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Habitat suitability model with maximum entropy approach for European roe deer (*Capreolus capreolus*) in the Black Sea Region

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Abstract Evaluating the relationships between wildlife species and their habitats helps to predict effects of habitat change for present and future management of wild animal populations. Building ecological models are good ways to understand and manage wildlife populations and to predict various environmental scenarios. Recently, management of ungulates is becoming more important in Europe due to a high demand of hunting and their role in biodiversity. European roe deer (*Capreolus capreolus*) is the smallest species of cervids and has a widespread distribution in Turkey. In this study, two habitat suitability models of roe deers, living in the Black Sea Region in Turkey, were created by using a maximum entropy (MaxEnt) approach. Two wildlife development areas, which have widely different habitat types, were selected as study sites. As a result of this study, area under the curve (AUC) values were found to be above 0.80. According to the modeling results, in two different habitat types, ecological variables are quite similar in general. This study is the first study on modeling European roe deers in Turkey.

Keywords Ecological modeling · MaxEnt · Ruminants · Roe deer · Wildlife management

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Introduction

Identifying the factors that affect the distribution of species is crucially important for the sustainability and conservation of wildlife. One of the first applications to be made for this purpose is to determine the species and the habitats in which the species are distributed. Areas with a high-rate usage of species belonging to wild animals are defined as habitats of that species (Oğurlu 2001). Thus, understanding the relationships between wildlife and habitat also helps us to predict the effects of habitat change and management in animal populations (Gündoğdu 2006). In order to understand why wild animals prefer specific habitats, various ecological factors in that area need to be examined (Patton 1992; Payne and Bryant 1998).

A wide range of different research and evaluation methods is used in ecology science from basic statistical methods to complex classification and modeling techniques (Özkan 2016). In this sense, a number of studies have been done in recent years and analytical methods based on probabilistic approaches have been performed in many areas of ecology (Phillips et al. 2006; Pueyo et al. 2007; Harte et al. 2008; Baldwin 2009; Kleidon et al. 2010; Slater and Michael 2012; Sobek-Swant et al. 2012; Harte and Newman 2014; Cunze and Tackenberg 2015; Kumar et al. 2015; Xiao et al. 2015; Özkan 2016).

There are many ways to evaluate the long-term field data, but modeling has been a recent approach predicting various environmental scenarios (Jung et al. 2014; Byeon et al. 2018). Modeling can be made by using many variables in wildlife studies. These models were used to obtain outputs by evaluating factors (process, effects, etc.) in the current time. By this way, researchers can make assumptions about the study area through vegetation changes over time and other alternative scenarios. In fact, such models can be evaluated in terms of migration conditions and movements of wildlife species. The potential different variables and the effects of the threats as a result of the evaluation of habitat models are also can be foreseen.

Habitat suitability models have great importance in terms of predicting the potential distribution of wildlife species in case of changes in habitats (Harte et al. 2008; Ertuğrul et al. 2017). One of the probabilistic approximation methods applied in habitat suitability models in recent years is the maximum entropy (MaxEnt) approach. By this method, the coefficients of niche functions can be evaluated ecologically and niche functions can be converted into factors that can be interpreted independently (Cunze and Tackenberg 2015). In addition, the study of maximum entropy modeling has an ability to work with the presence-only data and categorical and continuous data and can explain the relationship of species with less environmental variables. It can also create a map that shows the results of modeling (Hernandez et al. 2006, 2008; Elith et al. 2011).

Maximum entropy modeling for species distribution models (SDMs) has been widely used in recent years. Modeling with the maximum entropy approach can be used to make conservation planning of species and habitats, to predict potential distribution areas of endangered species, to reveal the potential distribution of diseases and disease-causing microorganisms in plants, and to identify potential areas that are susceptible to forest fires (Phillips et al. 2006; Harte et al. 2008; Hernandez et al. 2008; Slater and Michael 2012; De Angelis et al. 2015; Hanna et al. 2016; Narouei-Khandan et al. 2017).

Roe deer (*Capreolus capreolus* Linnaeus) is the smallest species of Cervidae family in Turkey. There is a large distribution area of roe deer on the Palearctic region. Roe deer distributed in Turkey on the west and north parts of the Marmara Region, the northwest part of the Aegean region, the Black Sea Region, the north side of the Eastern Anatolia, the Southeastern Anatolia, and the central and east parts of the Mediterranean region (Evcin 2018). Roe deer is an important species for biodiversity and hunting tourism in Turkey. Studies of habitat suitability models with the maximum entropy approach have been started in recent years especially in wildlife studies (Mert and Yalcinkaya 2017; Mert and Kirac 2019; Kıraç and Mert 2019), but there are very limited studies on this species in Turkey.

In this study, ecological niche modeling was performed with the maximum entropy approach by using the data obtained from the roe deer individuals which were GPS-collared between 2016 and 2017 at the Kastamonu Ilgaz Mountain Wildlife Development Area and Sinop Bozburun Wildlife Development Area placed in the Black Sea Region of Turkey. This is the first ecological modeling study specialized on roe deer in Turkey.

Material and methods

In this study, the construction of our method was divided into two parts: data collection and modeling process (Fig. 1).

Occurrence data

The occurrence locations of *Capreolus capreolus* were collected during a 2-year field survey and by using GPS-collared roe deers between the years of 2016–2017 in the Kastamonu Ilgaz Mountain Wildlife Development Area and Sinop Bozburun Wildlife Development Area. X and Y coordinates of the subjects received by GPS collars were used to build the model, and a portion of occurrence records was used to validate the model accuracy.

The study with GPS collars began in 2016 winter season. Collecting data was performed from the time of capture and collar deployment until the programmed automatic release date during 2018 winter. Five roe deer individuals were collared during the study. GPS collars were programmed to obtain coordinates every 3 h. Fix rates were assigned in this way to maximize collar battery life. Datasets of GPS-collared individuals were taken from the web-based system of collar software. Systems were allowed to take the coordinates of monitoring individuals as KML format. In total 3048 points were recorded by the GPS Collars. We took the coordinates in KML format and converted to the format of SDM as input data within ArcGIS.

In order to collect occurrence records, the distance sampling method (Waltert et al. 2008; Thomas et al. 2010; Wu et al. 2016) was used to design survey routes (1.5–2 km per line, 20 total lines sampled by walking).

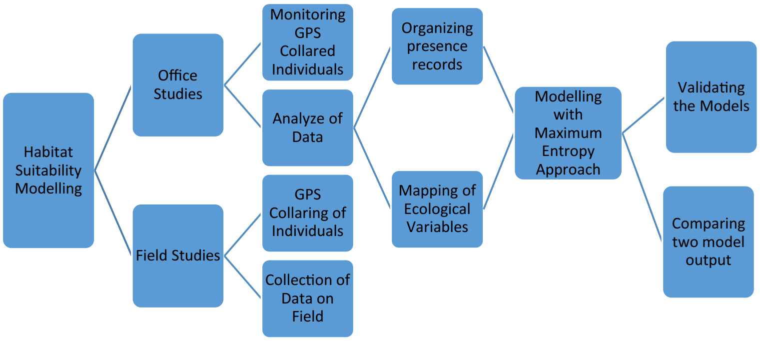


Fig. 1 Flowchart of the study method

Direct observations, footprints, repose imprints, feces, and tracks were used. Field investigations were conducted in 2016–2018. In total, 348 records were obtained in the field, and their geographic locations were recorded by GPS. GPS points were unified in a geographic coordinate system and converted to the format of SDM as input data within ArcGIS.

Study area

The Ilgaz Mountain Wildlife Development Area (17036 ha) is in the Ilgaz Mountains which is located in the northwest of Turkey. The geographic location of the study area is placed in the southern province of Kastamonu. The altitude of the study area varies between 1400 and 2500 m. The forests constituting 90.61% of the area are used by the Ministry of Agriculture and Forestry Affairs, for the purpose of forestry activities and wildlife development. The remaining 2.35% of the area is used for agricultural activities, 7.04% is pastureland, and 6.39% of the total is composed of national park area. The Ilgaz Mountains are located in the transition zone from bioclimatic direction. The characteristic of this type of transition climates is that they have semi-arid, less rainy, very cold Mediterranean and oceanic climates. Main types of vegetation spreading in the Ilgaz Mountain Wildlife Development Area are the terrestrial ecosystem which is represented by forest and bush ecosystems within the area. Forests consist of species mainly Kazdagi fir (*Abies nordmanniana* subsp. *equi-trojani* Coode et Cullen), which is an important endemic fir taxon, and Scots pine (*Pinus sylvestris* L.). The other floristic elements of this ecosystem dominantly consist of *Juniperus communis* var. *saxatilis* Pall., *Daphne oleoides* Schreber, *Epilobium angustifolium* L., *Bromus tomentellus* L., *Verbascum abieticolum* Bornm., and *Genista vuralii* A. Duran & H. Dural taxa (Kucuk et al. 2017).

The Sinop Bozburun Wildlife Development Area (1039 ha) is in the Sinop Province, and it is located north of Turkey. The geographic location of the study area is placed in the western province of Kastamonu. The elevation of the study area varies between 0 and 400 m. The Sinop Bozburun Wildlife Development Area is located in the coastal areas of Sinop Province where a climate similar to the Mediterranean climate is observed. There are small streams, dry streams, and small swamps outside the coastal area. Forests consist of species such as beech (*Fagus orientalis* Lipsky), hornbeam (*Carpinus betulus* L.), oak (*Quercus cerris* L.), maple (*Acer campestre* L.), elm (*Ulmus minor* Mill.), ash (*Fraxinus angustifolia* Vahl), and bay laurel (*Laurus nobilis* L.). There are also maritime pine (*Pinus halepensis* Mill.) plantations in the area (Anonymous 2017) (Fig. 2).

Roe deer (*Capreolus capreolus*) is the target species of both areas. Both areas have wild ungulate community including wild boar (*Sus scrofa Linnaeus*) and red deer (*Cervus elaphus Linnaeus*). Additionally, carnivore species such as brown bear (*Ursus arctos* Linnaeus), gray wolf (*Canis lupus* Linnaeus), and jackal (*Canis aureus* Linnaeus) exist in the area.

Ecological variables

Ten environmental variables grouped into three categories for the MaxEnt model (Table 1). Topographic variables such as elevation (digital elevation model (DEM)), aspect, slope, hillshade, topographic position index (TPI), roughness, and solar radiation were used. Water density and road density were included as land cover. The CORINE Land Cover map was used for the vegetation variable. All environmental

Fig. 2 Geographical position of the Kastamonu Ilgaz Mountain Wildlife Development Area and Sinop Bozburun Wildlife Development Area

variables were constructed as raster datasets with a spatial resolution of 30 m. The ASTER global digital elevation model (GDEM), version 2 (released in October 2011), mapped at 30 m spatial resolution, was obtained from U.S. Geological Survey (USGS) website (https://earthexplorer.usgs.gov). Aspect, slope, hillshade, TPI, roughness, and solar radiation were created by performing geographic information system (GIS) analysis in ArcMap (v. 10.5) software. As Phillips et al. (2009) and Merow et al. (2013) stated variables of distance to urban centers or roads, elevation or topographic roughness can help the prediction of ecological modeling. Surface roughness was calculated at the 100-m cell size using the method specified by Hobson (1972) and Khosravi et al. (2016). Rasterized maps were converted to American Standard Code for Information Interchange (ASCII) format.

Datasets of water density and road density variables were obtained from local forest district office. For water density and road density, maps having road density and water density were analyzed by using the Near tool in ArcGIS. For the analysis, buffer distance was taken as 30 m. Then, the created maps were converted to an ASCII raster map.

Input data for land cover variables (CORINE Land Cover map of Europe) were obtained from the Copernicus website (https://land.copernicus.eu/pan-european/corine-

Table 1 Description of environmental variables in the modeling

Category	Resolution (m)	Source
Terrain		
Elevation (DEM)	30	ASTER Global Digital Elevation Model
Aspect	30	ASTER Global Digital Elevation Model
Slope	30	ASTER Global Digital Elevation Model
Hillshade	30	ASTER Global Digital Elevation Model
Topographic position index (TPI)	30	ASTER Global Digital Elevation Model
Roughness	30	ASTER Global Digital Elevation Model
Solar radiation	30	ASTER Global Digital Elevation Model
Land cover		
Water density	30	Local database
Road density	30	Local database
Vegetation		
CORINE plant classes	100	European Environment Agency

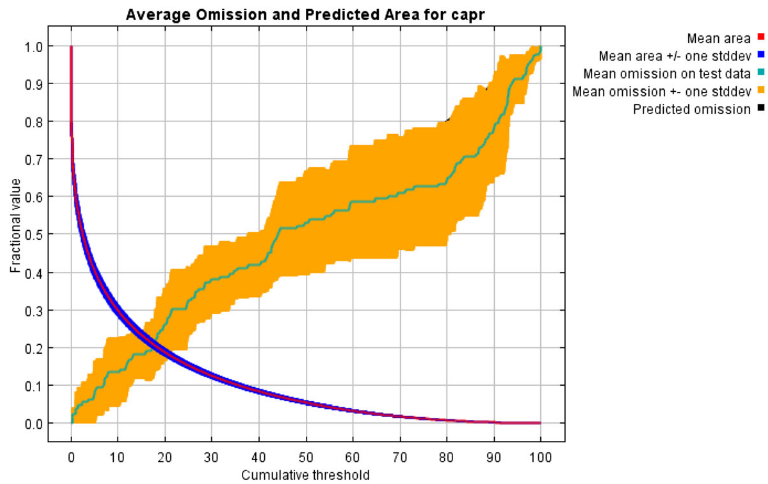


Fig. 3 Mean and predicted omission rates for the mean output of the MaxEnt model

land-cover). We used the CORINE Land Cover map thanks to being adaptive to ecological modeling and to use the universal standardized data. The CORINE Land Cover map was converted to the resolution of 30 m. The rescaled map was cropped and converted to ASCII format.

Model development

The MaxEnt (Phillips et al. 2006) modeling approach was used to build habitat suitability models for roe deer. The Java-based MaxEnt v.3.4.1 program, which uses the maximum entropy approach, has been used for data evaluation and modeling in recent years. The MaxEnt is a machine learning software program which uses the method of maximum entropy approach, and it is used for analyzing the presence-only data. MaxEnt models aim to estimate the potential distribution of a species with spatial distributions of species by using environmental variables with determining the distribution of maximum entropy (Phillips et al. 2006).

In order to use this software, it is necessary to create the base maps of the ecological variables and to convert the data into a format which can be read and analyzed by the program. The coordinates of the data obtained by the GPS collar were converted into the csv format. Base maps of the ecological variables (Table 1) were created by using ArcMap.

These datasets were cut to scale and converted to ASCII format. Bioclimate data were not included in our study due to their coarse spatial resolution (1 km × 1 km), and bioclimate variables became ahead of other ecological variables. For this reason, the effect of

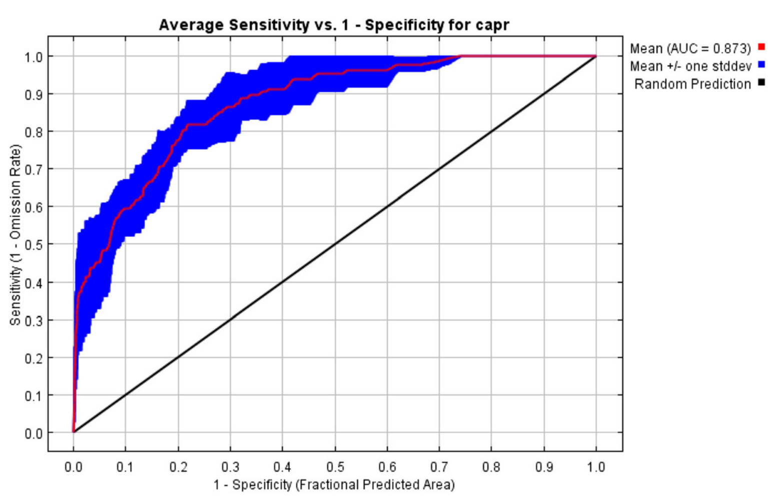


Fig. 4 AUC curve of modeling in the Ilgaz Mountain National Park

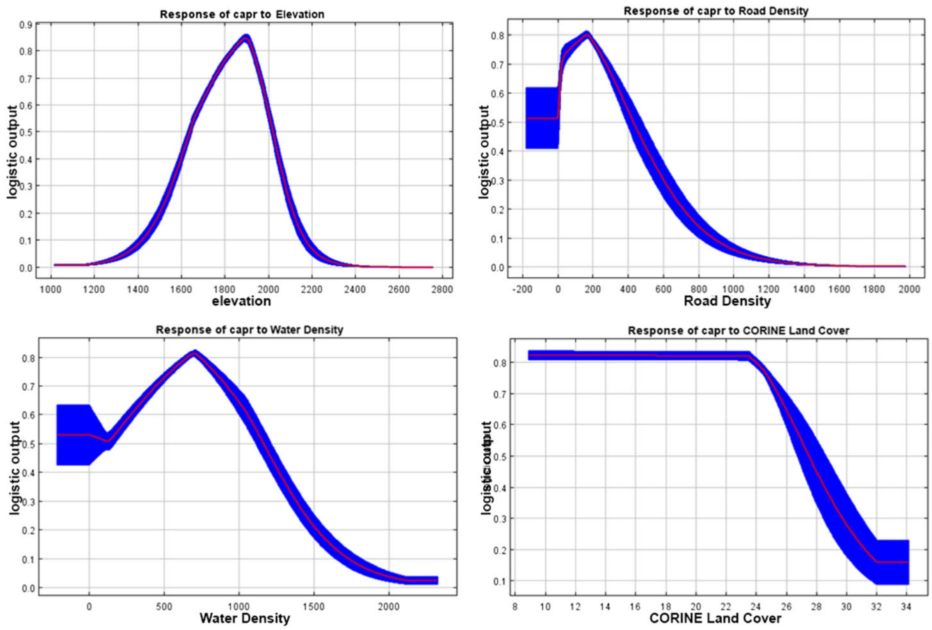


Fig. 5 MaxEnt response curves of the most contributive variables for the Ilgaz Mountain National Park

ecological factors which are expected to be the main factor in the field cannot be observed. Also, bioclimate data has been excluded from the MaxEnt modeling with the idea that resizing or interpolation methods may lose the reliability of modeling or may cause the models with low precision.

Model validation and analyses

The Jackknife validation model was used for the validation of model (Pearson et al. 2007). For each species, 75% of the location point data were used as a training model, and the remaining 25% were used for validating the MaxEnt model. Logistic format was used as the output format. The model was run with 10 replicates to achieve the optimum results. The regularization factor was taken as 1.

Averages of the outputs were transformed into raster format by using the ArcMap software. In order to test the model performance, receiver operating characteristic (ROC) analyses were used. An area under the receiver operating characteristic curve was examined for

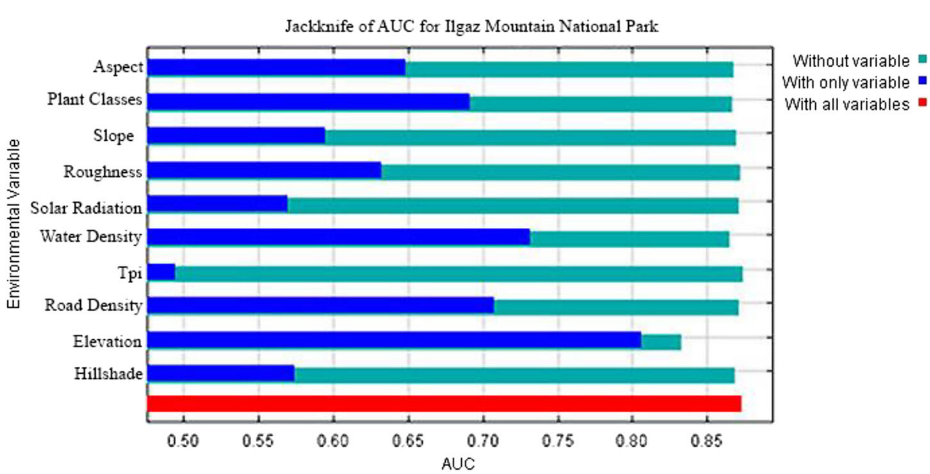


Fig. 6 AUC values of the jackknife analysis

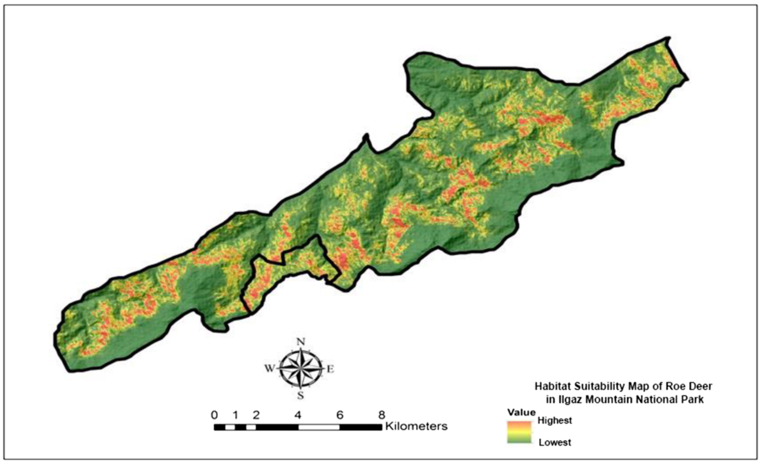


Fig. 7 Habitat suitability map of roe deer in the Ilgaz Mountain National Park

additional precision analyses. The jackknife test was used to assess the relative importance of the variables (Phillips et al. 2006; Zhang et al. 2018). Values of ROC are described as an excellent model between 0.9 and 1, good between 0.8 and 0.9, fair between 0.7 and 0.8, and poor below 0.7 (Preau et al. 2018).

The logistic outputs of habitat suitability were converted to binary outputs of habitat suitability values, and the maps were created showing the highest and lowest suitability by using the threshold.

Comparing the models

The area under the curve (AUC) values obtained from models and the percentages of the variables of two areas were compared. Also, occurrence points which are collected on the field were applied to model output map to test the accuracy of the models.

Results

The results of modeling consist of response curves of variables, species habitat suitability maps, and model evaluation with ROC curves (Fig. 3).

Ilgaz Mountain National Park

When the results were evaluated, habitat suitability model performances were found to be highly reliable (Fig. 4). The AUC value of the habitat suitability model was determined to be equal to 0.873. According to this result, the model was found to be successful (Phillips et al. 2006).

MaxEnt response curves, which contain the ranges determined to provide the highest contribution for each variable contributed to the creation of habitat suitability modeling, are given in graphs (Fig. 5).

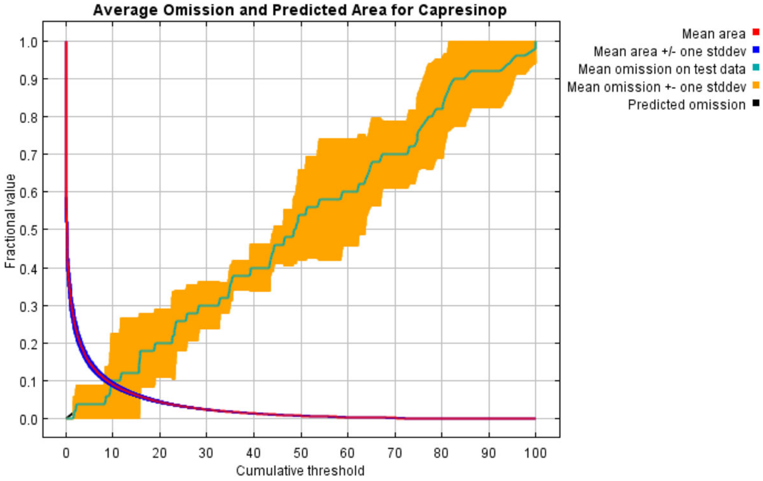


Fig. 8 Omission rates for the mean output of the MaxEnt model

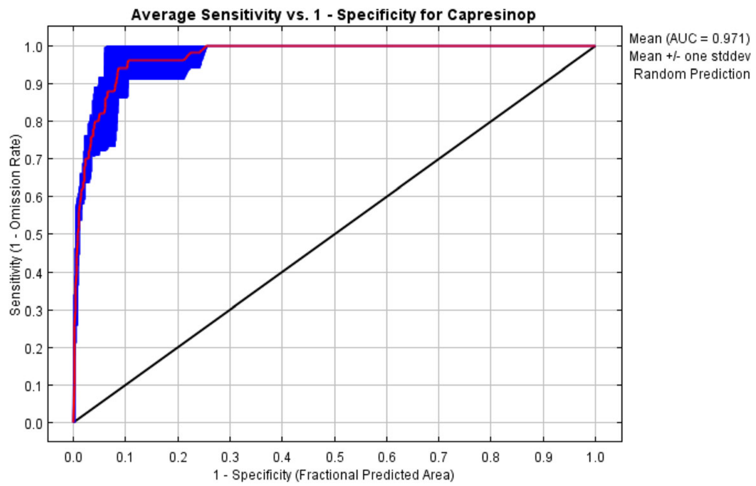


Fig. 9 AUC curve of modeling in the Sinop Bozburun Wildlife Development Area

Based on the jackknife test results (Fig. 6), elevation, water density, road network density, and CORINE Land Cover were identified as the most important variables. The results showed that the species *C. capreolus* has good habitat on the higher elevations (1800–2000 m) in the study area. Following variables were found as water density with a distance of 0–200 m and road network density with a distance of 500–700 m. Shrubs and coniferous trees were found as an important variable belonging to CORINE plant classes.

Maps of habitat suitability were predicted by the MaxEnt software for the roe deer (*Capreolus capreolus*) in the Ilgaz Mountain National Park. Habitat suitability is represented by a gradient, from very low suitability (0, in green) to very high suitability (1, in red) (Fig. 7).

Sinop Bozburun Wildlife Development Area

When the results were evaluated, habitat suitability model performances were found to be excellent (Figs. 8 and 9). The AUC value of the habitat suitability model was determined to be equal to 0.971. According to this result, the model was found to be successful (Phillips et al. 2006).

MaxEnt response curves, which contain the ranges determined to provide the highest contribution for each

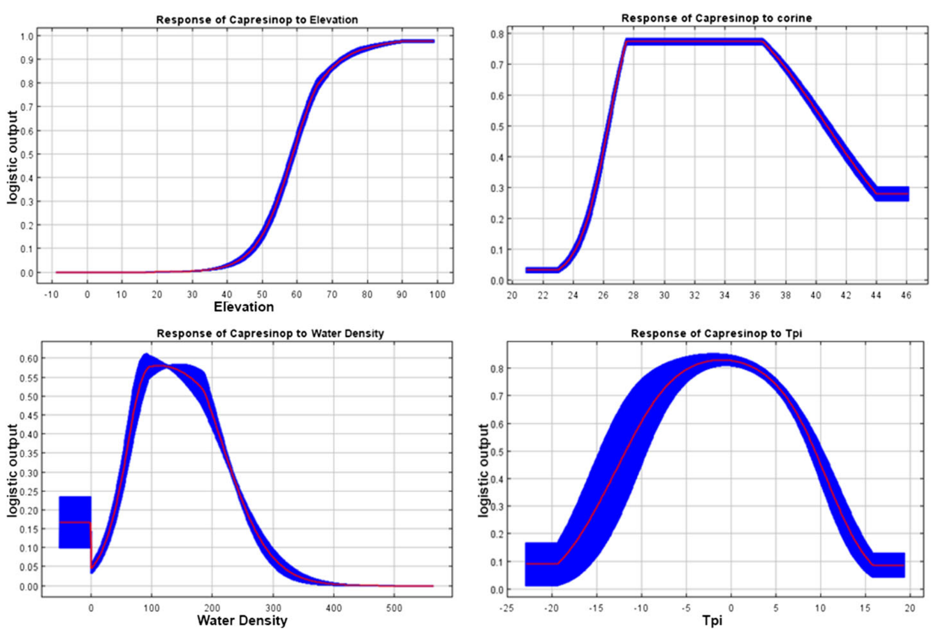


Fig. 10 MaxEnt response curves of the most contributive variables for the Sinop Bozburun Wildlife Development Area

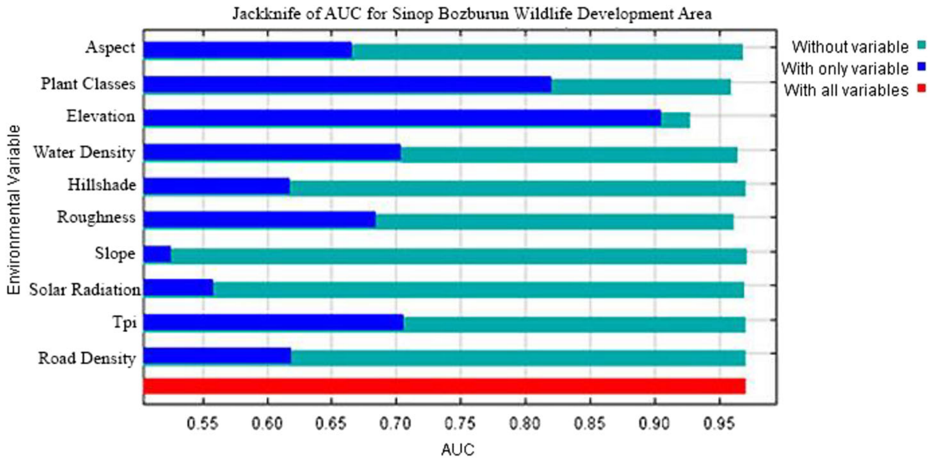


Fig. 11 AUC values of the jackknife analysis

variable contributed to the creation of habitat suitability modeling, are given in graphs (Fig. 10).

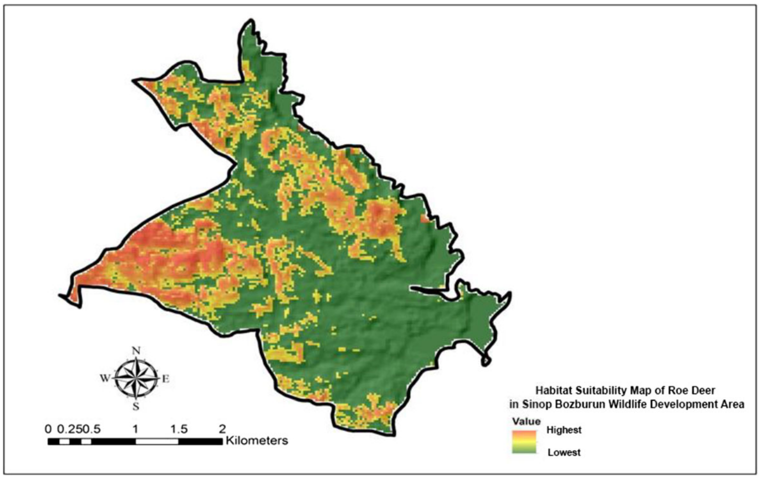
Based on the jackknife test results (Fig. 11), elevation, CORINE Land Cover classes, water density, and topographic position index were identified as the most important variables. The results showed that the species *C. capreolus* has good habitat on the higher elevations (60–80 m) in the study area. Following variables were found as CORINE Land Cover, including the classes of coniferous trees and bushes, and water density with a distance of 100–200 m.

Maps of habitat suitability were predicted by the MaxEnt software for the roe deer (*Capreolus capreolus*) in the Sinop Bozburun Wildlife Development Area. Habitat suitability is represented by a gradient, from very low suitability (0, in green) to very high suitability (1, in red) (Fig. 12).

Comparison of habitat suitability models

When the model results are compared, the highest value was found as a variable of elevation in the Ilgaz Mountain National Park. Following important variables were road network density, density of water resources, and CORINE land cover classes. According to the plant classes, it was found that the forests dominating the coniferous tree species in the area were more meaningful for the model. Elevation is the highest value again in the model of Sinop Bozburun Wildlife Development Area. CORINE land cover classes, density of water resources, and topographic position index were found as the following variables (Fig. 13). This situation shows that similar ecological variables are effective for the distribution of roe deer in areas which have different habitats and different topographic conditions.

Fig. 12 Habitat suitability map of roe deer in the Sinop Bozburun Development Area



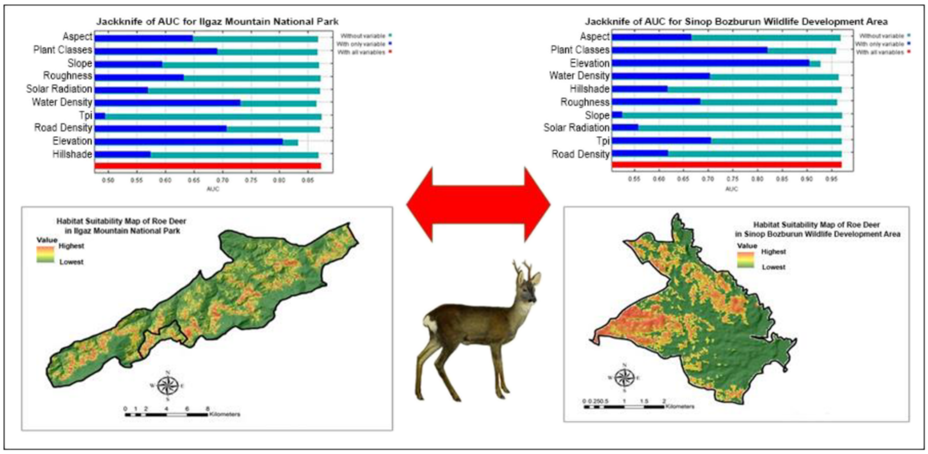


Fig. 13 Comparison of habitat suitability models

Model validation

Results of the modeling are highly compatible with the data obtained from GPS collar and occurrence data obtained from transect. This situation shows that our habitat suitability model is reliable and successful. As a result of the data on the roe deers in the Ilgaz region, it can be seen that roe deers prefer fir–scotch pine-mixed forests. According to habitat suitability models that were applied on map which has the collar data, the areas with fir–scotch pine-mixed stands have the highest potential distribution of the roe deers (Table 2).

Discussion

The results of our study are consistent with previous studies in the field (Evcin 2013). Two models, which are completely different from each other as habitat and living environment, have a high success rate in modeling due to the AUC curve. However, it is possible that variables may also produce improper distributions (Barbet-Massin et al. 2012). Therefore, in all models, distribution maps should be controlled with experts and non-related variables should be removed to prevent misguiding the model.

According to the results of the jackknife test, the highest value that affects the model belongs to the elevation variable. Subsequent variables are road network density in the area, density of water resources, and land cover. Most variables generated by using the DEM and variables based on DEM can show a positive correlation with the variable of elevation (Phillips et al. 2006; Hernandez et al. 2008; Elith et al. 2011).

Roe deer can be considered as a selective herbivorous species (Prior 1995; Danilkin 1996; Krop-Benesch et al. 2013), and water resources are important for their digestion systems. Density of water resources was found to be important as a result of modeling. Density of road network was found to be a significant variable due to model results. Roe deer generally choose dense forest stands when they crossed roads (Dussault et al. 2006; Meisingset et al. 2013). The area in Ilgaz region consists of forest parts separated by forest roads. This situation shows that roe deer can also use forest roads in addition to creating their own road patterns. We also observed footprints on forest roads in large quantities. Additionally, Keten (2017) stated that distance to forest roads has an important role for the distribution of roe deer.

In Turkey, Oruç et al. (2017) built a habitat suitability model with the maximum entropy approach in Eskişehir

Table 2 Comparing the habitat suitability model with the collar and occurrence data

Percentages of collar and occurrence data	Values of habitat suitability model
Ilgaz Mountain National Park	
2.79	Low
8.73	Medium
88.47	High
Sinop Bozburun WDA	
3.23	Low
12.32	Medium
84.44	High

region for the red deer (*Cervus elaphus*) and slope, topographic position index, forest road density, and vegetation variables were found as important environmental variables affecting the distribution of the species. The study of Wu et al. (2016) indicated that in their study, roe deer and red deer showed a high similarity due to the habitat suitability model built with the maximum entropy approach. They found important environmental variables as elevation, distance to agricultural areas, source of water, land cover, and distance to residential areas.

Machine learning systems and decision support systems are one of the useful tools used to reveal the habitat use of wildlife species, to understand species interactions, and to make sustainable planning for these species. The habitat suitability models were expected to be of help to understand the ecology of the species and to plan the future of the natural resources in the area. MaxEnt is one of the most common programs used for the maximum entropy approach. There are a number of combinations and options to create the habitat compliance models of the MaxEnt software. The resolution of the base maps effects modeling directly. bioclimate data is a reliable source for present situation and future forecasts. However, the low resolution of bioclimate data makes it impossible to use these data without interpolation. For this reason, it is considered that these data packets should be applied on small-scale maps. In addition, the creation of the infrastructure of the various base maps will ensure that such ecological models will be more reliable and accurate.

Conclusion

The habitat suitability models of wildlife species provide important forecasts into the potential distribution areas of species. These models also give the opportunity to understand species–habitat relationship, prey–predator relationship, planning of conservation studies of target species, planning of game areas, and integration of species to forest management plans. Determining the potential distribution areas of wildlife species can be forecasted with habitat suitability models with studies done locally across the Turkey. Thus, carrying an effective wildlife management and planning, determining suitable game areas, and building the core zones for target species belonging to wildlife are significantly important for protecting and maintaining the sustainability of Turkey.

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