



# Can highway tunnel construction change the habitat selection of roe deer (*Capreolus capreolus* Linnaeus, 1758)?

Özkan Evcin

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**Abstract** One of the main things wildlife does for survival is movement. Wild animals need movement to meet their needs, such as reproduction, breeding, foraging, and dispersal. Although wildlife species use roads for various purposes, they also use them when moving from one habitat to another. In recent years, especially when it comes to habitat fragmentation brought about by urbanization, wild animals frequently use highways. Highways have a wide range of effects on factors such as biodiversity, wildlife, and ecology. Roads can cause habitat loss, habitat fragmentation, and habitat degradation; alter the composition of vegetation; act as barriers to the flow of genes and movement; increase human access to pristine areas; and even increase the risk of extinction for many threatened species. Species belonging to the family Cervidae also include the species most affected by road networks. Roe deer (*Capreolus capreolus* Linnaeus, 1758) is the smallest of the 3 Cervid species living in Turkey. Roe deer are often injured or die in road accidents, and they are one of the most important species affected by the adverse effects of roads in Turkey. For this reason, it was investigated whether the road tunnel construction affected the distribution of roe deer in the region. In the study, the

general distribution of roe deer in the Ilgaz Mountain, and the factors affecting their possible distribution were determined by ecological niche modeling. Data were taken between before (2012–2015) and after the highway tunnel built (2020–2022) in Ilgaz Mountain, which connects the Western Black Sea and Central Anatolia and is located in the middle of Kastamonu and Çankırı provinces. As a result of the modeling, it was found that before the construction of the tunnel, the most influential factor in the distribution of the deer was road density. After the tunnel construction, roads ceased to be the main factor affecting the distribution of the species. This study showed that roe deer are disturbed by the density of vehicles on the road passing through the middle of their habitat. With the decrease in the number of vehicles, they are more willing to cross the road and tend to use the areas close to the road as they are less disturbed.

**Keywords** Habitat fragmentation · Road ecology · Ecological modeling · Turkey

## Introduction

Urban mobility is essential for the cities, but high levels of traffic can damage the environment in the long term (Čarský & Mačerinskienė, 2003). Road transport, which is increasingly important in the twentieth century, entered a rapid increase trend after World War II and became competitive with other transportation

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Ö. Evcin (✉)  
Dept. of Forest Engineering, Faculty of Forestry,  
Kastamonu University, 37150, Kuzeykent, Kastamonu,  
Turkey  
e-mail: oevcin@kastamonu.edu.tr

systems (Çetin et al., 2011). The worldwide road network is expanding quickly in pace with human economic progress day by day. Road development strives to increase economic growth and social integration by enabling people and commodities movement and lowering manufacturing costs (Alamgir et al., 2017; Barrientos et al., 2021; Laurance et al., 2014).

One of the primary things that wildlife must do to survive is the need to move. Wild animals need to move to meet their needs, such as breeding, food, and other necessities (shelter, mating, etc.). Understanding the movement patterns of wildlife is critical for understanding their ecology, biology, behavior, and requirements and for successful conservation (Rubenstein & Hobson, 2004). When dealing with road ecology, the most important issues to be considered are determining wildlife crossing routes and preventing accidents. Roads impact the overall environment, biodiversity, wildlife, and ecology. Roads can cause habitat loss, habitat fragmentation, and habitat degradation; change the composition of vegetation; function as barriers to gene and movement flow; and increase human access to areas that can be considered untouched, which can increase the risk of extinction of many threatened species (Forman et al., 2003; Santos et al., 2018; Silva et al., 2021; Underhill, 2003; Underhill & Angold, 1999; Van Der Ree et al., 2015). Considering the current rate of road expansion in the world, proper planning of these roads and effective mitigation of their inevitable impacts is one of the essential tasks for wildlife conservation efforts (Alamgir et al., 2017; Barrientos et al., 2021; Laurance et al., 2014). According to Barrientos et al. (2021), road ecologists should attempt to determine if roads impair functional connectivity and whether it is restored after mitigating activities. Although wildlife studies are increasing in developing countries (Brown, 2007; Mekonen, 2020; Lindsey et al., 2020), more is needed to know about the influence of roads on especially less charismatic animals (Barrientos et al., 2021).

Understanding the wildlife-habitat relationships helps us in predicting habitat change and management effects that may occur in animal populations. Identifying the variables influencing species distribution is critical to ensure wildlife's sustainability and conservation. To determine why wild animals prefer specific habitats, it is necessary to examine various ecological factors in that area (Patton, 1992; Payne & Bryant, 1998). In recent years, several models and methods have been

used to determine the crossing locations of wild animals (Clevenger et al., 2015; Quaglietta et al., 2019).

Transport networks can impact all species, independent of habitat type or taxonomic classification. Nonetheless, some research indicates that large mammals, reptiles, and amphibians are more susceptible (Holderegger & Di Giulio, 2010; Mimet et al., 2016; Rytwinski & Fahrig, 2012). Diet, abundance, body size, and reproductive rate have all contributed to species-specific differences in sensitivity to pathways (Rytwinski & Fahrig, 2012). Therefore, herbivorous and omnivorous animals appear more affected by road mortality than carnivorous species. Mobility and minimum habitat space also influence the susceptibility of animals to roads, with more mobile species and those requiring a greater minimum habitat area being more negatively impacted (Mimet et al., 2016; Rytwinski & Fahrig, 2012).

Many studies have been carried out in recent years in many areas of ecology with analytical methods based on probabilistic approaches (Barela et al., 2020; Evcin et al., 2019; Yang et al., 2021). Habitat suitability models are widely used tools that have been notably used in conservation and management studies for determining potential distributions of species, characterizing species niches, and predicting habitat changes in response to human impacts (Monsarrat et al., 2019). Roedenbeck et al. (2007) and van der Grift et al. (2013) stated that a manipulative or non-manipulative Before-After-Control-Impact (BACI) approach should be used for road ecology studies.

In specific locations, road-wildlife accidents are the most significant anthropogenic cause of mortality for cervids (Cervidae) (Steiner et al., 2014). Roe deer (*Capreolus capreolus* Linnaeus, 1758) is the smallest species of the Cervidae family distributed in Turkey and Europe. Roe deer is a common species for Turkey; although it is generally distributed in most parts of Turkey, it is mainly found in the Black Sea and Marmara Region (Evcin, 2018). Roe deer is an important game species due to biodiversity and game tourism in Turkey. Roe deer are at the forefront of the species that are victims of traffic accidents, especially with the increase in the road network. Unfortunately, problems with habitat fragmentation have not been adequately identified in Turkey, so there has been a lack of in-depth research confirming these risks and showing what happens to species in ecosystems (Altunel et al., 2021).

This study aimed to determine the effect of tunnel construction, which connects Kastamonu and Çankırı provinces, changes in the density and potential distribution of roe deer in Ilgaz Mountain National Park by comparing before and after the tunnel construction.

**Material and methods**

**Study area**

Ilgaz Mountain, located between Kastamonu and Çankırı provinces, is one of the most important

areas considering faunal and floral elements (Fig. 1). Ilgaz Mountain is one of the main routes connecting Central Anatolia to the Black Sea. İstiklal Yolu National Park, a national park in historical and cultural terms, also passes through this route. Ilgaz Mountain also hosts two important areas in terms of biodiversity: Ilgaz Wildlife Reserve and Ilgaz Mountain National Park.

Ilgaz Wildlife Reserve and Ilgaz Mountain National Park are located in the Ilgaz Mountains with a total of 17,036 ha. The elevation ranges from 1400 to 2500 m. The Ministry of Agriculture and Forestry Affairs manages the forests



**Fig. 1** A map showing the location of the study area

because they are state forests, which cover 90.61% of the land area. The remaining 2.35% of the land is agricultural, 7.04% is pastureland, and 6.39% is a national park (Anonymous, 2012; Evcin et al., 2019). The semi-arid, less humid, very cold Mediterranean and oceanic climates are characteristics of the Ilgaz Mountains' transition zone. The Ilgaz Wildlife Reserve has a rainy terrestrial ecosystem, which includes forests and bushes. The forests are dominated by the Kazdagi fir (*Abies nordmanniana* subsp. *equi-trojani*), a significant indigenous fir taxon, and Scots pine (*Pinus sylvestris* L.). Other dominant floristic elements of this ecosystem can be given as *Pinus nigra*, *Verbascum abieticolum* Bornm., *Daphne oleoides* Schreber, *Bromus tomentellus* L., *Mespilus germanica* L., *Sorbus torminalis* L. Crants, and *Genista vuralii* A. Duran & H. Dural are the significant floral traits that characterize this environment (Evcin et al., 2019; Kucuk et al., 2017).

The main large mammal species distributed in the area include Roe deer (*Capreolus capreolus*), wild boar (*Sus scrofa* Linnaeus), red deer (*Cervus elaphus* Linnaeus), brown bear (*Ursus arctos* Linnaeus), gray wolf (*Canis lupus* Linnaeus), red fox (*Vulpes vulpes*), and golden jackal (*Canis aureus* Linnaeus) (Evcin et al., 2019).

Ilgaz Mountain has an altitude of 1875 m. Before the tunnel was built in 2016, all drivers had to use the old road to get to another city. The old mountain road, used extensively due to tourism (skiing), has harsh road conditions due to extreme weather conditions in winter. In addition, the old highway separates the habitats in the forest, making it difficult for animals to pass, causing habitat fragmentation. With the

opening of the Ilgaz Mountain Highway Tunnel in 2016 (Fig. 2), the old route has become a route used only by those who want to ski in winter to access the national park (AA, Anatolian Agency, 2020). The tunnel road is 5488 m in total (Fig. 3).

## Methodology

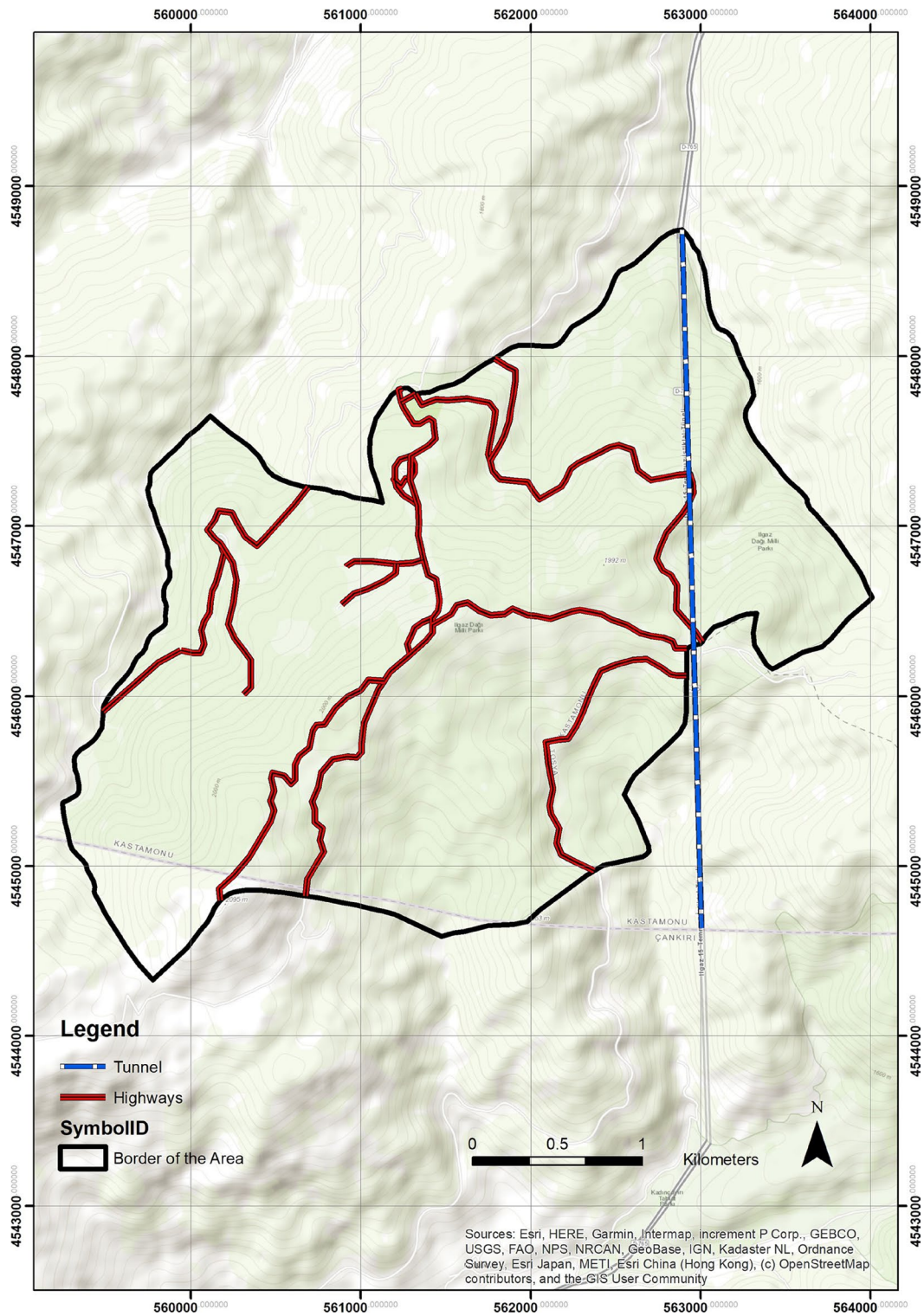
The flowchart showing the stages of data collection, data analysis, preparation of model, and mapping is given in Fig. 4.

## Data collection

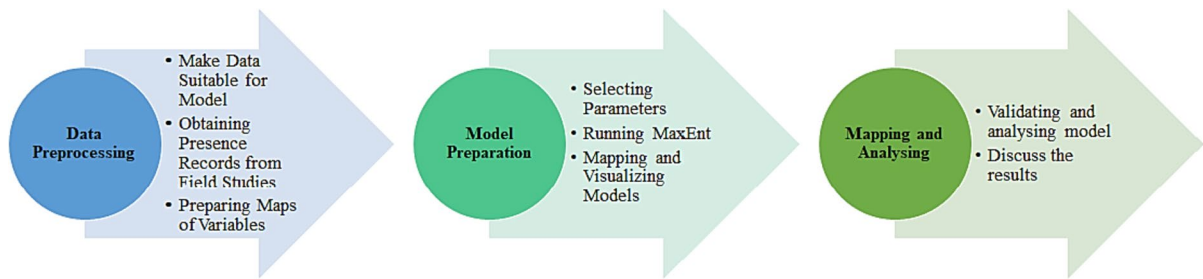
The occurrence data for the roe deer were obtained from various sources, opportunistic direct observation, scat identification, tracks, direct sightings, and vehicle–wildlife collisions between 2012 and 2015 before the tunnel construction and between 2020 and 2022 after the tunnel construction. Data on roe deer presence was collected from field studies (tracks, scats, footprints, direct observations) with opportunistic direct observation (Adamič & Jerina, 2010; Jerina et al., 2013). Fieldwork was carried out by car, and walking on the road was determined at least once a month. Most of the road was traveled by vehicle in the morning and at sunset, and attention was paid to fieldwork in all seasons. Secondary sources of roe deer occurrence records were also used from previously recorded observations and locations of vehicle–wildlife collisions by the National Park Directorate. A total of 1323 records were used. All the geographical locations of the occurrences were recorded. These points were coordinated to adapt to



**Fig. 2** Photo of Ilgaz Mountain Highway Tunnel and Old Forest Road



**Fig. 3** A map showing Ilgaz Mountain Highway Tunnel and old mountain road



**Fig. 4** Flowchart of study method

the model and variable maps and converted to CSV format. Data thinning was done to avoid overfitting using the SDM Toolbox with a distance of 300 m (Brown et al., 2017).

#### *Building the model*

The Maximum Entropy (MaxEnt) modeling approach was used to build the model for roe deer. As known, by implementing environmental factors to determine maximum entropy distribution, MaxEnt models attempt to estimate the probable geographical distribution of a species (Phillips et al., 2006; Phillips et al., 2017). This modeling is based on the characteristics of the environmental factors in the known location of the species; restriction conditions are proposed, and then, the probable distribution of maximum entropy under restriction conditions is examined to simulate the distribution of biological species in the area (Shao et al., 2023). Maxent models have a short run time and are easy to use (Li et al., 2020; Li et al., 2022). Maxent modeling can discover nonlinear relationships between environmental parameters and existing locations, and it has been frequently utilized in recent years to forecast ecological niches and species probability distributions (Cao et al., 2020; Helmstetter et al., 2021; Hemati et al., 2020).

Environmental variables are often chosen based on prior prediction performance, a known link to the species involved, or via a variable selection procedure (Synes & Osborne, 2011). SDM variables should be chosen from ecologically relevant variables so that models can give ecological insight while being transferable between areas (Bradie & Leung, 2017; Elith et al., 2011; Elith & Leathwick, 2009; Mac Nally, 2000).

Maximum Entropy (Maxent) modeling was used in this study to create a reliable binary distribution map through ecological niche modeling, to determine the distributional limits within the study site, and to identify the relevant environmental variables that correspond to the ecological niche and work well with the presence data.

At first, a total of 10 variables were selected for the modeling. After a first model run, four lesser predictor variables (contributed less than %5) were removed. Variables that are significantly correlated with each other have the potential to greatly affect the models and bias the choice of model parameters. Thus, we chose to eliminate these highly connected variables. The remaining six environmental variables were used for the MaxEnt model (Table 1).

The Copernicus website (<https://land.copernicus.eu/pan-european/corine-land-cover>) retrieved the CORINE Land Cover map for the land cover variable (CLC, 2018). Every environmental variable was built as a raster dataset with a spatial resolution of 30 m. The NASA Earth Data website provided the ASTER global digital elevation model (GDEM) with a spatial resolution of 30 m (<https://earthdata.nasa.gov>).

The variables of aspect and slope were generated by using Digital Elevation Model (DEM). The buffer distance was set at 30 m for the road and water density. Maps were created using geographic information system (GIS) analysis in ArcMap (v. 10.8) software. In these maps, a scale was made from green to red; the places indicated with green color are indicated as low density, those marked with yellow are indicated as medium density, and those marked with red color are indicated as high density. All rasterized maps were rescaled and converted to ASCII (American Standard Code for Information Interchange) format. ArcMap Software was used to create variable base maps.

**Table 1** Variables used for modeling

Category	Resolution (m)	Source
<b>Terrain</b>		
Elevation (DEM)	30	NASA Earthdata, ASTER Global Digital Elevation Model
Aspect	30	NASA Earthdata, ASTER Global Digital Elevation Model
Slope	30	NASA Earthdata, ASTER Global Digital Elevation Model
Hillshade*	30	NASA Earthdata, ASTER Global Digital Elevation Model
Topographic position index (TPI)*	30	NASA Earthdata, ASTER Global Digital Elevation Model
Roughness*	30	NASA Earthdata, ASTER Global Digital Elevation Model
Solar radiation*	30	NASA Earthdata, ASTER Global Digital Elevation Model
<b>Land cover</b>		
The density of water sources	30	Local database
Road density	30	Local database
<b>Vegetation</b>		
CORINE Land Cover map	100	Copernicus Land Monitoring Service, European Environment Agency (CLC, 2018)

\*Eliminated after first modeling

### Data analysis

The jackknife analysis was used for the validation and to assess the relative importance of the variables of the model (Pearson et al., 2007; Phillips et al., 2006; Zhang et al., 2018). A total of 75% of occurrence points are used as the training set, and the remaining 25% as the test set to evaluate accurately (Tang et al., 2020). Ten cross-validate replications were done for optimum results. The regularization factor was taken as 1. To test the model performance, AUC values were examined for precision analysis. It is also known that the accuracy of the model estimation is affected by the parameter settings (Tang et al., 2021). The AUC value ranges from 0.5 to 1.0. A value of AUC close to 1 indicates the successful performance of the model (Mousazade et al., 2019).

### Results and discussion

Our models demonstrated significant levels of predictive performance. According to model results, the AUC values of models were found to be before the tunnel construction (BTT) 0.753 and after the tunnel construction (ATT) 0.813 (Fig. 5).

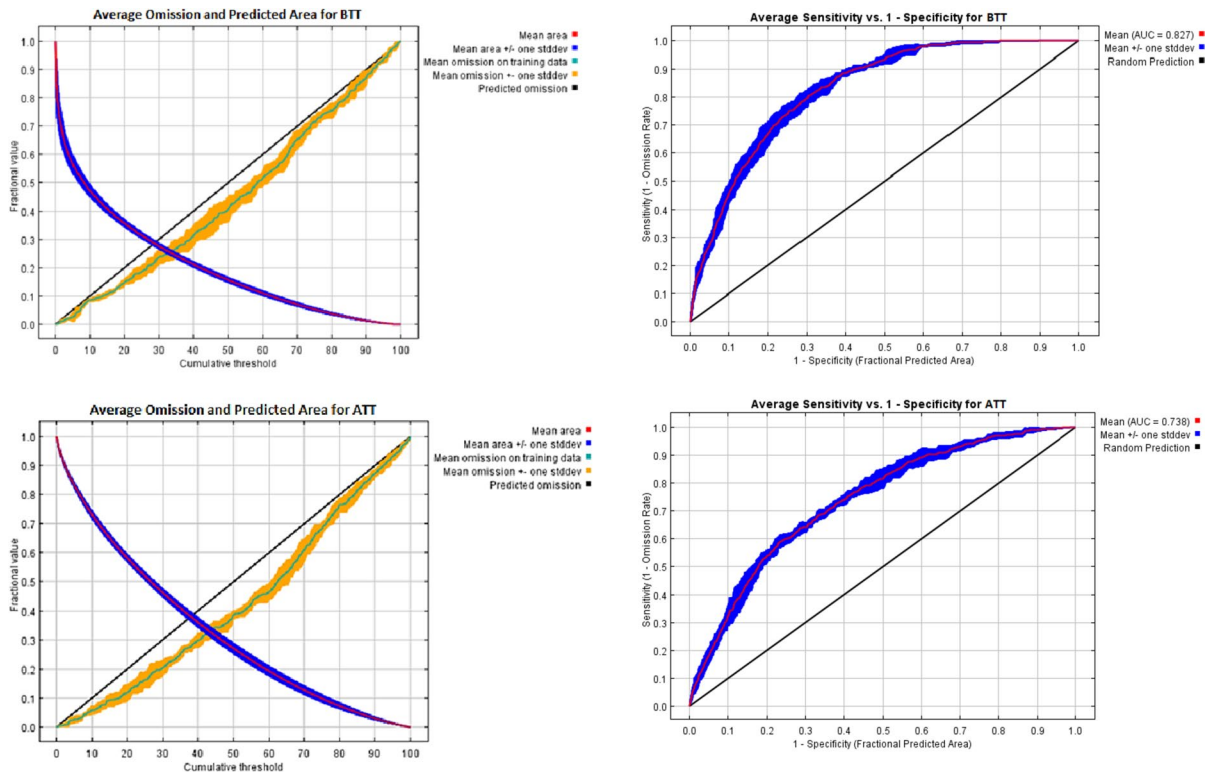
The primary use of species distribution modeling is to objectively determine which variables are most important for forecasting the species in modeling

(Phillips et al., 2017). Before the Ilgaz Mountain Tunnel was built, environmental predictors exhibited the highest mean contributions: road density, vegetation, and aspect. Regarding permutation importance, road density was the most important variable influencing the model (Table 2).

After the Ilgaz Mountain Tunnel was built, environmental predictors that exhibited the highest mean contributions were the Digital Elevation Model (DEM), road density, and density of water sources. Considering permutation importance, Digital Elevation Model (DEM), density of water sources, and road density, respectively, were the primary important variables that influenced the model (Table 3).

Response curves of individual predictors also offer more detailed and practical information that describes species distribution. These graphs demonstrate how, while maintaining all other variables at their mean sample values, the projected probability of the species distribution varies with each predictor’s variation. The MaxEnt model’s jack-knife plots were used to determine the contribution of all environmental factors. The Jackknife test also demonstrated the importance of factors when used in isolation and when each variable was removed separately. (Figs. 6 and 7)

Maps showing the distribution of roe deer on Ilgaz Mountain before the tunnel construction and after the tunnel construction are given below. As a result of the study, it was determined that in the model made



**Fig. 5** Graphs showing the average omission and predicted areas and AUC values of our models

before the tunnel, due to the density of vehicles and people on the road, roe deer prefer the areas away from the road as suitable for them, and after the tunnel, they are less affected by the effects of habitat fragmentation due to the decrease in the vehicle and human density, and they use the whole area more (Figs. 8 and 9).

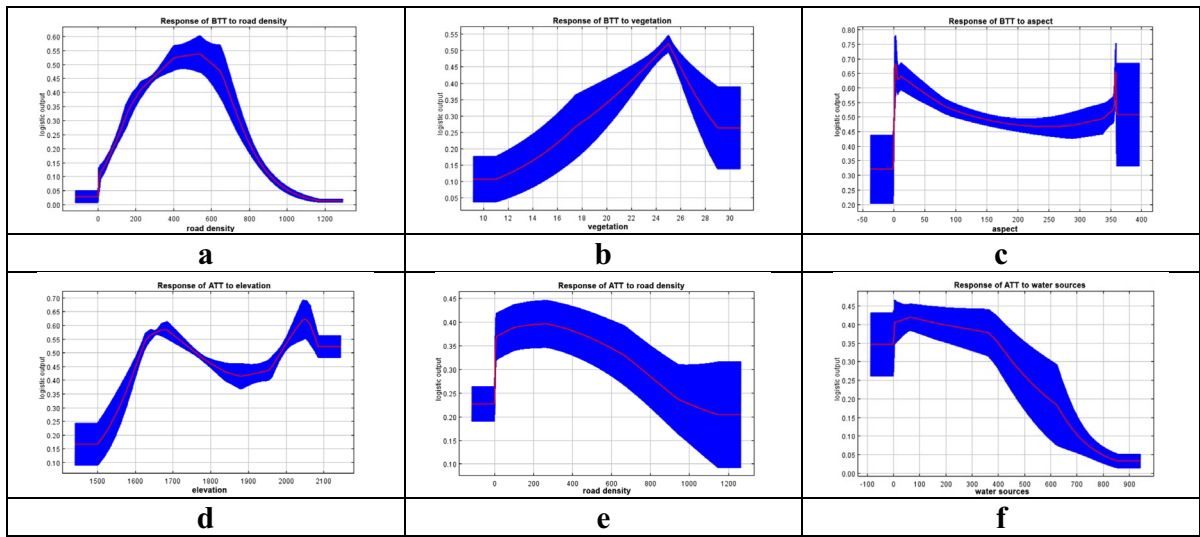
**Table 2** Table showing the estimates of the predictor environmental variables, relative contributions, and permutation importance to the MaxEnt model before the tunnel was built

Before the tunnel of İlgaz mountain		
Variable	Percent contribution	Permutation importance
Road density	69.4	62.7
Vegetation	9.7	6.8
Aspect	8.3	9.8
Slope	4.9	4.4
The density of water sources	4.2	9.5
Digital elevation model (DEM)	3.6	6.9

Within the scope of the study, a suitability model was made about the construction of a highway tunnel and how it affected the roe deers' potential behavior in the fragmented forest habitat, which was built as a better alternative to an old forest road that connects two provinces. Still, it also divides the existing forest habitats into pieces with a constant density of

**Table 3** The estimates of the predictor environmental variables relative contributions and permutation importance to the MaxEnt model after the tunnel was built

After the tunnel of İlgaz mountain		
Variable	Percent contribution	Permutation importance
Digital Elevation Model (DEM)	23.2	26.2
Road density	23.1	20.3
The density of water sources	20.1	23.9
Aspect	15.6	11.5
Slope	11	10.3
Vegetation	7	7.8



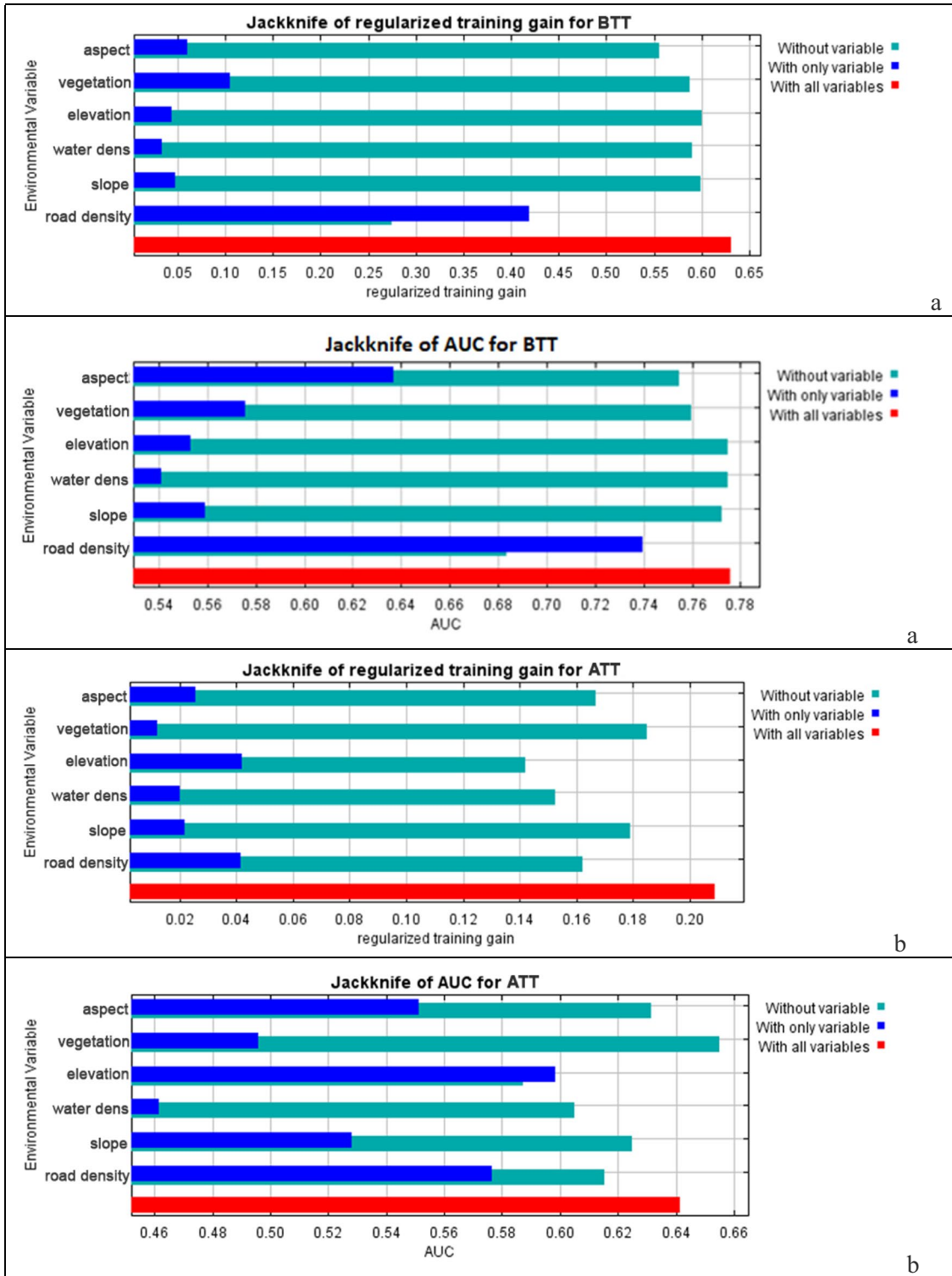
**Fig. 6** Response curves of significant variables **a** road density, **b** vegetation, **c** aspect, **d** elevation, **e** road density, **f** water sources

vehicles. The most significant variables affecting the distribution of the species before the Ilgaz Tunnel were road density, land cover, aspect, and slope, respectively, and the cumulative contribution rate of the top four variables was more than 90% (Table 2). This situation demonstrates that the road is one of the most important factors affecting species distribution in a fragmented area caused by highways. Animals in a fragmented forest structure must go from one habitat to another; either they cross the road and cause an accident, get harmed, or prefer not to cross at all and become trapped in the habitat patches. The top variables that affected the roe deer population in Ilgaz Mountain After the tunnel (ATT) were the digital elevation model, road density, distance to water sources, and aspect with the cumulative contribution rate of the top four variables of more than 90% (Table 3). The variables are consistent with previous studies on habitat suitability modeling of roe deer. Franchini et al. (2023) used Corine plant classes as a variable for roe deer ecological modeling in their research; they stated that topographic variables could potentially affect the distribution of roe deer, supporting previous literature (Bakhshi et al., 2016; Evcin et al., 2019; Mahmoodi et al., 2020). In this context, our study is also consistent with the results of previous studies.

The continuation of economic development and the reduction of biodiversity as a result of increased

human impact are inevitable (Dirzo et al., 2014; Fraser et al., 2019; Li et al., 2010; Sijtsma et al., 2020; Young et al., 2005). This situation, in particular, can result in habitat fragmentation due to increased environmental noise, pollution, and roadways (Sawaya et al., 2019; Sijtsma et al., 2020; Torres et al., 2016; Wilson et al., 2016). The ecological effects of roads and traffic on wildlife populations are essential to wildlife management, affecting all species that move. Roads often adversely affect wildlife species that use the road to move between fragmented habitats. This situation often leads to road accidents. Habitat fragmentation is defined as changing the size and shape of a land’s natural landscape components so that they become distorted, divided, or fragmented. The degradation of habitats generates small patches, resulting in local decline or even extinction of low-level populations, poorer inter-population connectivity, and less colonization of patches (Dennis et al., 2013; Hanski, 1998; Lindenmayer & Fischer, 2013).

Road accidents also occur as a result of habitat fragments that are divided due to the construction of roads in this way, and in studies conducted in the field of road ecology in Turkey, it is emphasized that roads have a negative effect on species (Özcan & Özkazanç, 2017; Özcan & Özkazanç, 2020). Benítez-López et al. (2010) stated that roads negatively affect the species even if the species belonging to Artiodactyla are far away from the road. When deers cross the



**Fig. 7** Jackknife test evaluating the relative importance of variables before the tunnel (a) and after the tunnel (b). The values displayed are averages of replicate runs

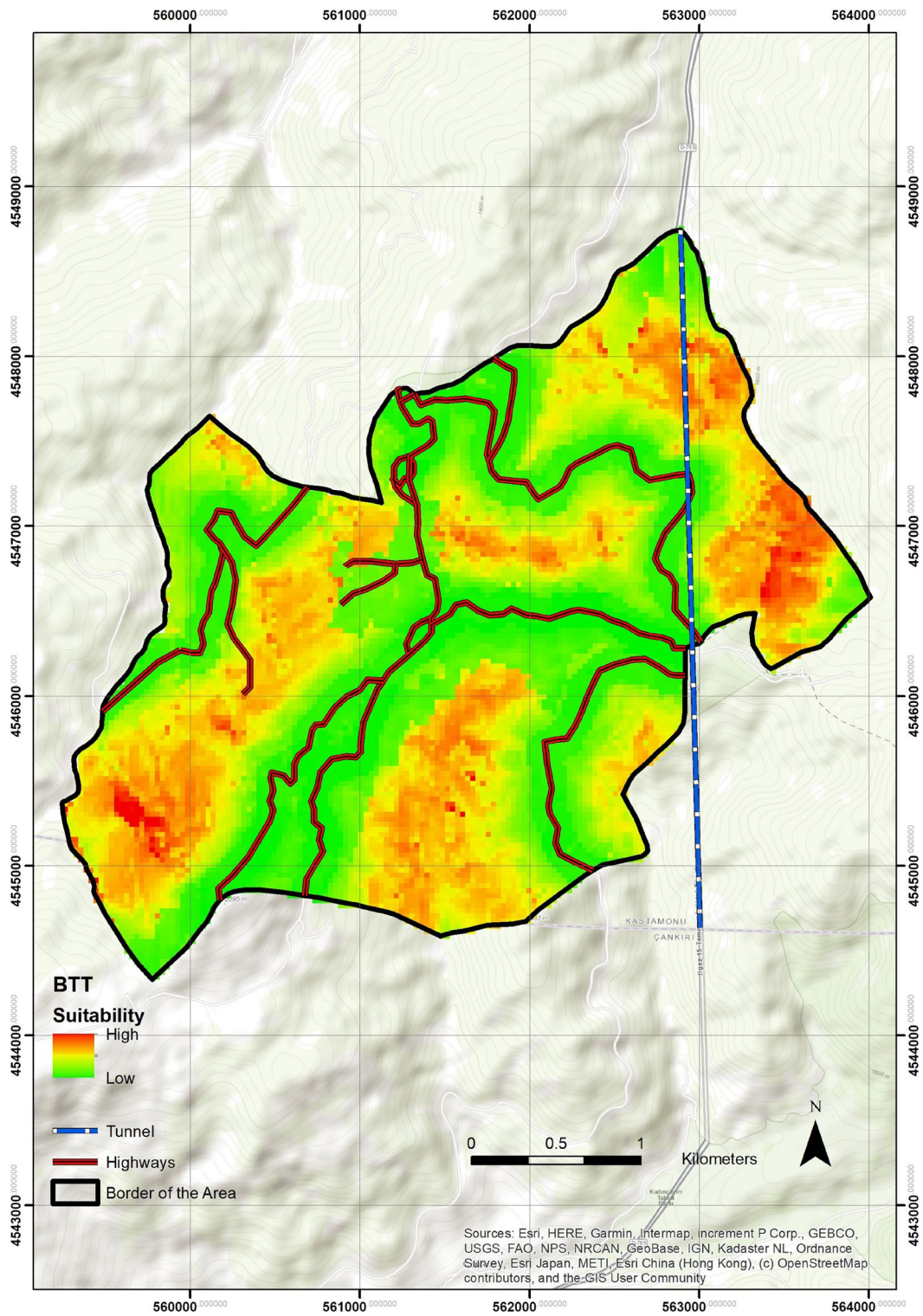
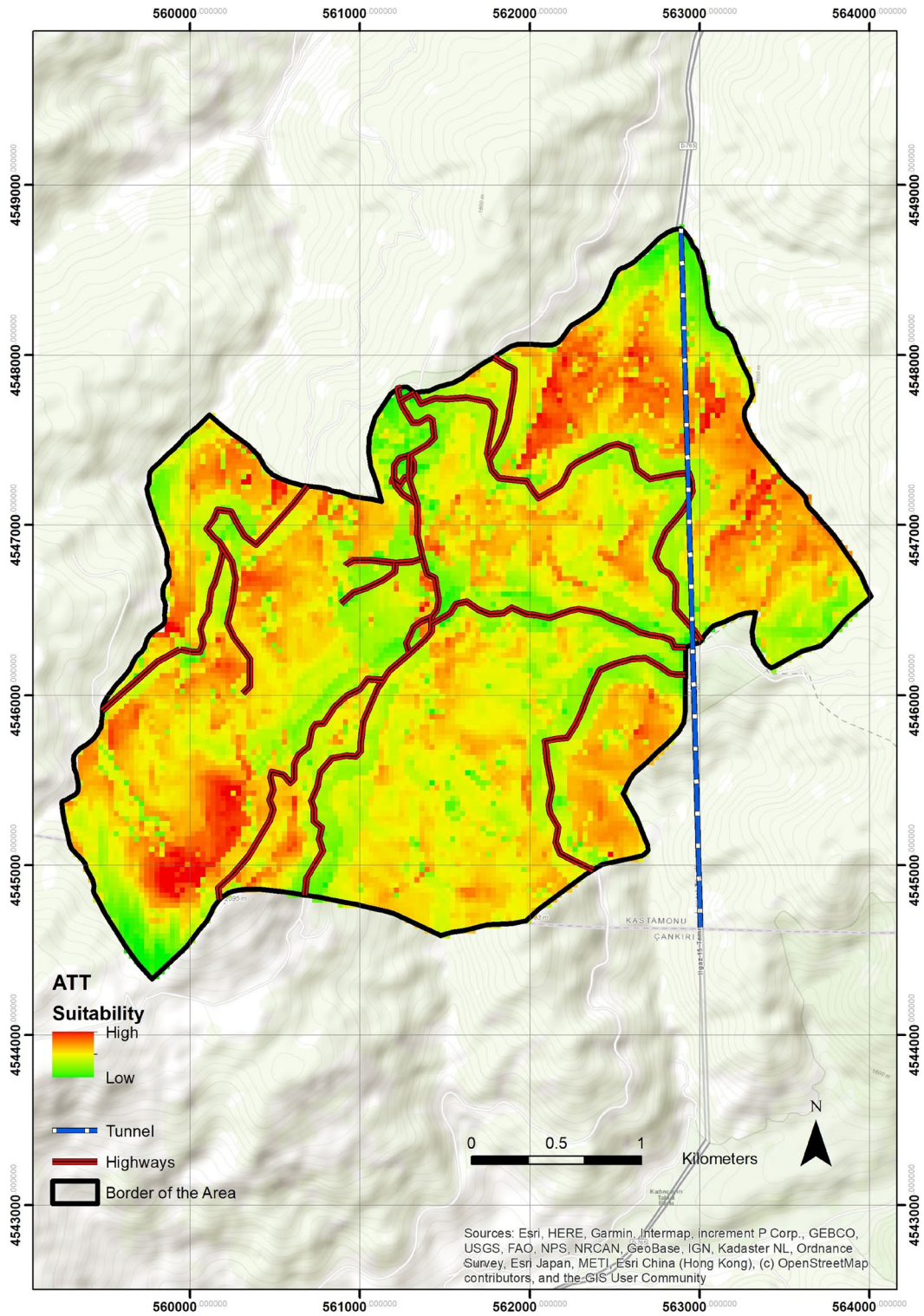


Fig. 8 The map of distribution for roe deer before the tunnel



**Fig. 9** The map of distribution for roe deer after the tunnel

road, they first hesitate and then cross over in panic (Hothorn et al., 2012). The exposure rate to vehicle collisions with wildlife, especially in America and Europe, has been stated to exceed 1 million (Conover et al., 1995; Kämmerle et al., 2017; Langbein et al., 2010). Especially for the deer species, it was stated by Hothorn et al. (2012) that approximately 200,000 individuals had traffic accidents in Germany. Roedenbeck et al. (2007) and Taylor and Goldingay (2010) state that the impact of roads and vehicles on wildlife has not been adequately explained for wildlife populations.

Turk et al. (2021) emphasized that the species is frequently affected by the roads, even on the roads in the forest. Thus, Keten (2017) stated that roads adversely affect roe deer. Bonnot et al. (2013) indicated that roe deer may change their habitat use due to human intervention, and they tend to avoid open living areas during the day and places close to where disturbed by humans. Coulon et al. (2008) noted that anthropogenic infrastructure work has a high potential negative impact on wildlife populations. The result of our study shows that Cervids can change their spatial behavior according to proximity to roads and other potential disturbing sources of human origin, and our study is consistent with previous studies in the literature (Bonnot et al., 2013; Coulon et al., 2008; Jiang et al., 2008; Kjøstvedt et al., 1998; Mysterud et al., 1999; Webb et al., 2011).

## Conclusion

This study aimed to show how the passage of a new road through the mountain with tunnel construction changed the distribution behavior of roe deer. It has been observed that the behavior of the deer has changed positively as a result of the fact that the tunnel built, which was actively used until a short time ago, passing through the middle of the national park and wildlife development area and causing habitat fragmentation, is no longer used as actively as before.

In conclusion, roads have significant effects on wildlife and biodiversity. As human populations continue to grow and infrastructure development expands, the negative impacts of roads on ecosystems cannot be overlooked. Road construction and subsequent traffic create physical barriers, fragmenting habitats and disrupting animal movement and gene

flow. The increase in roadkill incidents further threatens various species, particularly those with low reproductive rates or small populations. Pollution from vehicle emissions and noise pollution from road traffic also have detrimental effects on wildlife, affecting their behavior, reproduction, and overall well-being.

Innovative solutions are being explored to mitigate the adverse effects of roads on wildlife and biodiversity. Wildlife crossings, such as overpasses and underpasses, can reconnect fragmented habitats and facilitate safe animal movement across roadways. These structures have successfully reduced wildlife–vehicle collisions and promoted gene flow between populations. Moreover, strategic road planning that considers ecological considerations, such as identifying and protecting critical wildlife corridors and habitats, can help minimize the negative impacts of roads on biodiversity (Bruinderink & Hazebroek, 1996).

To preserve and protect our natural heritage, it is essential to continue to study the effects of roads on wildlife and biodiversity, implement effective mitigation measures, and prioritize ecological considerations in road planning and design.

Detailed inventory and survey studies on the spatial distribution of deer species should be carried out, considering management actions. For the construction of roads, road ecology should be taken into account, and the ecological demands of the species living in the area should be met by planning in a way that will have the most negligible impact on habitat fragmentation and habitat degradation. In wildlife management and planning, considering the environment and traffic, it is also necessary to plan for vehicle collisions. By doing so, we can balance human development and preserve our precious ecosystems, ensuring a sustainable future for wildlife and ourselves.

**Author contribution** ÖE (first author/corresponding author): conceiving and designing research, obtaining of data, and writing the manuscript

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**Data availability** The datasets created and/or analyzed during the current research are accessible from the corresponding author upon reasonable request.

**Declarations**

**Ethics approval** No formal ethical approval is required. The paper was not published in any journal. "All authors have read,

understood, and have complied as applicable with the statement on “Ethical responsibilities of Authors” as found in the Instructions for Authors.”

**Competing interests** The author declares no competing interests.

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