolsys.39.110707.173545.
[81] Sintayehu, D. W. (2018): Impact of climate change on biodiversity and associated key ecosystem services in Africa: a systematic review. – Ecosystem Health and Sustainability 4(9): 225-239. https://doi.org/10.1080/20964129.2018.1530054.
[82] Stein, A. B., Fuller, T. K., Marker, L. L. (2008): Opportunistic use of camera traps to assess habitat-specific mammal and bird diversity in northcentral Namibia. – Biodiversity and Conservation 17(14): 3579-3587.
[83] Sunquist, M. E., Sunquist, F. C. (2002): Wild Cats of the World. – The University of Chicago Press, Chicago.
[84] Ünal, Y., Çulhaci, H. (2018): Investigation of fallow deer (*Cervus dama*, L.) population densities by camera trap method in Antalya DüzlerçamıEşenadası Breeding Station. – Turkish Journal of Forestry 19(1): 57-62.
[85] Ünal, Y., EryIlmaz, A. (2020): Jungle cat (Felis chaus Schreber, 1777) population density estimates, activity pattern and spatiotemporal interactions with humans and other wildlife species in Turkey. – Applied Ecology and Environmental Research 18(4): 5873-5890.
[86] Ünal, Y., Koca, A., Kisaarslan, Y., Yelsiz, M. Ş., Süel, H., Oğurlu, İ. (2019): Antalya DüzlerçamıYabanHayatıGeliştirmeSahası'nda yayılış gösteren karakulak (Caracal caracal Schreber, 1776)'ın populasyonu durumu, günlük aktivitedeseni ve habitat tercihi. – Turkish Journal of Forestry 20(4): 474-481.
[87] Ünal, Y., Pekin, B. K., Oğurlu, İ., Süel, H., Koca, A. (2020): Human, domestic animal, Caracal (Caracal caracal), and other wildlife species interactions in a Mediterranean forest landscape. – European Journal of Wildlife Research 66(1): 1-10. https://doi.org/10.1007/s10344-019-1343-x.
[88] Ünal, Y., Şentürk, Ö., Kavgacı, A., Süel, H., Gülsoy, S., Oğurlu, I. (2022): Modeling habitat suitability and utilization of the last surviving populations of fallow deer (Damadama Linnaeus, 1758). – Journal of Forestry Research 33(2): 721-730. https://doi.org/10.1007/s11676-021-01391-z.
[89] Václavík, T., Meentemeyer, R. K. (2009): Invasive species distribution modeling (iSDM): are absence data and dispersal constraints needed to predict actual distributions? – Ecological Modelling 220(23): 3248-3258. https://doi.org/10.1016/j.ecolmodel.2009.08.013.
[90] Veals, A. M., Burnett, A. D., Morandini, M., Drouilly, M., Koprowski, J. L. (2020): Caracal caracal (Carnivora: Felidae). – Mammalian Species 52(993): 71-85. https://doi.org/10.1093/mspecies/seaa006.
[91] Wang, R., Kalin, L., Kuang, W., Tian, H. (2014): Individual and combined effects of land use/cover and climate change on Wolf Bay watershed streamflow in southern Alabama. – Hydrological Processes 28(22): 5530-5546.
[92] Willis, K. J., Bhagwat, S. A. (2009): Biodiversity and climate change. – Science 326(5954): 806-807. https://doi.org/10.1126/science.117883.
[93] Windell, R. M., Lewis, J. S., Gramza, A. R., Crooks, K. R. (2019): Carnivore carrying behavior as documented with wildlife camera traps. – West. N. Am. Nat. 79: 471-480.
[94] Wisz, M. S., Hijmans, R. J., Li, J., Peterson, A. T., Graham, C. H., Guisan, A. (2008): Efects of sample size on the performance of species distribution models. – Divers Distrib 14: 763-773. https://doi.org/10. 1111/j.1472-4642.2008.00482.x.
[95] Yousefi, M., Kafash, A., Valizadegan, N., Ilanloo, S. S., Rajabizadeh, M., Malekoutikhah, S., Ashrafi, S. (2019): Climate change is a major problem for biodiversity conservation: a systematic review of recent studies in Iran. – Contemporary Problems of Ecology 12(4): 394-403.

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[96] Zanin, M., Palomares, F., Brito, D. (2015): What we (don't) know about the effects of habitat loss and fragmentation on felids. – Oryx. 49: 96-106. https://doi.org/10.1017/S0030605313001609.

[97] Zanin, M., Palomares, F., Mangabeira Albernaz, A. L. (2021): Effects of climate change on the distribution of felids: mapping biogeographic patterns and establishing conservation priorities. – Biodiversity and Conservation 30(5): 1375-1394. https://doi.org/10.1007/s10531-021-02147-1.

[98] Zimbres, B. Q., de Aquino, P. D. P. U., Machado, R. B., Silveira, L., Jácomo, A. T., Sollmann, R., Torres, N., M., Furtado, M. M., Marinho-Filho, J. (2012): Range shifts under climate change and the role of protected areas for armadillos and anteaters. – Biological Conservation 152: 53-61.

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