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Identifying the hotspots of wildlife–vehicle collision on the Çankırı–Kırıkkale highway during summer

Ali Uğur ÖZCAN[1,2,*], Nuri Kaan ÖZKAZANÇ[2]
[1]Department of Landscape Architecture, Faculty of Forestry, Çankırı Karatekin University, Çankiri, Turkey
[2]Department of Forestry, Faculty of Forestry, Bartın University, Bartın, Turkey

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Abstract: In this study, we identified hotspots of mammal–vehicle collisions that occurred on the Çankırı–Kırıkkale highway between May and October 2014. We collected 58 records from 6 species. Sixteen casualties occurred on the part of the road with low traffic volume (1818 vehicles/day) and 42 casualties occurred on the part with moderate traffic volume (4680 vehicles/day). The two species with the highest number of records were hedgehog *Erinaceus concolor* (n = 27) and red fox *Vulpes vulpes* (n = 21). Hotspots of mammal–vehicle collisions were detected with the CrimeStat3 program using 750-m bandwidth. We identified two spots of high incidence of roadkill and 3 spots of moderate incidence of roadkill on the highway. Strategies to reduce the incidence of roadkill should be considered for these hotspots.

Key words: Hotspot, vehicle collision, wildlife, motorway, mammals, Turkey

1. Introduction

Roads and traffic have various negative ecological and environmental effects on wildlife (Forman et al., 1997; Trombulak and Frissell, 2000; Fahrig and Rytwinski, 2009). One of the major effects on wildlife is additional mortality due to vehicle collisions. However, the effects of traffic and roads on animal populations are not limited to animal fatalities. Other negative effects of roads include barriers limiting the migration/dispersal of wildlife, the attraction effect resulting from the presence of new nutritional sources (for example, carrion on roadsides) (Harris and Scheck, 1991), and disturbance due to traffic noise, night lights, pollution (salt, heavy metals, herbicide, nitrogen), management activities on road borders, increased human presence, artificial sets, and erosion, all of which have a great effect on the quality of wildlife habitats (Forman and Alexander, 1998; Hujiser, 1998; Forman et al., 2003).

It is known that in various countries some species of wild animals have experienced population decrease due to road accidents. It is estimated that over 40% of the mortality rate of Britain's adult European badger (*Meles meles*) population is a direct result of traffic accidents (Harris and Scheck, 1991; Clarke et al., 1998). In Portugal, estimates show that 10% of the Iberian wolf (*Canis lupus*) population, an endangered species, is hit annually by vehicles south of the Douro River (Grilo et al., 2009). It is also estimated that every year 230,000 to 350,000 western hedgehogs (*Erinaceus europaeus*) in Belgium (Holsbeek et al., 1999) and 113,000 to 340,000 in the Netherlands (Huijser and Bergers, 2000) die as a result of traffic accidents. There is no current scientific study about this topic in Turkey.

Several studies showed that wildlife–vehicle collisions (WVCs) do not take place randomly, and there are factors that explain some temporal and spatial aggregation of roadkill (Puglisi et al., 1974; Hubbard et al., 2000; Joyce and Mahoney, 2001; Clevenger et al., 2003; Ramp et al., 2005). Due to the effects of road deaths on animal populations, protection planners should investigate why deaths take place at varying frequencies and locations. Identifying hotspots for roadkill is crucial for protection planners. Although peaks for road fatalities vary among species (Mysterud, 2004), breeding seasons correspond to high incidences of roadkill (Beaudry et al., 2008; Grilo et al., 2009).

In recent years, several studies identified WVC hotspots (Ramp et al., 2005; Seiler, 2005; Beaudry et al., 2008). Hotspots can be a valuable tool in statistical models for understanding how the wildlife population, traffic, and landscape explain the incidence of roadkill (Malo et al., 2004; Ramp et al., 2005; Gomes et al., 2009; Danks and Porter, 2010). Detection of the features associated with

* Correspondence: auozcan@karatekin.edu.tr

road accident areas is an important step for decreasing casualties (Cain et al., 2003; Ramp et al., 2005). The main approach used in the analysis of hotspots is the comparison of the relational qualities between the areas where collisions do not take place and the areas where collisions take place (Bashore et al., 1985; Hubbard et al., 2000).

The main goal of this study is the identification of the hotspots of mammal–vehicle collision along the Çankırı–Kırıkkale highway between May and October 2014.

2. Materials and methods

2.1. Study area

The study area comprised 94 km of the Çankırı–Kırıkkale 765 (05-06-07) Highway (Figure 1). The territory where the road course is located has a rough topography, with an altitude between 650 and 950 m. In general, the landscape consists of agricultural areas, with some areas dominated by pastures. The Kızılırmak, Tüney, and Tatlıçay streams occur parallel to each other along the highway.

2.2. Traffic volume

The speed limit for vehicles on the Çankırı–Kırıkkale highway is 110 km h^{-1} and it is 90 km h^{-1} for trucks, buses, and rigs. Traffic volume data were obtained hourly each month according to vehicle type from two vehicle measurement stations belonging to the General Directorate of Highways. The data are given as the total for both directions. The highway is composed of two sections with low and moderate traffic density. The vehicle volume averages were 1800 vehicles/day (low-traffic volume section) and 5000 vehicles/day (moderate-traffic volume section).

2.3. Field study

We recorded all roadkill of wild species on the Çankırı–Kırıkkale highway between 1 May 2014 and 1 October 2014 (Appendix). Records were collected at dawn every 3 days on average over a period of 183 days. We recorded the coordinates of all carcasses using a Garmin GPS with 5-m accuracy and placed them at the roadside to prevent double counting. Eight photos were taken at a 45° angle from the point where the collision occurred, and one photo was taken from a 50-m distance in the direction in which the collision occurred.

2.4. Hotspot identification

The kernel method consists of placing a seed (probability density) on every analyzed point in sampling. Kernel density estimation (KDE) is a mathematical model used for conditions with many variables (Silverman, 1986; Seaman and Powell, 1996). It is calculated according to Eq. (1):

$$f(x) = \left[\frac{1}{nh^2}\right]\Sigma_{i=1}^{n} K\left(\frac{x - X_i}{h}\right) \quad (1)$$

where n is the number of analyzed points; h is the bandwidth; K is the kernel function; x is the vector of x, y coordinates of the location where the function is estimated; and X_i is the vector series of the coordinates where all analyzed points are defined in Eq. (1).

Because all carcasses were on the road, distance measurements were done by using network distance rather than direct measurements (Gomes et al., 2009). The CrimeStat3 program was used for the calculations (Levine, 2006). Gomes et al. (2009) calculated the K function by using Ripley's K function and K function network. In all of the deaths, the K function was obtained with ArcGIS Kernel Density Tools by being taken as a normal (Gaussian) function. Ramp et al. (2005) and Gomes et al. (2009) took the bandwidth as 500 m; Ramp et al. (2006) took it as 300 m. To choose different bandwidths (250 m, 500 m, 750 m, 1000 m, 1250 m, 1500 m, 2000 m, 3000 m) the bandwidths were applied visually one by one. While kernel density maps were very sensitive at high bandwidths, they were less so at low bandwidths. As a result, 750 m was chosen as the most suitable bandwidth for the study area.

3. Results

Throughout the 5-month summer season, 58 accidents with casualties from 6 species of mammals were recorded. Monthly distribution of mammal roadkill is given in Table 1. Hedgehogs (*Erinaceus concolor*) (n = 27) and red foxes (*Vulpes vulpes*) (n = 21) were the species with the highest numbers of records.

The yearly roadkill rate for all mammals along the road is 0.62 ind./km (Table 2). The yearly roadkill rate in areas with moderate traffic density is 0.68 ind./km; it is 0.52 ind./km in areas with low traffic density. The yearly death rate between the 20th and 50th kilometers of the road rises to 1.15 ind./km (Figure 2). Hedgehogs had an average yearly roadkill rate of 0.29 ind./km (0.24 ind./km on the moderately dense traffic part and 0.39 ind./km on the low-density traffic part). Foxes had an average yearly roadkill rate of 0.224 ind./km (0.29 ind./km on the moderate traffic density part and 0.10 ind./km on the low traffic density part of the road).

According to the General Directorate of Highways, throughout the working period, the average daily traffic volume between Çankırı and Kalecik was an average of 4680 vehicles, and between Kalecik and Kırıkkale it was an of average of 1818 vehicles (Figure 3). The traffic reached its highest density in September for both of the highway segments. The density of vehicles in traffic fluctuates at different times throughout the day, particularly on weekends and between 0700 and 1700 hours (Huijser et al., 2009). The traffic density started to decrease after 0700 hours on both of the roads and increased after 1700 hours. The risk of accidents increased 1 h after sunset because of

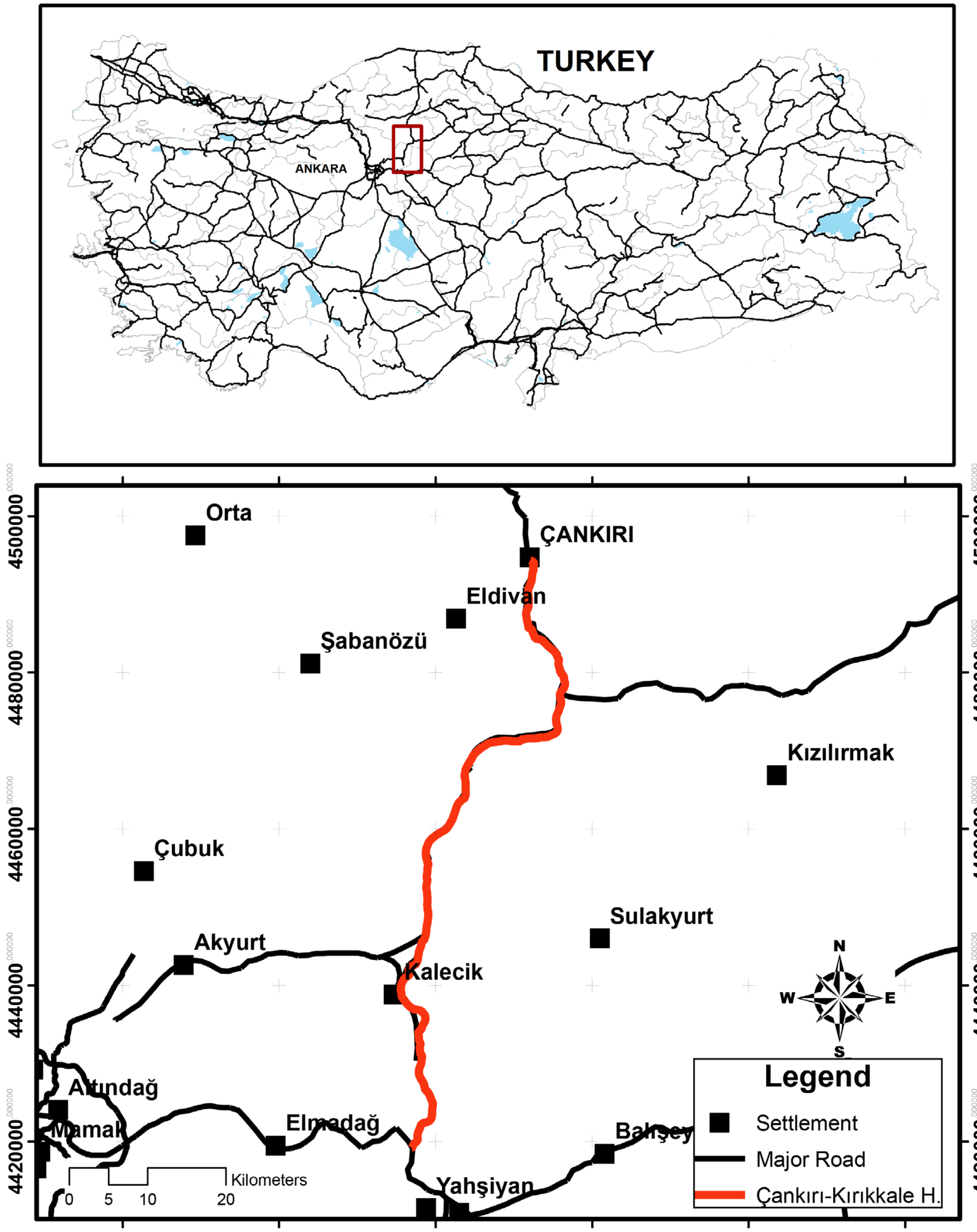

Figure 1. Study area.

poor visibility (Haikonen and Summala, 2001). In other words, during the time when accidents occur most often (between 2000 and 2200 hors), 2 vehicles pass on the low-density road every minute and 5 vehicles pass on the moderate-density road every minute.

According to kernel density calculations, there is a cluster of 2 dense hotspots and 3 less dense hotspots (Figure 4). One of the 2 dense hotspots is located in the moderate-density traffic area (KDE length = 4250 m), and the other is located in the low-density traffic area of

Table 1. Monthly distribution of mammal roadkill on the Çankırı–Kırıkkale highway.

Species	May	Jun	Jul	Aug	Sep	Oct	Total
Hedgehog (*Erinaceus concolor*)	3	7	9	3	3	2	27
European hare (*Lepus europaeus*)	1	1			1		3
Wolf (*Canis lupus*)	1						1
Red fox (*Vulpes vulpes*)	1	4	2	5	4	5	21
Stone marten (*Martes foina*)	1	2				2	5
European badger (*Meles meles*)	1						1
Total	8	14	11	8	8	9	58

Table 2. The number of animals that were killed as a result of vehicle collisions on the Çankırı–Kırıkkale highway (May–October 2014).

Species	Low traffic volume (62.7–93.8 km)		Moderate traffic volume (0–62.7 km)		Total (0–93.8 km)	
	Carcass number	Carcass %	Carcass number	Carcass %	Carcass number	Carcass %
Hedgehogs (*Erinaceus concolor*)	12	20.69	15	25.86	27	46.55
European hare (*Lepus europaeus*)			3	5.17	3	5.17
Wolf (*Canis lupus*)			1	1.72	1	1.72
Red fox (*Vulpes vulpes*)	3	5.17	18	31.03	21	36.21
Stone marten (*Martes foina*)	1	1.72	4	6.90	5	8.62
European badger (*Meles meles*)			1	1.72	1	1.72
Total	16	27.59	42	72.41	58	100.00

the road (KDE length = 2750 m). According to KDE, 13 accidents with casualties from 6 species occurred on the part of the road with the highest risk (KDE length = 4250 m), including red fox (n = 5) and hedgehog (n = 4). In the low-traffic volume area, we found 10 accidents in total, with casualties of 6 red foxes and 5 hedgehogs.

4. Discussion

We used KDE in order to determine the spatial distribution of road casualties. We determined that road fatalities of mammals were spatially clustered on the Çankırı–Kırıkkale highway. In the study period, we recorded 58 animal carcasses from 6 species. Most deaths were hedgehogs (n = 27) and red foxes (n = 21). There were 2 high-risk and 3 moderate-risk clusters. We also found that most of the roadkill occurred in June.

Generally, the 6 species of mammal that were accidentally killed in the study area are nocturnal (Alkan, 1965; Rühe and Hohmann, 2004; Elmeros et al., 2005; Kusak et al., 2005; Dudin and Georgiev, 2015). Red fox is active between 1700 and 0500 hours, and it reaches its most active state between 2100 and 0100 hours (Adkins and Stott, 1998). Baker et al. (2007) identified that the number of red fox road crossings increases during low traffic at midnight. The fact that the density of vehicle traffic varies during the day affects wildlife accidents at different rates. In particular, 1 h after sunset, the risk of collision increases for both drivers and animals due to poor visibility in the dark (Haikonen and Stott, 1998). During the time when accidents most often occur (between 2000 and 2200 hours), 2 vehicles pass on the low-density road every minute and 5 vehicles pass on the moderate-density road every minute. When we assume that a hedgehog walks 110 m per hour on average and 380 m maximum, it can walk a 24-m road platform in 13 min on average and at 3.5 min maximum. This makes it inevitable for hedgehogs to be hit by vehicles (Rondinini and Doncaster, 2002).

Other than animal activity, the most important factor for all of the accidents occurring at night is poor visibility. There is a 300-m visibility range for both directions of the road during the day, but this range is limited to the range of the light of headlamps at night. There is a negative correlation between speed and the driver's vantage point. A standing person has a 140° visibility angle, but a driver

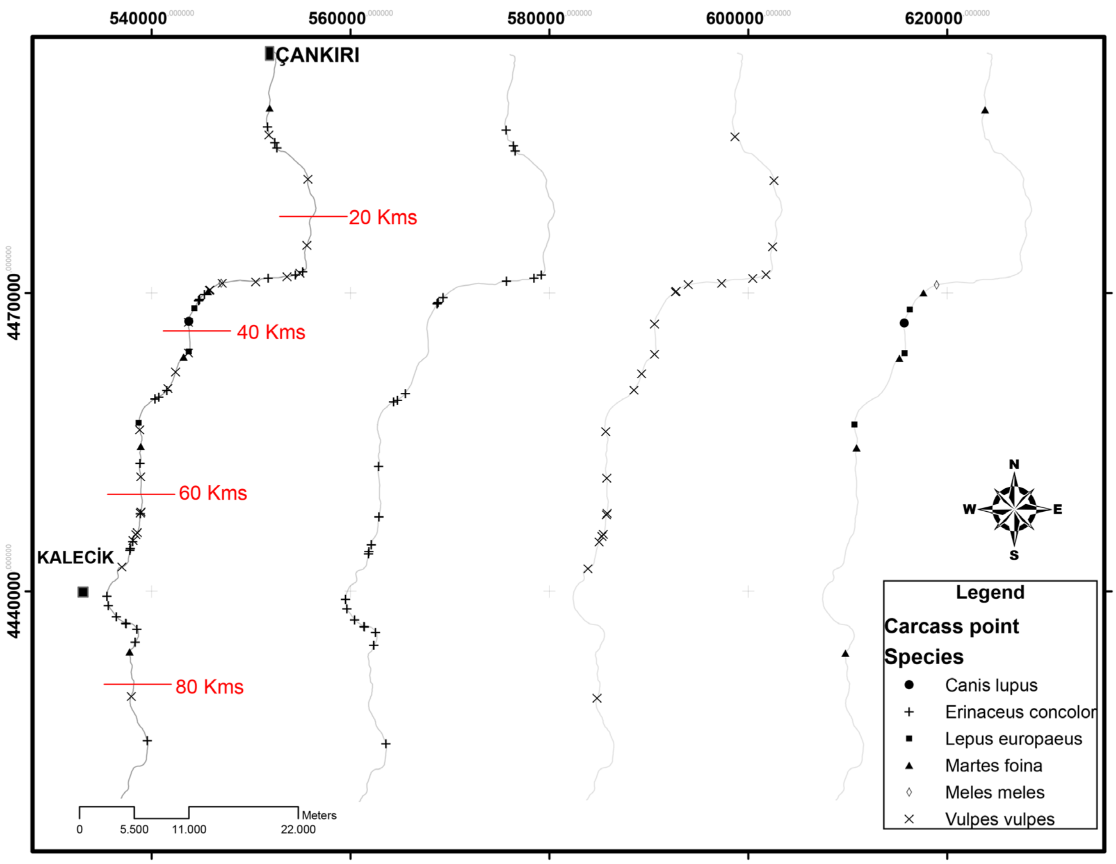

Figure 2. The distribution of accidentally killed mammals on the road course.

with 35 km h^{-1} speed has an angle of 104°, a driver with 65 km h^{-1} has 70°, and a driver with 130 km h^{-1} has just 30° driver vantage point (Çubuk and Hatipoğlu, 2006). In addition to this, Rodger and Robins (2006) found that both moose and driver perception-reaction time increased with increasing vehicle speed at night. This shows that even if a wild animal encounters a vehicle driving under the speed limit during the night, the possibility of collision is quite high. In addition, the headlights of the vehicles diminish the visual abilities of wild animals.

Many researchers have examined the relationship between traffic volume and WVCs (Seiler, 2005; Krisp and Durot, 2007). Some researchers have examined the relationship between traffic volume and WVCs. In many studies, it was emphasized that there is a nonlinear relationship between traffic volume and WVCs. For example, with increasing traffic volume, Seiler (2005) found that roe accidents increased; however, Huijers et al. (2009) stated that the number of hedgehog accidents decreased. Huijers et al. (1998) argued that high traffic volume did not always lead to more road deaths, because a larger barrier effect could prevent some species from passing. Our study also found that more hedgehog deaths occurred on the road in low traffic volume, but fox deaths demonstrated the opposite result. Lower traffic volume, which leads to a lower barrier effect, may cause species to be active more often.

Moreover, the density of fox deaths was nearly 3 times greater on the road with moderate density than the road with low density. Baker et al. (2004) underlined the difference between road types and distribution of WVCs and reported that most of the red fox kills occurred on major roads. Although Orlowski and Nowak (2004) stated that higher daily traffic volume increased the possibility of collisions for hedgehogs, more hedgehogs died on the low-traffic sections of the Çankırı–Kırıkkale highway. This difference can be explained by the density of the hedgehog population. In West Europe, the population volume of hedgehogs is 30 per km^2 near residential areas (Huijser, 1999), while it is 10–20 per km^2 in parks near detached houses in Wroclaw, Poland, and 100–200 per km^2 in woody and gardened areas (Orlowski and Nowak, 2004). The portion of the road with low-density traffic where hedgehogs are most frequently killed borders fruit and vegetable gardens.

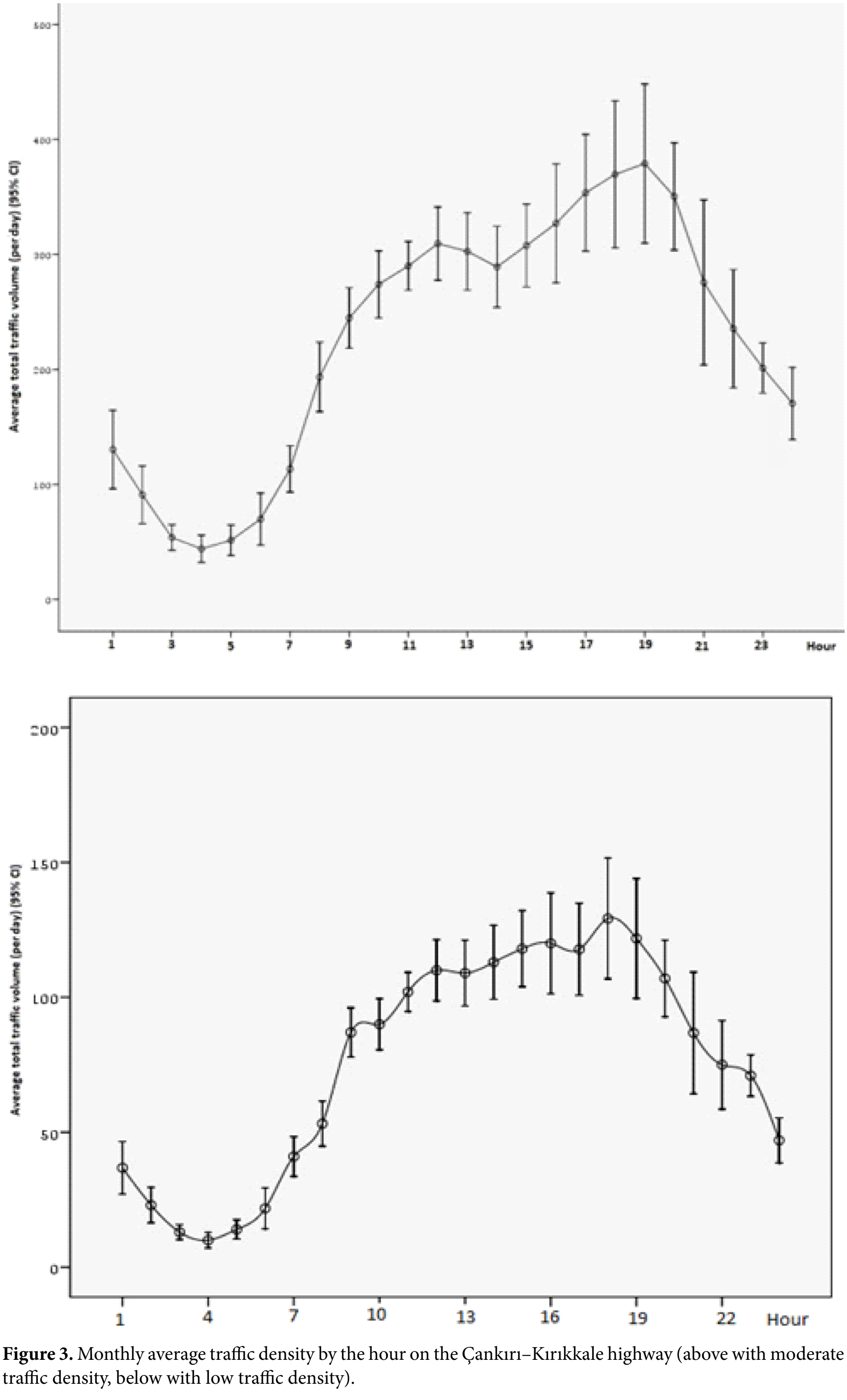

Figure 3. Monthly average traffic density by the hour on the Çankırı–Kırıkkale highway (above with moderate traffic density, below with low traffic density).

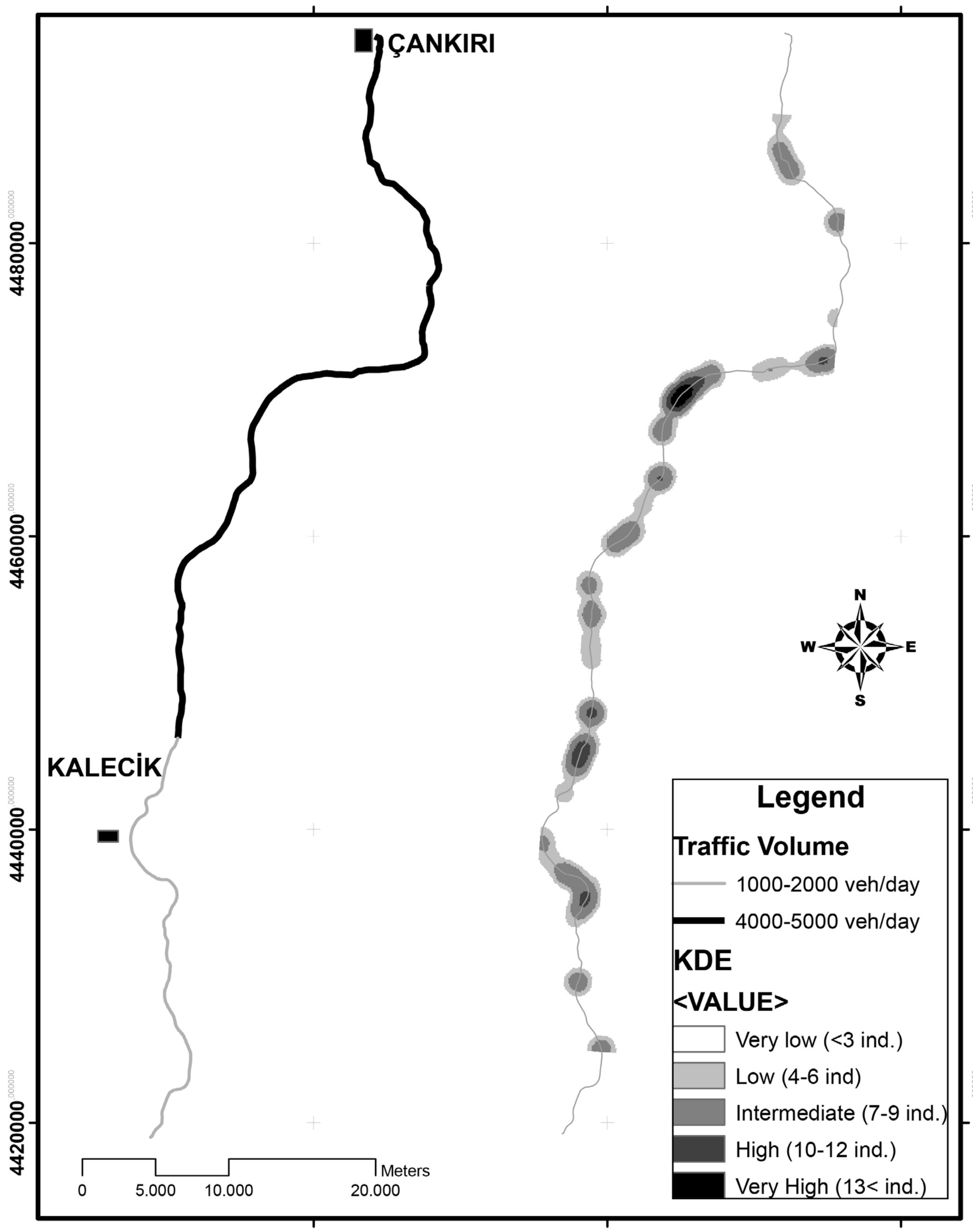

Figure 4. The KDE map of the mammals that were killed in accidents on the Çankırı–Kırıkkale highway.

Orlowski and Novak (2006) found that over 80% of WVCs occurred between May and October. It was found that most of the mammalian deaths from WVCs took place in the summer months (Fuellhaas et al., 1989; Orlowski and Novak, 2006; Grilo et al., 2009). According to Orlowski and Novak (2004), most of the traffic deaths of hedgehogs, which have a high mortality rate, take place during the summer. Most deaths of carnivores are recorded during the late spring (May and June). We found that spring and early summer are critical periods for red foxes. High numbers of roadkill might be related to high mobility periods such as breeding and dispersal periods (Grilo et al., 2009). On the Çankırı–Kırıkkale highway, the highest red fox death rate occurred in August. This difference might be related to the breeding season. The breeding season of the red fox is from December to April in warm climate regions such as the Mediterranean (Larivière and Pasitschniak-Arts, 1996).

Detecting the volume of wildlife deaths on roads is very important for decreasing deaths and secondary effects on wildlife. Managing these effects on all areas of roads is not possible economically or logistically. Smith (1999, 2003) carried out intense locational analysis of road deaths in Florida and defined how to diminish WVCs by suggesting where to plan and how to design by taking animal mobility, distribution, landscape pattern, and locations of road deaths into account. In addition, the data collected via traffic accidents can be used not only in decreasing accidents or preventing deaths, but also in other types of studies of species, such as population densities and habitat uses.

Future research should analyze the effect of the landscape in the vicinity of roads, traffic volume on roadkill likelihood, and the impact of the observed roadkill on species populations (Clevenger and Waltho, 2000; Clevenger et al., 2003; Malo et al., 2004; Dussault et al., 2006; Jaarsma et al., 2007). That information can be used to understand the real impacts of mortality on wildlife populations and, if needed, can act as a guide in building wildlife overpasses, underpasses, and barriers and in taking precautions like periodic wildlife signals, decelerator wildlife reflectors, roadside wildlife management, and speed bumps.

According to transportation planners, warning signs are most effective when the driver is warned about a danger on the road (Hedlund et al., 2004). However, the use of these signs may not always be effective on driver behavior. The overuse or misuse of warning signs may make them lose effectiveness for drivers (Krisp and Durot, 2007). Efficiency of warning signs increases in sections where wildlife regularly passes. Of course, WVC hotspots can give us indications of which areas need warning signs. Identifying WVC hotspots may not be enough, however; in addition, evaluations should be made by experts on rare species.

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Appendix. Table for each record (European Datum-1950 and UTM-36 Zone).

Number	Species	X	Y	Record dates	Traffic volume
1	*Canis lupus*	36E 543756.98	4467174.02N	05/05/2014	Moderate traf. vol.
2	*Erinaceus concolor*	36E 555221.50	4472186.17N	13/06/2016	Moderate traf. vol.
3	*Erinaceus concolor*	36E 551739.91	4471554.44N	13/06/2016	Moderate traf. vol.
4	*Erinaceus concolor*	36E 538555.74	4436247.13N	25/05/2014	Low traf. vol.
5	*Erinaceus concolor*	36E 535678.61	4438602.20N	25/05/2014	Low traf. vol.
6	*Erinaceus concolor*	36E 544845.03	4469430.08N	06/06/2014	Moderate traf. vol.
7	*Erinaceus concolor*	36E 545353.72	4469938.89N	09/06/2014	Moderate traf. vol.
8	*Erinaceus concolor*	36E 544801.17	4469352.26N	12/06/2014	Moderate traf. vol.
9	*Erinaceus concolor*	36E 554477.46	4471874.16N	17/06/2016	Moderate traf. vol.
10	*Erinaceus concolor*	36E 539594.61	4425024.64N	17/06/2014	Low traf. vol.
11	*Erinaceus concolor*	36E 540384.41	4459425.73N	16/07/2014	Moderate traf. vol.
12	*Erinaceus concolor*	36E 552612.38	4484675.52N	25/06/2014	Moderate traf. vol.
13	*Erinaceus concolor*	36E 544762.31	4469298.82N	07/07/2014	Moderate traf. vol.
14	*Erinaceus concolor*	36E 538120.99	4445062.32N	09/07/2014	Low traf. vol.
15	*Erinaceus concolor*	36E 537883.99	4444368.54N	16/07/2014	Low traf. vol.
16	*Erinaceus concolor*	36E 538382.41	4434931.73N	07/07/2014	Low traf. vol.
17	*Erinaceus concolor*	36E 541559.20	4460250.48N	07/07/2014	Moderate traf. vol.
18	*Erinaceus concolor*	36E 552406.89	4485205.86N	22/07/2016	Moderate traf. vol.
19	*Erinaceus concolor*	36E 538855.00	4452923.48N	21/07/2014	Moderate traf. vol.
20	*Erinaceus concolor*	36E 536466.67	4437493.79N	07/07/2014	Low traf. vol.
21	*Erinaceus concolor*	36E 535529.60	4439558.23N	01/08/2014	Low traf. vol.
22	*Erinaceus concolor*	36E 538385.90	4434934.94N	24/08/2014	Low traf. vol.
23	*Erinaceus concolor*	36E 540758.05	4459609.31N	29/08/2014	Moderate traf. vol.
24	*Erinaceus concolor*	36E 538912.83	4447845.77N	10/09/2014	Low traf. vol.
25	*Erinaceus concolor*	36E 537864.93	4444167.14N	10/09/2014	Low traf. vol.
26	*Erinaceus concolor*	36E 537415.30	4436815.63N	19/09/2014	Moderate traf. vol.
27	*Erinaceus concolor*	36E 537448.69	4436806.15N	10/10/2014	Low traf. vol.
28	*Erinaceus concolor*	36E 551673.66	4486764.13N	15/10/2014	Moderate traf. vol.
29	*Lepus europaeus*	36E 544329.00	4468527.06N	25/05/2014	Moderate traf. vol.
30	*Lepus europaeus*	36E 538730.75	4456990.73N	13/06/2014	Moderate traf. vol.
31	*Lepus europaeus*	36E 543782.98	4464163.93N	01/08/2014	Moderate traf. vol.
32	*Martes foina*	36E 538943.66	4454627.67N	29/05/2014	Moderate traf. vol.
33	*Martes foina*	36E 537824.27	4433970.23N	16/06/2014	Low traf. vol.
34	*Martes foina*	36E 551875.79	4488647.90N	10/10/2014	Moderate traf. vol.
35	*Martes foina*	36E 545687.86	4470211.73N	23/06/2014	Moderate traf. vol.
36	*Martes foina*	36E 543250.95	4463621.92N	01/10/2014	Moderate traf. vol.
37	*Meles meles*	36E 545841	4471080.45N	15/05/2014	Moderate traf. vol.
38	*Vulpes vulpes*	36E 537051.67	4442488.31N	25/05/2014	Low traf. vol.
39	*Vulpes vulpes*	36E 538818.31	4456283.91N	02/06/2014	Moderate traf. vol.
40	*Vulpes vulpes*	36E 538934.25	4451589.70N	02/07/2014	Moderate traf. vol.
41	*Vulpes vulpes*	36E 547144.13	4471054.13N	04/08/2014	Moderate traf. vol.
42	*Vulpes vulpes*	36E 541670.88	4460457.83N	04/06/2014	Moderate traf. vol.

Appendix. (Continued).

43	*Vulpes vulpes*	36E 553627.83	4471697.71N	01/10/2014	Moderate traf. vol.
44	*Vulpes vulpes*	36E 543730.24	4464047.28N	09/08/2014	Moderate traf. vol.
45	*Vulpes vulpes*	36E 554945.48	4472069.16N	04/08/2014	Moderate traf. vol.
46	*Vulpes vulpes*	36E 538594.60	4445959.00N	09/09/2014	Moderate traf. vol.
47	*Vulpes vulpes*	36E 555738.52	4481516.43N	16/09/2014	Moderate traf. vol.
48	*Vulpes vulpes*	36E 538162.72	4445179.39N	22/07/2014	Low traf. vol.
49	*Vulpes vulpes*	36E 542443.92	4462097.87N	01/08/2014	Moderate traf. vol.
50	*Vulpes vulpes*	36E 537977.02	4429475.18N	12/06/2014	Low traf. vol.
51	*Vulpes vulpes*	36E 551833.35	4485960.51N	01/10/2014	Moderate traf. vol.
52	*Vulpes vulpes*	36E 538912.76	4447917.47N	25/06/2014	Moderate traf. vol.
53	*Vulpes vulpes*	36E 555624.35	4474866.14N	21/10/2014	Moderate traf. vol.
54	*Vulpes vulpes*	36E 543736.39	4467113.70N	24/08/2014	Moderate traf. vol.
55	*Vulpes vulpes*	36E 538964.73	4448043.40N	05/09/2014	Moderate traf. vol.
56	*Vulpes vulpes*	36E 545910.10	4470381.59N	15/10/2014	Moderate traf. vol.
57	*Vulpes vulpes*	36E 538456.23	4445745.32N	05/09/2014	Moderate traf. vol.
58	*Vulpes vulpes*	36E 550498.21	4471196.66N	10/10/2014	Moderate traf. vol.