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EVALUATION OF THE EFFECT OF ENVIRONMENTAL FACTORS ON WILDLIFE ROADKILL IN CENTRAL TURKEY

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Abstract

Transport networks, including highways, have many negative ecological impacts, such as habitat loss and landscape fragmentation. One of the most consicuous negative effects is wildlife vehicle collision (WVC). The basic aims of this study, conducted on the Kırıkkale-Çankırı Highway, Turkey, are the following: i) identifying locations of WVC events, ii) modeling the effects of landscape pattern and traffic characteristics on WVC and iii) proposing a solution to mitigate WVC. In the study area, 389 medium and large mammal wild animals of 9 species were recorded. Approximately 93% of road deaths in the study area belonged to three species (Red fox, hedgehog and stone marten). The animal that was killed most often from WVC was the eastern hedgehog (*Erinaceus concolor*) with 182 deaths. The model showed that for all species the probability of a fatal accident increases with decreasing of traffic volume and distance to agricultural land, and with increasing of road width and distance to orchards.

Key words: accident, animal, ecological, highway, territory, traffic

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1. Introduction

Traffic and the transportation network have many negative ecological effects on wildlife (Buğday, 2018; Fahrig and Rytwinski, 2009; Forman and Alexander, 1998). Wild animals must move through the landscape in order to meet their vital needs, including access to nutrition, water, breeding and dispersal. One ofg the most important barriers facing wild animals are roads. The effect of traffic and roads on animal populations is not only limited to wildlife-vehicle collision (WVC). The roads divide the migration routes and habitats of wildlife and lead to habitat fragmentation. The presence of carcasses and other food sources in the road corridors turns the roadside into an ecological trap for some species (Harris and Scheeck, 1991). Furthermore, roads cause other environmental problems, such as an increased habitat destruction, environmental pollution, noise, etc. (Forman and Alexander, 1998; Forman et al., 1997; Huijser, 1999). Importantly, the most important factor that explaining WVC is the traffic volume and vehicle speed (Trombulak and Frissell, 2000). Road affected area ranges from a few meters to kilometres. This value, which differs for each wild animal species, increases as the size of the animal's increase. For example, this effect for the hedgehog is 10-20 meters, while for the fox it increases up to 3 or 4 kilometers (Underhill and Angold, 1999).

Scientists have focused on on not only mitigating but also preventing WVC at the landscape scale (Diaz-Varela et al., 2011; Polak et al., 2018; Snow et al., 2018). Coffin (2007) remarks that roads affect the landscape connectivity, habitat fragmentation, and landscape processes in conjunction with the development of landscape ecology and analyses. Keken et al. (2016) analyzed the landscape structure with wildlife collisions in the Czech Republic between 1950 and 2012. As a result, they found that the landscape pattern also changed

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significantly, resulting in a high risk of WVC. Bartonička et al. (2018) reported that high-risk spots should be identified on roads where accidents occur to reduce the risk of animal-vehicle collisions. Recent studies have modeled WVC temporally (D'Amico et al., 2015; Guter et al., 2005; Lagos et al., 2012; Mysterud, 2004; Orlowski and Nowak, 2004; Philcox et al., 1999, Rodríguez-Morales et al., 2013; Smith-Patten and Patten, 2008) and spatially (Cain et al., 2003; Clarke et al., 1998, Grilo et al., 2009; Malo et al., 2004; Ramp et al., 2005). Many variables that are used to model wildlife vehicle collisions and multidimensional spatial scales, including the road characteristics and landscape level, are discussed in the analysis (Borda-de-Água et al., 2011; Clevenger et al., 2003; Colino-Rabanal et al., 2011; Cureton and Deaton, 2012; Gunson et al., 2011; Ha and Shilling, 2018; Keken et al., 2019; Kušta et al., 2017; Jaarsma et al., 2007; Malo et al., 2004; Ramp et al., 2005; Roger and Ramp, 2009; Seiler, 2005; Snow et al., 2015). According to these studies, traffic volume (Cureton and Deaton, 2012; Ha and Shilling, 2018), vehicle speed (Jaarsma et al., 2007), vegetation cover (Ramp et al., 2005), road topography (Clevenger et al., 2003), and the human population density (Ha and Shilling, 2018) are important road and landscape characteristics that affect WVC.

In this study, we modelled to effects of landscape pattern and road features on wildlife vehicle collision for highways that have two different traffic volume in the steppe landscape of central of Turkey. We conducted this study to achieve three goals; i) to determine the diversity and proportion of wild animals dying as a result of WVC, ii) to calculate the road mortality rate and iii) to model the effects of the landscape pattern and road characteristics on WVC. The framework represented in this study can be applied to protect biodiversity and human security at different spatial scales and roads by decision marker, experts and road ecologists.

2. Materials and methods

2.1. Study area

The Kırıkkale-Çankırı highway is located in Central Anatolia, Turkey and is approximately 94 km in length (Fig. 1). The land on which the highway is located has a rough topography, with an altitude of 650-950 m a.s.l. The landscape is generally exposed to anthropogenic effects, and agricultural areas and grasslands are predominant. The Kızılırmak, Tüney, and Tatlıçay streams flow alongside the highway. The speed limit on the Çankırı-Kırıkkale Highway is 110 km h^{-1} for automobiles and is 90 km h^{-1} for buses and trucks. The highway consists of two parts, namely low and medium traffic volume. The section of the Kırıkkale-Çankırı Highway with low the traffic volume is about 32 km long and is between Irmak (Kırıkkale) and Kalecik (Ankara). The average traffic volume of this part of the highway is about 1.500 vehicles/day. The other part of the highway, which has a medium traffic volume, is about 62 km long, and the traffic volume is about 6.500 vehicles/day. The highway is not fenced to protect the terrestrial wildlife crossing it. The highway round trip is divided into two lanes. The roadside shoulder is about 2 meters and has a stabilized structure. Strip lines are available on the road.

2.2. Roadkill survey

We recorded the number of wild animal carcasses as a result of vehicle collision on the Kırıkkale-Çankırı Highway from May 2014 to May 2018. The records were collected very early in the morning once a week. We removed the carcasses to the side of the road to avoid double counts. The coordinates of the locations of the carcasses were taken by Global Positioning System (GPS), with a sensitivity of 5 meters. As a result of the studies along the road, the points where wildlife vehicle collisions are recorded with GPS are given in Fig. 2.

2.3. Spatial analysis

We tested whether there was a difference in the species of wildlife casualty with regard to the landscape and road features. The three animal species that stood out in terms of density were foxes (Vulpes vulpes), eastern hedgehogs (Erinaceus concolor), and martens (Martes foina). A one-way ANOVA analysis was applied to determine whether there was a diffence in the species of wildlife casualty with regard to the landscape and road features (Schmider et al., 2010). The variables, including the landscape and road features, did not have a normal distribution. Thus, the Kruskall-Wallis test was used, because the assumption of equal variance was not met. Levene statistics showed that variances of the variables of the distance to human settlement, distance to woodland, distance to agricultural area, distance to underpass, and distance to orchard area were homogeneous (>0.05); while the variances of the other variables were not (<0.05). The three animal species that were the subject of our study stood out in terms of their density (these included red fox, eastern hedgehogs, and martens). The other six identified mammalian wild animals were not included in the evaluation, because they were too few. A post-hoc test (non parametric Tamhane) was used to determine whether there were differeces among the species in multiple comparisons.

In our study, we aimed to determine the factors leading to fatal accidents. For this reason, the relationship among the variables was tested through a logit regression analysis (Hosmer and Lemeshow, 2000). The dependent variables were explained to reveal whether the location was the accident point or a non-accident point. Two values of the dependent variable were coded as either "1" or "0". A value of "0" was used to refer to the absence of the corresponding variable. In this context, a logit regression model was built in order to estimate the probability of the effects of the landscape and road variables expressed in Table 1.

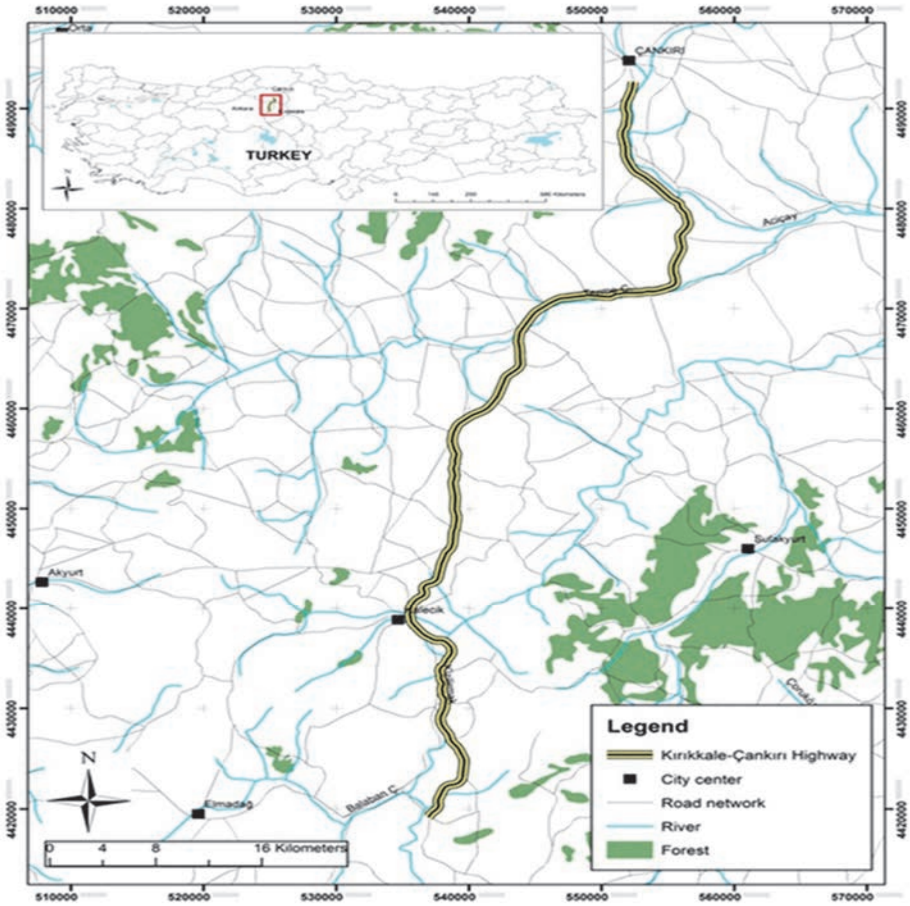

Fig. 1. Study area

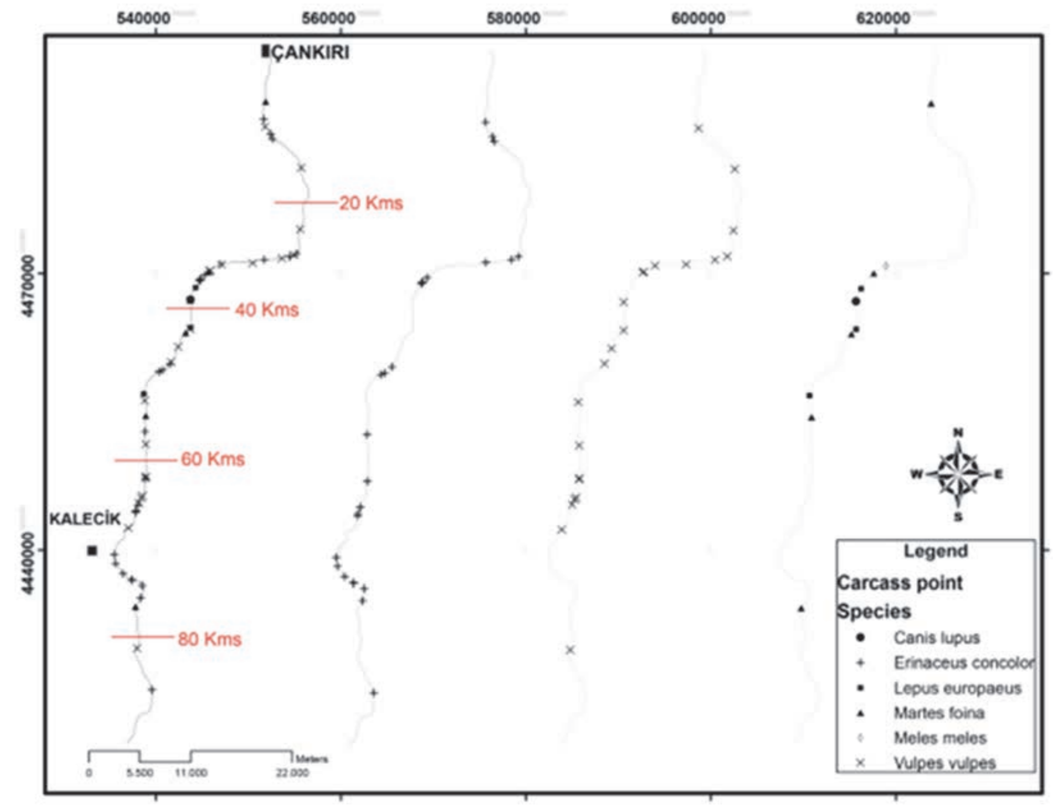

Fig. 2. The distribution of dead mammals on the road course

Table 1. Model variables

Variable code	***Definition***	Measurement technology
Landscape		
D_WOOD	Distance (meter) to the nearest woody area (minimum 1.000 m^2)	Satellite image
D_TOWN	Distance (meter) to the nearest residential area (minimum 1.000 m^2)	Satellite image
D_STREAM	Distance to nearest stream (meter)	Satellite image/DEM
D_A_HOUSE	Distance to nearest single house (meter)	Satellite image
D__AGRI	Distance (meter) to the nearest agriculture area (minimum 1.000 m^2)	Satellite image Satellite image
D_GRASS	Distance to the nearest pasture (meter)	Satellite image
D_ORC	Distance to the nearest orchard (meter)	Satellite image
Road		
R_PASS	Distance to the nearest underpass (meter)	Survey/ Satellite image/DEM
R_WIDTH	Width of road (m)	Survey/ Satellite image
R_VOL	Traffic volume (vehicle/day)	General Directorate of Highways Data
ELEVATION	Elevation from sea level (meter)	Survey/DEM

In the case of a one-unit change in the independent variables, the probability of a fatal accident was calculated. A total of 778 data sources were used for each variable in our model, and five of these data sources were removed, because they were inaccurate. All the statistical calculations were carried out using SPSS 22.0 for Windows software. In order to compare the model, non-accident points were selected as random points. Manly et al. (2002) recommended that the number of random points for logit models should be taken as the minimum number of sampling. The coordinates of the random points were created with the Create Random Points tool in ArcGIS 10.3. The landscape variables in the model were calculated using satellite/aerial photographs and a digital elevation model, with the help of Geographical Information Systems. The traffic volume data was taken from two vehicle measurement stations belonging to the General Directorate of Highways.

3. Results and discussion

A total of 389 medium and large mammal carcasses were identified to be due to WVC on the Kırıkkale-Çankırı Highway from May 2014 to May 2018. Among these, 297 (76.35 %) of the accidents occurred on the medium density traffic volume portion of the highway, and 92 (23.65 %) of the accidents occured on the low density traffic volume portion of the highway. The animal that accounted for highest number of deaths (n=182; 46.79 %) was the eastern hedgehog (*Erinaceus concolor*). The subsequent number of deaths of the wild animal were the red fox (*Vulpes vulpes*) (n=136, 34.96 %), the stone marten (*Martes foina*) (n=44, 11.31 %), the wild boar (*Sus scrofa*) (n=12, 3.08 %), the grey wolf (*Canis lupus*) (n=6, 1.54 %), the brown hare (*Lepus europaeus*) (n=5, 1.29 %), the badger (*Meles meles*) (n=2, 0.51 %), the jerboa (*Allactaga williamsi*) (n=1, %0.26) and the weasel (*Mustela nivalis*) (n=1, 0.26 %). The road mortality rate on the Kırıkkale-Çankırı Highway was 108 animal/100 km/year (Table 2). The road mortality rate was 120.83 animal/100 km/year on the portion of the highway with a medium traffic volume and was 82.5 animal/100 km/year on the portion of the highway with a low traffic volume. Data have been pooled afther chaking pooling conditions. Our distributions are neither normal nor holds equal variance assumption (test results are available in appendix). Thus Levene's non parametric test has been implemented to check if the variances are equal among different time periods. (Nordstokke and Zumbo, 2010; Nordstokke et al., 2011). We conclude that for p>.01 we reject all null hypothesis which means there is a support for equal variance condition in order to data to be pooled.

The average increase in the number of vehicles on the road was 10-12 % per year. The average traffic volume for 2015, 2016, and 2017 was 5.253, 5.887 and 6.501 vehicles/day, respectively. The highest vehicle traffic volume was in September ($\bar{X}$=8.319 vehicles/day), while the minimum vehicle traffic was in January ($\bar{X}$=4.291 vehicles/day). In addition to the seasonal behaviors of the wild animals, their daily behaviors also affected the occurrence of the traffic accidents, because all of the victim species identified are known to be more active at night. While the number of vehicles on the highway increased with sunrise, it reached its maximum value per hour between 18:00-19:00 ($\bar{X}$=449±108 vehicles/day). At sunset, the number of vehicles decreased again. Since the sun sets earlier in the wintertime, the number of vehicles reached its maximum value per hour between 17:00-18:00, and the number of vehicles was minimal per hour between 3:00-4:00($\bar{X}$=39±13.6 vehicles/day).

According to the post-hoc test results, there was a significant difference for WVC among the red fox, eastern hedgehog, and stone marten in terms of the traffic volume and road width variables. With respect to road width variable, there were significant differences in favor of the hedgehog compared to both the marten and fox.

Table 2. Frequency table for WVC

	Medium traffic volume		***Low traffic volume***		***Total***	
	N	***%***	***N***	***%***	***N***	***%***
Williams's jerboa *Allactaga williamsi*	1	0.26	0	0.00	1	0.26
Wild boar *Sus scrofa*	10	2.57	2	0.51	12	3.08
Weasel *Mustela nivalis*	1	0.26	0	0.00	1	0.26
Eastern hedgehog *Erinaceus concolor*	110	28.28	72	18.51	182	46.79
Grey wolf *Canis lupus*	6	1.54	0	0.00	6	1.54
Badger *Meles meles*	2	0.51	0	0.00	2	0.51
Stone marten *Martes foina*	41	10.54	3	0.77	44	11.31
Brown hare *Lepus europaeus*	5	1.29	0	0.00	5	1.29
Red fox *Vulpes vulpes*	121	31.11	15	3.86	136	34.96
Total	297	76.35	92	23.65	389	100.00

For traffic volume, there were also differences between the hedgehog and both the marten and fox. According to the results of the logistic regression, the distance to agriculture, distance to orchard, road width, and traffic volume variables significantly affected whether a collision occurred or not during the WVC period (Table 3, $p<0.05$), but with different correlation trends. Namely, the tendency for a WVC decreased with the increasing distance to agriculture and the traffic volume, and increased with the increasing distance to orchards and road width.

In the model, the level of explanation of the dependent variable by the independent variables was estimated as 12.9 %. The model predicted 219 out of 389 non-accident points, and the percentage of the model estimation without an accident point was 56.3 %. Our model predicted 268 out of the 389 accident points, and the percentage of model estimation with an accident point was 68.9%.

A logistic regression is frequently used to predict WVC (Grilo et al., 2009; Ramp et al., 2005; Seiler, 2005; Snow et al., 2015). Litvaitis and Tash (2008) evaluated the three most commonly used approaches for WVC and concluded that collision models offered the greatest potential for investigating the effects of roads on wildlife. The reasons for this selection are based on the availability of the data and the possible implementation of the results.

Many studies (Clevenger et al., 2003; Grilo et al., 2009; Malo et al., 2004) in recent years have shown that roadkill clustering occurs depending on the density of the population, species biology, habitat, landscape, road, and traffic characteristics. In order to analyze this cluster well, many models have been used, but the main one is logit regression (Borda-de-Água et al., 2011; Clevenger et al., 2003; Colino-Rabanal et al., 2011; Cureton and Deaton, 2012; Danks and Porter, 2010; Finder et al., 1999; Gunson et al., 2011; Jaarsma et al., 2007; Lode, 2000; Malo et al., 2004; Nielsen et al., 2003; Ramp et al., 2005; Roger and Ramp, 2009; Saeki and Macdonald, 2004; Seiler, 2005; Snow et al., 2015). The possibility is that WVC increases when the road width and the traffic volume increase on the Kırıkkale-Çankırı Highway.

A general model for WVC prediction does not exist. Depending on the wildlife species and the locality, some landscape features can be crucial predictiors. For example, increased human settlements on the roadside increase the probability of vehicle collision for marten (Grilo et al., 2009), red fox (Grilo et al., 2009), and hedgehog (Orlowski and Novak, 2004). On the contrary, decreasing the percentage of human settlements increases the probability of vehicle collision for the wildboar (Malo et al., 2004). According to road elements, the probalility of a wild boar vehicle colision increases when more road features are present, such as a roadside barrier (e.g. fence, wall, Malo et al., 2004), and traffic volume increases the probability of a hedgehog (Orlowski and Novak, 2004) and marten (Grilo et al., 2009) vehicle collision. Orlowski and Nowak (2006) reported that the daily traffic volume increases the frequency of collisions for the hedgehog species; but on the Kırıkkale-Çankırı Highway, the largest number of hedgehog-vehicle collisions occurred in the low-traffic volume section. This difference can be explained by the density of the hedgehog population. The population density of hedgehogs is approximately 30 hedgehog/km^2 for areas close to human settlement in Western Europe (Huijser, 1999) and is 100-200 hedgehog/km^2 for the wooded and agriculture areas in Poland (Orlowski and Nowak, 2004). Specifically, for the section at Kırıkkale-Çankırı Highway where there was a large number of hedgehog deaths on the highway, orchards and human settlements are intense. For this reason, the hedgehog population density may be high. Grilo et al. (2009) reported that an increase in traffic volume increased WVC for the red fox. Fox deaths on the Çankırı-Kırıkkale Highway were approximately four times higher in the medium traffic volume section of the highway (50 animals per year/100 km) than in the low traffic volume section of the highway (15 animals per year/100 km). The road mortality rate for the red fox on the Ankara-Kırıkkale Highway, with high traffic volume, was 190 animals per year/1.000 km (Özcan et al., 2018). These results showed that fox vehicle collisions were higher on a highway with a medium traffic volume. This may be because foxes avoid high traffic volume areas, like the roe deer - *Capreolus capreolus* (Diaz-Varela et al., 2011) in northwest Spain or moose - *Alces alces* in southeastern Norway (Torres et al., 2011).

Table 3. Model results

		B	*S.E.*	*Wald*	*df*	*Sig.*	*Exp(B)*	*95% C.I.for EXP(B)*	
								Lower	*Upper*
Step 1	ELEVATION	-0.02	0.002	0.598	1	0.439	0.998	0.994	1.003
	D_STREAM	0.000	0.000	0.125	1	0.723	1.000	1.000	1.000
	D_TOWN	0.000	0.000	2.964	1	0.085	1.000	1.000	1.000
	D_A_HOUSE	0.000	0.000	1.364	1	0.243	1.000	1.000	1.000
	D_WOOD	0.000	0.000	0.622	1	0.430	1.000	1.000	1.000
	D_AGRI	-0.002	0.001	11.459	1	**0.001**	0.998	0.996	0.999
	D_GRASS	0.000	0.000	3.747	1	0.053	1.000	1.000	1.001
	R_PASS	0.000	0.000	0.205	1	0.651	1.000	1.000	1.000
	D_ORC	0.000	0.000	3.892	1	**0.049**	1.000	1.000	1.000
	R_WIDTH	1.779	0.380	21.930	1	**0.000**	5.925	2.814	12.475
	R_VOL	-1.408	0.282	24.966	1	**0.000**	0.245	0.141	0.425
	Constant	1.158	1.444	0.643	1	0.423	3.183		

Wild animals that use the home range or travel rute on the highway are more exposed to a risk for WVC. Similarly, slow-moving wild animals, with limited agility, are more vulnerable to road deaths because they take more time to cross the road (Ashley and Robinson, 1996; Bonnet et al., 1999; Rosen and Lowe, 1994). Colino-Rabanal et al. (2011) identified that wolf deaths, as a result of WVC, were the highest on motorways (2,96 ± 1,57 animals per year/1.000 km), and this was significantly different from other roads (γ 2 = 23.020, df = 3, p <0.001). We determined the wolf mortality rate was 16.5 animals per year/1.000 km on the Kırıkkale-Çankırı Highway with a medium traffic volume. On the Ankara-Kırıkkale Highway, the wolf mortality rate was 10 animals per year/1.000 km (Ozcan et al., 2018). These results showed that wolf deaths are quite high compared to European countries. Importantly, rare species, such as grey wolf and weasel, are protected by IUCN and DLMPGM (Directorate General for Nature Conservation and National Parks) in Turkey. Therefore, not only should the number of deaths of the species, but also the risk of extinction, should be taken into account.

The logistic regression model estimated the model results for WVC quite well, because it estimated the accident points at a rate as great as 70 %. Predictive studies (model studies) are used to identify high-risk locations of WVC for many species (Gunson et al., 2011), but these studies are affected by various measurement errors. At the beginning of these errors is the incomplete reporting of WVC (Donaldson and Lafon 2010). Consequently, many WVCs are excluded from such scientific studies or are classified as non-collisions. The limitation of our study, it was time to collect carcasses and to collect them only from the road platform. Snow et al. (2015) reported that statistical models that identify WVC effects were only reliable with ≥ 30 % of the data. Therefore, the number of carcasses collected and the recording time of the carcasses were sufficient for the logistic regression model. Road ecologists, which is a new developing profession, use statistical models to determine the risk factors (landscape characteristics, distribution and abundance of wild animals and habitats, as well as traffic density, road width) affecting WVC (Clevenger et al., 2003; Dussault et al., 2006; Jaarisma et al., 2007; Joyce and Mahoney, 2001; Malo et al., 2004). This information can be used as a guide for building wildlife overpasses, underpasses, barriers, as well as for periodic wildlife signals, speed-reducing wildlife reflectors, and speed bumps.

4. Conclusions

In this study, we have analyzed WVC data in the steppe landscape of central Turkey for purpose of testing and developing the logistic regression model. Logistic regression models are often used to identify risks in wildlife vehicle collisions. This article is one of the pioneering studies on the modeling of wildlife vehicle collisions in Turkey. The major deficiency in Turkey is the fact that data of WVC cannot be collected except for scientific projects. For this reason, our priority is the collection and regular recording of data by government agencies.

An advantage of these models is that they can be updated with new data. In addition, through a change of the model variables by ecologists or experts, the degree of their impact on accident probabilities can be estimated and simulated. For example, decision makers or experts for our study area can focus primarily on traffic volume and road width. Thus, the model can also function as a landscape or road planning tool.

WVC has a significant impact on both human safety and on wildlife populations. Serious economic and scientific support is needed to reduce or eliminate this negative impact. This will provide an advantage for managers to create a mechanism for mitigation plans, and road safety. In fact, utilizing logistic models in plans of reducing WVC will lead to economic benefits.

As our field of study is especially in steppe landscapes, it has similar landscape features for many areas. Considering the success of the model, it can be used to simulate wildlife vehicle collisions in similar areas. In the future, the model framework will assist planners and decision makers in planning transport projects and in reducing wildlife vehicle collisions.

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