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Spatio-Temporal Patterns of Wildlife Road Mortality in Golestan National Park-North East of Iran

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Abstract

Nowadays, wildlife road mortality is acknowledged as a main source of threatening long-term survival of wildlife. This paper as the first to analysis wild life vehicle collisions in Iran, aims to reconstruct and interpret the spatio-temporal patterns of WVCs on Asiaei highway in Golestan National Park (GNP). With the collaboration of environmental protection department of GNP, we identified about 1900 WVC Records involving 34 different species of mammals, birds, reptiles and amphibians between 2004 and 2013. Mammals were involved in more than 50% of overall WVCs, among which wild boar (*Sus scrofa*), Golden Jackal (*Canis aureus*), Red Fox (*Vulpes vulpes*), hedgehog (*Erinaceus concolor*), stone marten (*Martes foina*) and porcupine (*Hystrix indica*) were involved in more than 90% of mammals' mortalities; So, we focused on analyzing spatio-temporal pattern of vehicle collisions of these six mammal species. During the study period, these species have undergone 95% increase in road mortalities, averagely. Detailed temporal analyses exhibited an increasing trend of road mortalities from spring to summer and then a reducing one to late winter. It was shown that a large number of collisions occurred in holiday periods when recreational trips considerably increased the traffic volume of Asiaei highway. Preliminary inspection of spatial patterns using Kernel density analysis revealed six collision hotspots, mostly located in the road bends with densely forested land cover on both sides; the promenades along the road seemed to play a significant role too. Scale dependency analyses of collision patterns, demonstrated clustering pattern at micro scales less than 10 km, randomness at meso scales 10 - 20 km and both regularity and clustering at macro scales more than 20 km. This paper suggests that road mortality of common species in GNP is a momentous issue, which needs to be considered by relevant governmental and public organizations. We also emphasize that the analyses of spatial and temporal patterns of WVCs are fundamentals to plan for mitigate wildlife road mortality.

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Keywords

Golestan National Park, Wildlife Vehicle Collision (WVC), Spatio-Temporal Pattern, K-Function

1. Introduction

To meet the demands of increasing human population and economic development, in past decades, the road networks were expanded and volume of traffic has rapidly increase [1]. Roads can affect wildlife in numerous different ways, both direct and indirectly. Habitat loss, degradation and fragmentation [2] [3], as well as animal mortality [4] [5] are acknowledged as direct and reduction of permeability [6], barrier effects [7] and loss of connectivity [8] [9] are indirect effects, which collectively reduce long-term survival and population viability [10]. Nowadays, besides of commercial exploitation, pollutions and introduced species, non-natural sources of mortality of wildlife, road mortality has become a serious source of wildlife mortality worldwide [11]. As roads are built and expanded in rural areas, the rate of wildlife-vehicle collisions increases dramatically [12]. On a 50 kilometers coastal road of Colombia, eighteen months Survey indicated 216 vertebrate deaths [13]. By threatening traffic safety and causing traumas and even in some cases death of car drivers or passengers, WVCs not only have ecological but also economic and social consequences [14]. In the United States, the total number of annual deer vehicle collision was estimated at more than 1 million in the early 1990s [15] causing 155 - 211 human fatalities, 13,713 - 29,000 human injuries and more than 1 billion US $ in property damage a year [15] [16]. In 2000, Canada experienced more than 30,000 collisions with animals resulting in 23 human fatalities, 1887 human injuries and more than 60 million US $ in property damage [17]. Similar figures are available from Europe, where in France this cost has been evaluated to 200 million Euros for the year 2003, much more than the cost of damage to agriculture by wildlife for the same period [18]. The conflict between the transportation infrastructure and the natural environment will increase, due to the inevitable need for transportation development and subsequent growth in traffic volume. The remaining challenge is that, how current and future transportation networks can be modified towards establishing a sustainable transport system. To prevent WVCs, road and wildlife managers need to know about the critical times and spaces that particular species are susceptible to high road-kill rates. Having accurate information on both hot times and locations of WVCs, more effective mitigation measures, established at the right time and the right place, are expected. It is acknowledged that WVCs have temporal and spatial patterning [19]-[22]. While temporal variations in traffic kills can be linked to animal activity and behavior (which in turn are determined by biological characteristics e.g. the daily rhythm of foraging and resting, periodical migrations, mating and breeding habits and dispersal of juveniles) [23]-[25], key elements that affect the spatial patterns are population density, landscape structure and habitat distribution [26]. Location and timing of accidents can also be influenced by traffic and road related factors [22] [27] [28], as well as temporary variations of environmental factors e.g. temperature, rainfall or snow cover [29].

In recent decades, both population and economic growth in Iran, have led to development of transportation infrastructures. Construction of new roadways and renovation of existing ones have resulted in fundamental changes in natural landscapes all over the country. The Asiaei highway, a critical road in northeast of Iran, as a perfect example of renovation cases, has led to Impressive adverse effects on natural landscape of Golestan National Park (GNP); among which, vehicle collision of valuable wildlife is a critical issue [30], must be investigated more precisely. Despite of frequently occurring road related mortality of wildlife in protected areas of the country, no study has ever attempted to summarize and interpret their patterns. Reconstructing the spatial patterns and timing of wildlife road mortality in Golestan National Park is required for diagnosing conflicting areas and times, making effective decisions to mitigate road mortality effects on scarce low density wildlife of this biosphere reserve as well as improving passenger's safety [11]. Nonetheless, there is no existing research that has investigated the spatio-temporal pattern of WVCs in Iran. Thus, in this study, we aimed to examine the spatial and temporal patterns of WVCs on the Asiaei highway, a pioneering research in Iran, addressing hot places and times of WVCs, helping sustainable transportation infrastructures utilization and development. In this context, we aim to: 1) quantify the numbers and exact locations of road mortalities of each species, 2) compare the numbers of fatalities among the species, 3) address the monthly, seasonal and annual distribution of mortalities, 4) present wildlife fatality hot spots and, 5) examine scale dependency of collision patterns.

2. Material and Method

2.1. Study Area

Our study area is the Golestan National Park (GNP), the north east part of Iran, ranging between 37˚824'N and 55˚58'E 37.403˚N and 55.976˚E [31]. The park has an area of 87402 ha Located in Golestan, North Khorasan and Semnan Provinces (**Figure 1**). Having been protected since 1957, it became the first national park of Iran in 1967 prior to its recognition as a biosphere reserve in 1976. Nowadays, GNP is the most important protected area of Iran with great habitats for many wildlife species of which some are included in IUCN red list of threatened species [32] [33]. The average annual precipitation in GNP is 400 mm and the annual average temperature is 11.98˚C. Gradually reducing toward the east, the elevation ranges from 450 to 2,400 m above sea level. The mean annual precipitation is 150 in east and 700 mm in the west part [31] [32] [34]. The vegetation can be divided into two zones: the Hyrcanian forest in the west with a high humidity and the Iran-Turanian vegetation in the east of the park where it is dry [35].

A two lane highway, the Asiaei is of national importance in that it provides the main access to Mashhad, a metropolis of tourism importance. Thus, in weekends and holidays, traffic volume of the Asiaei highway is two to three times more than working days (average 3920 and 13,188 vehicles per day in working days and holidays, respectively). Most of the traffic comprises passenger vehicles (84%), the rest being truck and lorries [30]. Speed limit on the highway is 85 in night and 95 km/h in day. On 35 km of its length, the highway runs through the park and divides it into northern and southern parts; then, it goes along to the end of southern boundary of the park at Gharehbil village [36]. The history of the road dates back to the late 1980s, when it was a dirt road utilized as local access road to different parts of the park. Later, the paved and widened road became a national highway with a great volume of daily traffic. Annually, numerous wildlife vehicle collisions are reported on this road, resulting in valuable rare species death.

2.2. Wildlife Vehicle Accident Data

There are many sources of WVCs data, insurance companies [37], transportation management agencies at local and national scale [38] [39], police road accident databases [40] [41] and so on, each focusing on specific subjects. In our case, the environmental protection department of GNP is directly responsible for managing the park issues. On this way, WVCs are recorded through daily patrolling along the highway. We used the WVC database of 10 years (2004 to 2013), involving about 1900 Records for mammal, birds, reptiles and amphibian species. Data collected for each accident were included species involved, date and vernacular name of location. The location of collisions were also recorded by a GPS set with an accuracy of 200 m and transferred the data to GIS software.

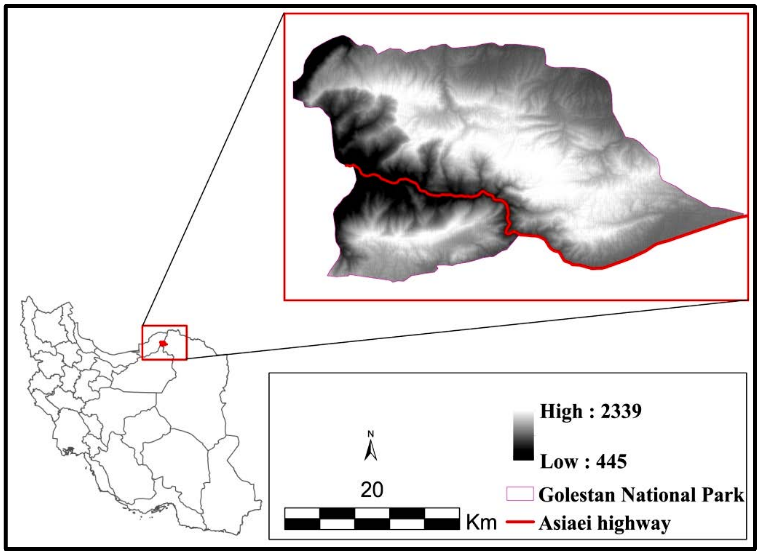

Figure 1. Golestan national park and the Asiaei highway.

2.3. Temporal and Spatial Pattern Analysis

Annual, seasonal and monthly patterns of collisions were the subjects of temporal pattern analyses. On this way, temporal variations in frequencies of roadkills were examined applying excel diagrams; We also used Chi-square goodness of fit test to Investigate if there were significant variations in relative frequencies of roadkills [12]. To analysis spatial pattern of WVCs, firstly, using kernel density estimation [42], hotspots of WVC for all roadkills were identified and spatial point distributions inspected visually. Secondly, WVCs spatial structure at various spatial scales was examined using the Global auto K function [43]. SANET® 4.1. Beta [44] under ArcGIS 10.2 was used for spatial pattern analyses.

2.4. Kernel Density Analysis

Kernel Density Analysis is a traffic accident clustering method not only reveals the clustering or dispersion tendency of traffic accidents but also the hotspots location of accidents [18]. To identify hotspots, Kernel density calculates the number of collisions per kilometer of roads. The bandwidth of the kernel exhibits a strong influence on the estimation results. The bandwidth determines the search radius in which roadkills will contribute to the hotspot identification [18]. We used a search radius of 500 m to investigate collision clusters, a reasonable distance between mitigation measures in hot spots (if necessary) [45]. The estimator of network kernel density is:

$$\lambda(s) = \sum_{i=1}^{n} a_i \frac{1}{t} k\left(\frac{d_{is}}{r}\right)$$

where $\lambda(s)$ is the density at location *s*; *t* is the band width; d_{is} is the distance from the estimation to the observation point *i*; *k* is the function of ratio between d_{is} and *t* to measure the distance decay effect and a_i is the number of points at *s*.

2.5. Ripley K Function

Wildlife roadkill patterns, regarding to species intrinsic and extrinsic characteristics, occur at different spatial scales [22] [45]. To examine scale dependency of WVC patterns, The K-function method was used. As an advantage, K-function analysis does not include just the nearest neighbor but it uses all point-point distances, to show spatial clustering [42]. However, to calculate the Euclidean distance between points, it assumes that the environment is homogenous. So, in case of irregular road networks it can result in over detection of clustering patterns [43] [46]-[48]. To conduct K-function analysis of point data on networks more precisely, Okabe and Yamada (2001) developed a new method of K function, so called network K function (instead of Planer K function) [43] [49]. Ripley K function is Originally used for two dimensional applications, In our case, because of small width of road compared with its length, distribution of roadkill points assumed one dimensional and Global auto K function provided by the SANET was used [40] [43] [49]. Investigating WVCs in GNP, network K-function calculated as Equation (1):

$$\hat{K}(t)_{network} = \frac{RL_T}{n(n-1)} \sum_{i=1}^{n} \left(P \in RL_p(t)\right) \quad (1)$$

where *n* is sample size, RL_p is a section of entire road network (RL_T), and *P* includes the number of WVC points on RL_T within a distance$t$ of point *i* [49]. Using the Global auto K function In SANET, for each 500 m ($t = 500$ m) along RL_T, we computed an observed and an expected spatial distribution of real and random WVC points respectively [49]. To investigate the significance of departure of the network $\hat{K}(t)$ from CSR, the deviation of the observed number from expected number of points were plotted againstt. To calculate expected values and constructing confidence envelope, Monte-Carlo simulations of random points distributed along the road network (RL_T) was applied (100 simulations). If plot of $\hat{K}(t)$ lie outside the upper and lower confidence intervals, then points of P are tending to clustering and regularity, respectively. Conversely, $\hat{K}(t)$ values lied within the confidence envelope represent random distribution of points P [40] [43] [45].

3. Results

In total about 1900 WVCs of 34 different species of mammals (21 species), birds (8 species), reptiles and amphibians (5 species) were identified in GNP. Mammals were involved in more than 50% of total WVCs among which wild boar (*Sus scrofa*), Golden Jackal (*Canis aureus*), Red Fox (*Vulpes vulpes*), hedgehog (*Erinaceus concolor*), stone marten (*Martes foina*) and porcupine (*Hystrix indica*) take the largest partmore than 90% of mammals (**Table 1**). So, we focused on analyzing spatio-temporal pattern of vehicle collisions of these six mammal species.

3.1. Temporal Distribution

Mammals' road mortality increased by 95% during the study period. Specifically, roadkill increased by 93% for wild boar, 52% for golden jackal, 242% for roe deer, 143% for red fox, 150% for porcupine, 600% for stone marten, and 300% for hedgehog (**Figure 2**). The decreasing trend since 2009 to 2010 is likely due to destruction of the road by torrent and subsequently decline of traffic volume. To examine temporal pattern of road mortalities in GNP, we adjusted season and month time scales to the Iranian calendar where spring, summer, autumn and winter coincide with April-June, July-September, October-December and January-Jun, respectively. Chi-square goodness of fit test showed that accidents of all six species investigated here are not uniformly distributed seasonally. hedgehog ($\chi^2 = 52.7$, df = 3, $p < 0.05$), stone marten ($\chi^2 = 22.7$, df = 3, $p < 0.05$), Porcupine ($\chi^2 = 15.9$, df = 3, $p < 0.05$), red fox ($\chi^2 = 52.5$, df = 3, $p < 0.05$), Golden Jackal ($\chi^2 = 29.3$, df = 3, $p < 0.05$) and Wild boar ($\chi^2 = 113.7$, df = 3, $p < 0.05$). In general, casualty frequencies with most of species increases in spring and summer; after that, takes a decreasing trend to the winter (**Figure 3**).

All species investigated showed not uniform monthly distribution of accidents (**Figure 4**). Casualties with hedgehog ($\chi^2 = 52.1$, df = 11, $p < 0.05$) increase in April, June and September. For stone marten ($\chi^2 = 30.4$, df = 11, $p < 0.05$) accidents peak also in September. In comparison to others, Porcupine ($\chi^2 = 20.1$, df = 11, $p < 0.05$) and Jackal ($\chi^2 = 46.2$, df = 11, $p < 0.05$) accidents are distributed more evenly, with a considerable decrease of causalities from January to March. Red fox ($\chi^2 = 55$, df = 11, $p < 0.05$) accidents show peaks in July and September and wild boar ($\chi^2 = 113.2$, df = 11, $p < 0.05$) road mortalities, present high frequency from April to September and then decrease in next six months.

Table 1. Roadkilled mammals in GNP 2004-213

Species	Scientific Name	IUCN Red List Category*	Roadkill Number	Percentage %
European Badger	*Meles meles*	LC	2	0.16
Tolai Hare	*Lepus tolai*	LC	2	0.16
Bat	*Rhinolophus ferrumequinum*	LC	1	0.08
Gerbil	*Rhombomys opimus*	LC	3	0.23
Roe Deer	*Capreolus capreolus*	LC	4	0.31
Wolf	*Canis lupus*	LC	5	0.39
Red Deer	*Cervus elaphus*	LC	5	0.39
Pine Marten	*Martes martes*	LC	7	0.55
Least Weasel	*Mustela nivalis*	LC	8	0.63
Leopard	*Panthera pardus saxicolor*	NE	12	0.94
Gazelle	*Gazella subgutturosa*	VU	10	0.78
Bear	*Ursus arctos*	LC	13	1.02
Wild Cat	*Felis silvestris*	LC	21	1.64
Jungle Cat	*Felis chaus*	LC	27	2.11
Hedgehog	*Erinaceus concolor*	LC	52	4.06
Stone Marten	*Martes foina*	LC	63	4.92
Porcupine	*Hystrix indica*	LC	77	6.02
Red Fox	*Vulpes vulpes*	LC	106	8.28
Golden Jackal	*Canis aureus*	LC	257	20.08
Wild Boar	*Sus scrofa*	LC	605	47.27

*LC: Least Concern, VU: Vulnerable, NE: Not Evaluated.

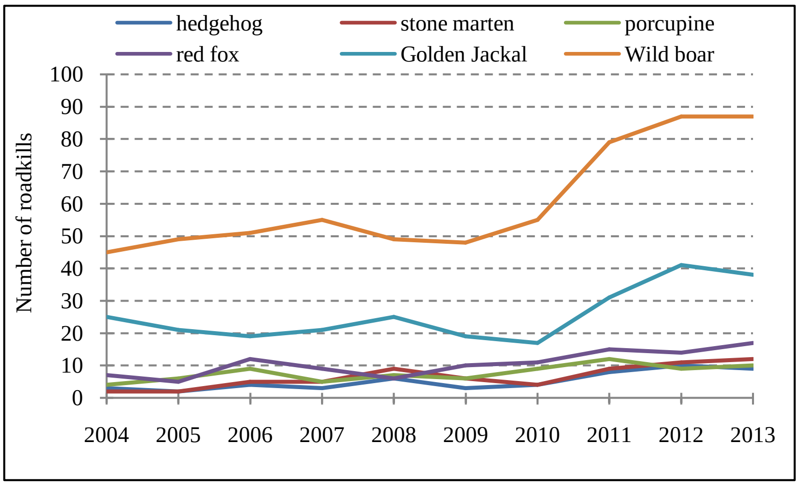

Figure 2. Annual variation of the number of accidents involving wild boar, golden jackal, red fox, porcupine, hedgehog and stone.

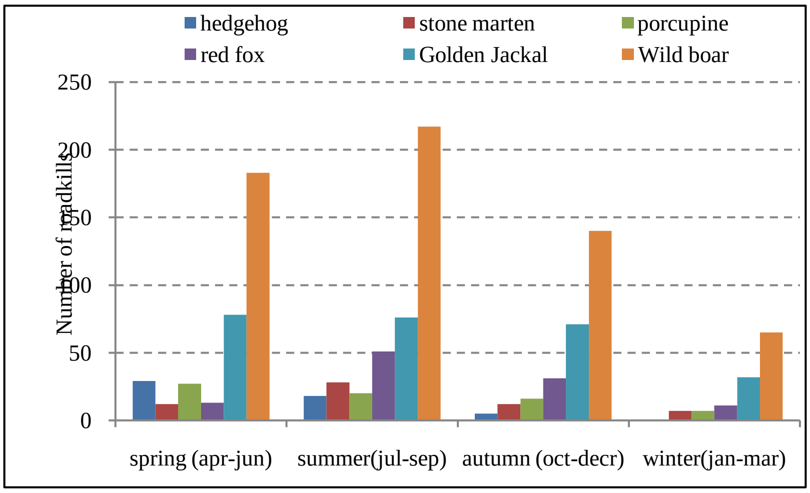

Figure 3. Seasonal distribution of casualties for investigated species.

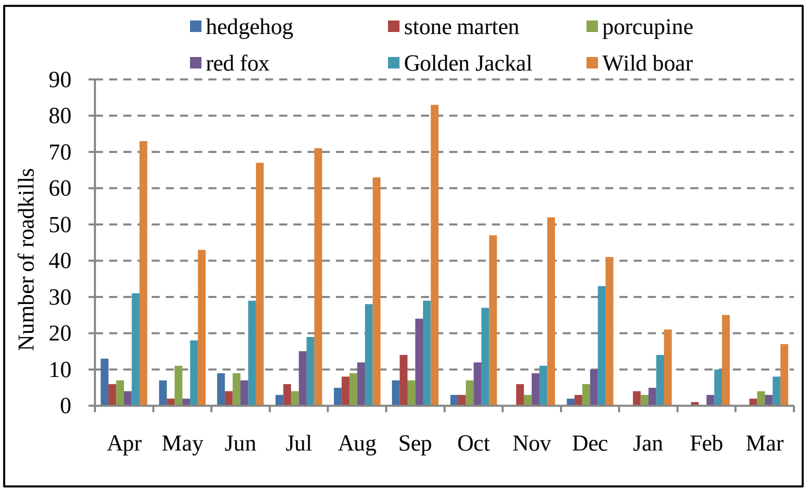

Figure 4. Monthly distribution of casualties for investigated species.

3.2. Spatial Pattern

Kernel estimations of spatial point patterns density analysis, considering all species along the whole length of highway and study period, revealed heterogeneous distribution of WVCs (**Figure 5**). High risk areas were concentrated at 27 km of the western part of the highway (red rectangle in **Figure 5**) showing six strong clusters of road kills. Thus, subsequent spatial analyses were conducted on this section of the highway.

Univariate spatial pattern analysis using the network K-function confirmed Kernel analysis results, showing deviations from CSR at various spatial scales. Plots of $\hat{K}(t)$ versus t showed deviation from CSR as well as randomness at different spatial scales. Except for boar that showed clustering pattern at all scales, others showed some degrees of clustering, randomness and regularity at different scales. Red fox road mortalities at scales 0 - 7, 7 - 23 and more than 23 km show clustering, randomness and regularity patterns, respectively. Stone marten, porcupine and hedgehog exhibited similar pattern, clustering at extremes and randomness at middle ranges and finally, multiple fluctuation of plot of $\hat{K}(t)$ was recorded for jackal. **Figure 6** presents network K function plots of six selected mammal species.

4. Discussion

For the studied period, about 1900 WVCs of 34 different species of mammals, birds, reptiles and amphibians were recorded in GNP. Mammals were included in more than 50% of wildlife road mortalities and birds, reptiles and amphibians were ranked as next prevailing road killed wildlife, respectively. We didn't review the causal factors of low frequencies of accidents with birds, reptiles and amphibians in deep, however we might suspect underestimation because of removal of carcasses by scavengers. Mammals of small to medium size are the most roadkilled in GNP, so that, wild boar, jackal, red fox, hedgehog, stone marten and porcupine are involved in more than 90% of collisions of mammals. Overall road mortality numbers showed an increasing trend for these six species. The most increase in the rate of road mortality was occurred for stone marten during the study period; hedgehog, roe deer, porcupine, red fox, wild boar and golden jackal were ranked as next. Road kills rate seems to increase with Traffic intensity, road tortuosity, animal activity and population density. Wildlife road mortality is a problem with at least four main components: animal related, biological and behavioral factors (e.g. density, behavior, foraging, mating), habitat related factors (e.g. habitat patches distribution, resources availability), weather conditions (in turn, affects visibility or animal behavior) and anthropogenic causes (e.g. land use, traffic density, and driver related conditions) [38].

4.1. Temporal Pattern

Temporal analysis of the road mortalities of six selected species demonstrated non-uniform pattern for multiple

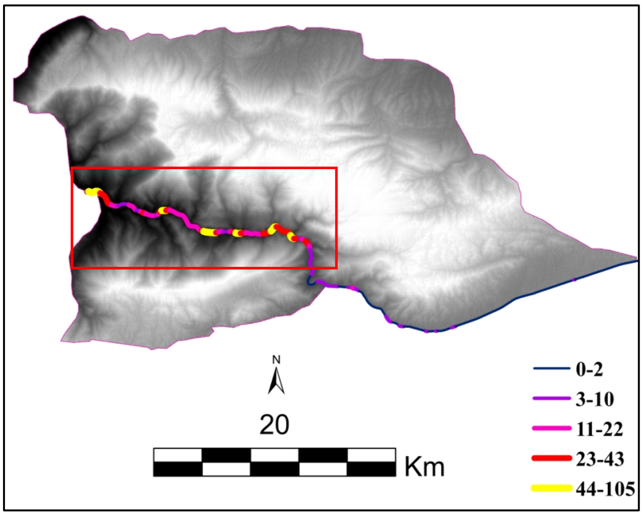

Figure 5. Kernel density estimation (WVCs per km) applying bandwidth of 500 m. Classification method was natural breaks.

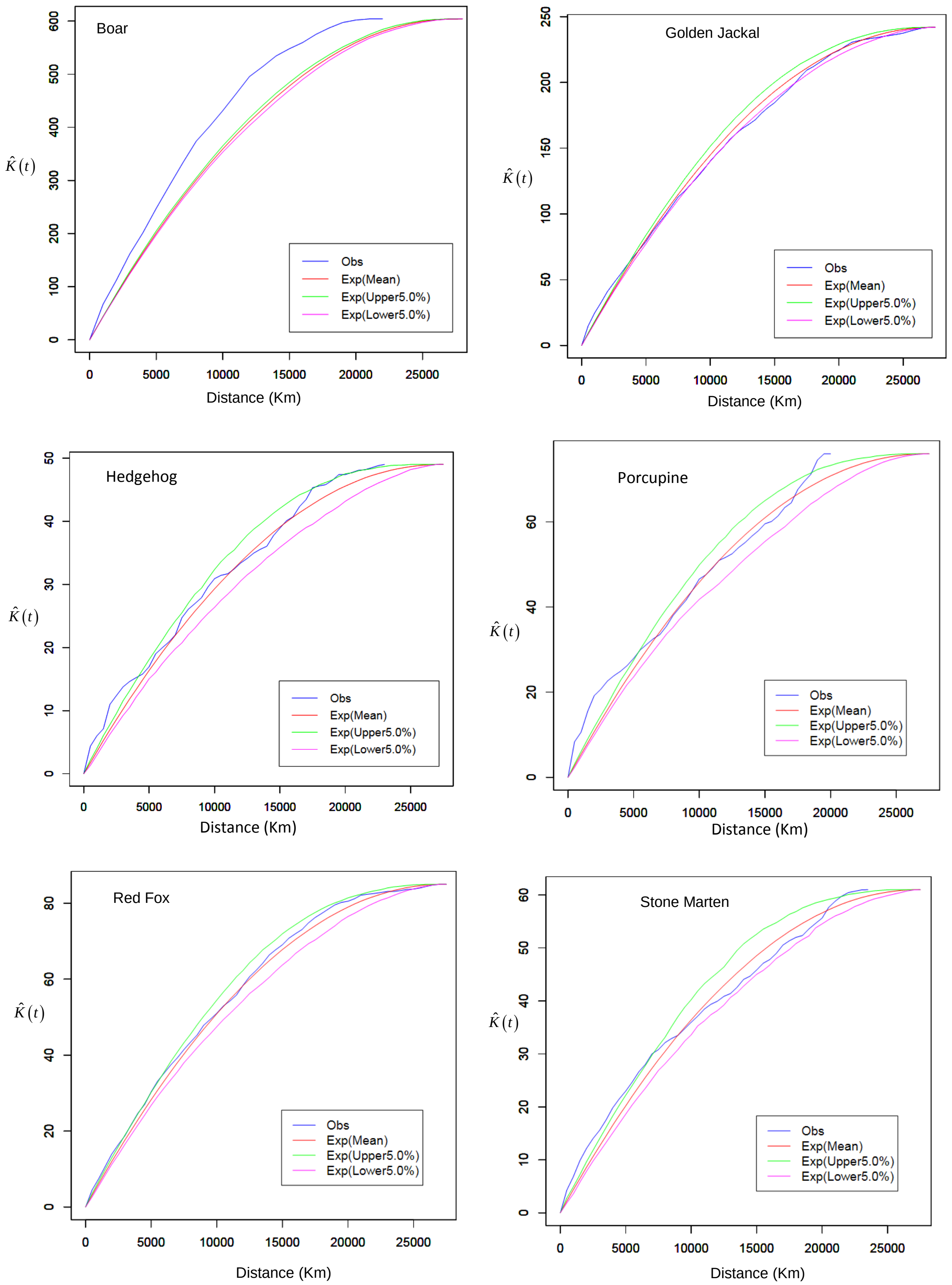

Figure 6. Univariate spatial pattern analysis using network K-function for distribution of six selected mammals roadkills in GNP, showing the observed statistic $\hat{K}(t)$ plotted against *t* and 95% confidence envelope for CSR.

timescales. Except for 2009 to 2010, an annually increasing trend can be seen for the study period. Decline of traffic volume because of reconstruction of destructed road by torrent, seems to be the explanation. Seasonal and monthly peaks of road mortalities of six species investigated in spring and summer coincides with holiday times in Iran (especially April and September) which high rates of recreational trips increase the traffic volume of the Asiaei highway in these times, significantly. There are promenades along the Asiaei highway, densely populated in holidays. Remaining food of tourists attracts generalist species (red fox, jackal and boar) increasing road crossing, intensifying collision frequencies. As illustrated in **Figure 5**, Most of collisions occur on a section about 27 km of road, surrounded by dense deciduous forest which limits both drivers and wildlife field of view in these seasons. Increase in WVC In spring and summer is likely to denote the importance of land cover too. Lower recreational trip and subsequent reduction in traffic volume, expansion of field of view and reduction of wildlife activity in autumn and winter explain low WVCs in these seasons. Availability of permanent water along the western part of the highway undoubtedly accounts for the high rates of roadkills during the late dry season [50].

4.2. Spatial Distribution

For all road killed species, spatial analyses showed that the distribution of accidents along the Asiaei highway was not random. Although WVCs occur all over the Asiaei highway, we indeed observed highly clustering pattern along 27 km of western part of highway, showing six hotspots based on the result of the kernel density estimation considering all species along the whole length of highway. So we concentrated on analyzing spatial structure of accidents at various scales by means of the network K function on this smaller length of road. Univariate spatial pattern analyses of road kills for selected mammals confirmed deviations from CSR at various spatial scales. Except for boar, showing clustering at all spatial scales, the general patterns are clustering at micro scales less than 10 km, randomness at meso scales from 10 to 20 km (except for jackal) and randomness, clustering and regularity at macro scales more than 20 km, simultaneously. Clustering pattern of boar road mortalities at all scale ranges can be explained regarding to dramatically high collision numbers of boar all over the length of the western Asiaei highway. for red fox, jackal, stone marten, porcupine and hedgehog, Clustering patterns at micro scales may be partly due to densely killed individuals on road lengths adjacent to promenades, or because of environmental or road related factors, need to be investigated deeply. The randomness at meso scale ranges is perhaps the representation of homogenous distribution of collisions at road length except for sections bearing promenade. In general, spatial structures of WVCs can be interpreted regarding to two main general and species specific causes. Road characteristics, land cover type and availability of habitat, food and water resources are general causes; ecology, behavior and population density are species specific ones.

The western part of the Asiaei highway has characteristics may explain the clustering pattern of WVCs. more frequent tortuous sections in western part of highway, partly explains the agglomeration of collisions. According to KDE, while there is no hot spot in eastern part of highway (31 km), six hot spots are located in western part, among which three are in sharp road bends. In addition, the speed limits of 85 and 95 km/h for night and day respectively, are relatively high and seem not to be effective in reducing WVCs. Dense forest land cover on both sides, close to the road edges, limit the field of view of drivers and wildlife increasing collision risk [51] [52]. Certainly, habitat condition around the road affects composition and abundance of wildlife. The land cover around the western part is mainly composed of forest and ecotone of forest and meadow, to less extent. Affluence of nutrient, complexity of food chains and habitat diversity, providing high quality habitats, result in high degrees of species diversity and population density. In competitive conditions, wildlife movement increases which in turn results in increasing of road crossing and collision rate.

As stated previously, most of the mammals that die in road accidents in the Asiaei highway have willingness to road [30]. In ecological terms, road verges have considerable potential to provide ecological resources for wildlife [53]. Food scraps and other wastes along the Asiaei highway, especially in promenades, attract jackal, fox and boar. Dangerous path to these foods and feeding around road increases the collision likelihood for these three species. Indeed, in the case of generalist species like boar, fox and jackal, relatively high population density, Low dependency to high quality habitat conditions, there upon high mobility potential, and tendency to location of human presence [54] [55] seem however to reflect the root causes of car-accidents. For stone marten, porcupine and hedgehog, small body size, low mobility potential, and dark coloring pattern of body, which in turn, adversely affect visibility as well as response time of drivers, contribute to their high collision numbers.

5. Conclusions

Our research is the first to begin to investigate the species involved in vehicle collisions and the temporal and spatial patterns of these accidents in Iran. Although considerable uncertainty exists, we believe our research provides an important basis to begin analyzing wildlife road mortality impacts on persistence of wildlife populations. Many species of birds, reptiles, amphibians and mammals are involved in collisions among which mammals are involved in about 50% of fatalities. In the case of mammals, wild boar, jackal, red fox, porcupine, stone marten and hedgehog are involved in more than 90% of accidents. The results endorsed the role of intrinsic wildlife characteristics as well as extrinsic ones in explaining temporal patterns of WVC occurrence. Multi-scale spatial analysis of WVCs in GNP demonstrated the clustering pattern of fatalities especially in fine scales. Increase in traffic volume, due to high recreational trips frequency in holidays, seems to affect both spatial and temporal pattern of WVCs. Maintaining viability of Common species populations, as facilitator of ecosystem processes [56] [57], is a vital component of biodiversity conservation efforts [58]. Concentration of conservation efforts already on threatened species and little attention to road mortality of common species, which in most cases constitute the majority of road-kills, remains them largely unexplored [52]. Taking both spatial and temporal components into account, the results highlight that: 1) high collision rates of common species in GNP may result in substantial decline of common species population and deficiency in their functional role and 2) there are spatial and temporal scales critical to conserve wildlife from fatality due to collision with vehicles.

The next step of our research will be dedicated to development of predictive models to identify WVC hotspots incorporating road and landscape variables and to propose mitigation measures that could enhance road permeability, functional habitat connectivity, and traffic safety. However, this is the first research on WVC in Iran. We hope it will be a start point to convincing governments, road planners and constructors so that more sustainable road transportation system could be achieved in near future.

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