Human–Wildlife Interactions 10(1):103–109, Spring 2016

Evaluating wildlife–vehicle collision hotspots using kernel-based estimation: a focus on the endangered Asiatic cheetah in central Iran

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Abstract: The transportation networks within and adjacent to protected areas degrade natural habitats and contribute to a higher risk of mortality through roadkill. Following years of unplanned and unsustainable road network development in Iran, the protected areas of significant biodiversity value have suffered from such phenomenon. Yazd Province, one of Iran's important biodiversity reservoirs for large mammals, especially the Asiatic cheetah (*Acinonyx jubatus venaticus*), has witnessed a noticeable rate of road expansion along with an associated anthropogenic development. A large percentage (7 out of 50–70) of Asiatic cheetahs has been lost due to vehicle collisions in the region over the last decade. In this study, we employed a well-known spatially-explicit algorithm for density-based calculation of collision locations, adopting kernel density estimation method. We evaluated the location of 31 wildlife–vehicle collisions (WVCs) from 2007 to 2011, including 12 Persian gazelle (*Gazella subgutturosa*), 6 Asiatic cheetah, 5 striped hyena (*Hyaena hyaena*), 5 golden jackal (*Canis aureus*), 2 caracal (*Caracal caracal*), and 1 gray wolf (*Canis lupus*). Our results detected 4 hotspots of vehicle collisions in the Kalmand-Bahadoran Protected Area. The findings of this study could be employed to protect the populations of the Asiatic cheetah and other threatened species in this area. Potential mitigation strategies proposed include: wildlife warning sign usage, increasing public awareness, traffic devices to reduce vehicle speed in dangerous areas, utilization of warning lights for drivers, and improved crossing structures.

Key words: *Acinonyx jubatus venaticus*, Kalmand–Bahadoran Protected Area, kernel density estimation, wildlife–vehicle collision

The consequences of road development on the natural environment is a growing concern around the world. During the last century, increasing road expansion has exerted substantial pressure on the protected areas and the biodiversity of ecosystems (Ramp et al. 2005, Switalski and Nelson 2011, Gunson and Schueler 2012, Skórka 2015). The negative effects of environmental degradation due to road expansion on wildlife are well known, particularly for large and rare carnivores with large territory ranges and low population densities (Grilo et al. 2008, Colchero et al. 2011). Some of these effects include: increased wildlife road mortality, habitat fragmentation, and habitat loss. Therefore, the wildlife–vehicle collision (WVC) hotspot studies are of critical importance in areas with noticeable conflicts between human welfare and nature conservation. Understanding the effects of human disturbance is critical for practical management and conservation of the endangered species (Kerley et al. 2002, Colchero et al. 2011, Switalski and Nelson 2011, Chen and Wu 2014).

The impact of increasing wildlife road mortality rates on local population dynamics has risen to the forefront of many wildlife studies (Ramp et al. 2005, Litvaitis and Tash 2008, Yu et al. 2014). Yazd Province in central Iran has been one of the most challenging areas where extensive construction of roads and associated anthropogenic infrastructure are conflicting with wildlife conservation. For example, from an estimated population of Asiatic cheetahs (*A. jubatus venaticus*), 7 out of 50–70 individuals have been killed in this region over the course of 10 years (Yazd Department of Environment 2011). Loss of individuals through road mortality is one of the most prominent threats to some endangered populations, including Asiatic cheetahs. In this case, lack of sufficient management measures might result in an increased mortality rate

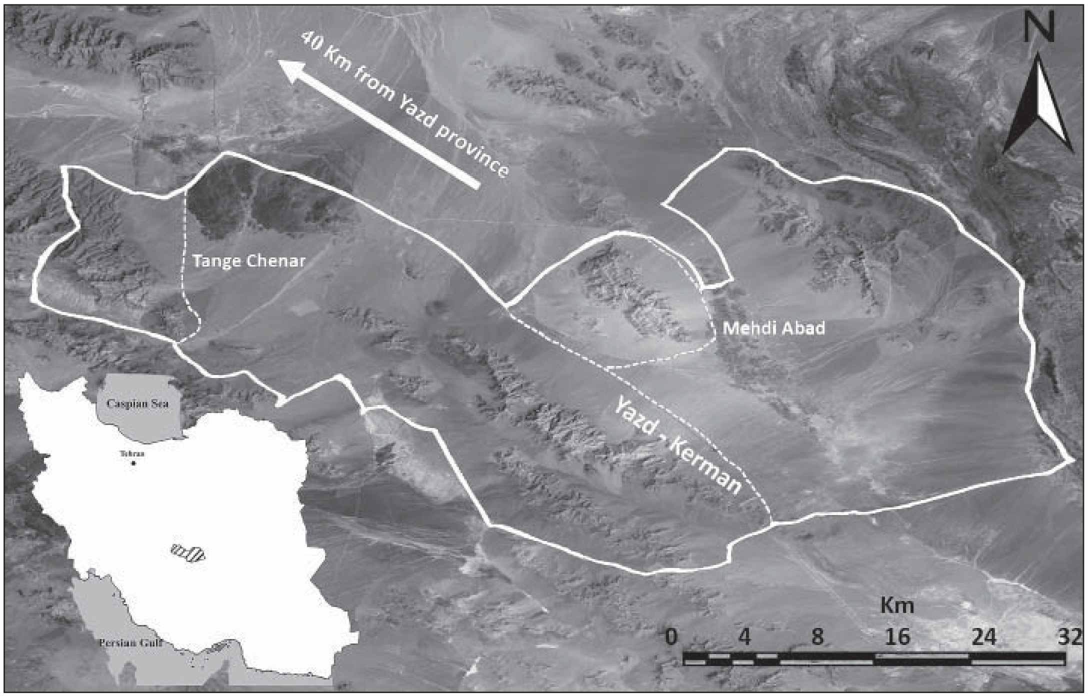

Figure 1. Geographic location of the study area.

in cheetahs over time. Due to high cost of mitigation, location prioritization to implement the mitigation measures is essential to maintain cost-effectiveness. Identification of high-risk road locations (e.g., hotspots) is an essential component of the highway safety improvement process (Yu et al. 2014). Hotspots can be defined as locations with a higher risk of crashes than other similar locations (Yu et al. 2014). Detecting hotspots is an important component of the mitigation measures for wildlife fatalities (Ramp et al. 2005, Snow et al. 2014). A common approach is density-based studies, such as kernel density estimation (KDE), to determine the location of WVC hotspots (Lu 2000, Xie and Yan 2013, Yu et al. 2014, Skorka et al. 2015, Gunson and Teixeira 2015). KDE has been proposed over the years for identification of hazardous road segments (Yu et al. 2014). Designing mitigation measures are even more essential for protecting local populations of large mammals in Yazd Province, among which the Asiatic cheetah species has gained considerable public attention at the national and international scales. This study aims to identify the hotspot locations and propose plausible mitigation measures for large animals, such as Asiatic cheetahs, using the KDE method.

Methods

Study area

The Kalmand-Bahadoran Protected Area, with a total area of 2,550 km^2, is located in the southeast of Yazd Province. The terrain varies in elevation from 1,400 to 3,290 m. This area is characterized by an average of 66 mm annual precipitation and a temperature variation between 12–43°C. The dominant plant species are *Artemisia sieberi, Amygdalus scoparia*, *Astragalus* sp, *lacccttuca orientalis*, and *salsola* sp. The predominant mammalian species in the ecosystem include: Asiatic cheetahs, leopards (*Panthera pardus*), caracals (*Caracal caracal*), striped hyaenas (*Hyaena hyaena*), wild goats (*Capra aegagrus*), wild sheep (*Ovis orientalis*), and goitered gazelles (*Gazella subgutturosa*). The 3 major roads crossing the area are Yazd-Kerman transit, Mehdi Abad Village, and Tange Chenar (Figure 1).

Kernel density estimate analysis of wildlife–vehicle collision (WVC) hotspots

The WVC location data from 2007–2011 were obtained from Yazd Province, Department of Environment. The officials collected the data using a handheld GPS device (Garmin GPS

Map 62S) to record the position of the collisions.

KDE replaced the grid over the points (5 × 5 grid cell was used in this study). After determining the bandwidth (radius), weights were computed for each point within the kernel radius. Consequently, the points closer to the center received a higher weight and contributed more to the cells' total density value. Lastly, the final grid values were calculated by adding the values of all circle surfaces for each location (Silverman 1986). We used a 5 × 5 grid cell to cover all distribution points (animal accident points on the road), where a large grid size significantly affected the local variation details of the output kernel estimation (Xie and Yan 2008).

Selecting an appropriate bandwidth is a critical and important component of KDE studies (Williamson et al. 1998, Krisp and Durot 2007, Xie and Yan 2008, Anderson 2009). If the bandwidth is too large, the estimated density will be similar everywhere, which produces a generalized map in appearance. In contrast, a small bandwidth will result in less uniformity with a generated layer depicting local variations in the form of point densities (Williamson et al. 1998, Krisp and Durot 2007, Xie and Yan 2008, Kuter et al. 2011). In this study, we used the Nearest Neighbor Distance algorithm (Williamson et al. 1998) for the bandwidth estimation where having more than 3 points was considered a hotspot. Because the number of road fatalities was low, the *k* value was assigned as 1 (Williamson et al. 1998).

Optimizing wildlife warning sign locations

Conservation of the Asiatic cheetah projects (CACP) installed a number of warning signs for the Asiatic cheetah in our study area without considering any analysis and consideration standard (Figure 2). We used KDE as an indicator for choosing wildlife warning sign locations, using a map with 5 x 5-m cells to analyze WVC points. Following that, we calculated density in every surface unit by using kernel function. To determine suitable bandwidth for locating wildlife warning signs, we used the Nearest Neighbor Distance method. When hotspots were determined on the road in North-South and South-North runways of Kalmand-Bahadoran, we considered points for installing wildlife warning signs systematically before each hotspot.

Results

We located 31 WVC, which involved large mammals including the following species: Persian gazelles (12), Asiatic cheetahs (6), striped hyenas (5), golden jackals (5), caracals (2), and gray wolves (1).

Based on the nearest neighbor distance methodology, the bandwidth of 850 m was determined to be the most effective to estimate the density of WVCs. Finally, 4 hotspots were detected in this study (average of ≥4 points). Three of the main hotspots were located in the Yazd-Kerman transit, while the Tange-Chanar road retained only 1 point as a hotspot for WVCs (Figure 2). Furthermore, the detected WVC hotspot locations were far from the existing warning signs along Yazd-Kerman transit, where the hotspots were located ≥10 km (on average) from the existing warning signs (Table 1).

Because the exact locations of WVCs were unlikely to be predictable, the efficiency of the current wildlife warning signs were maximized through the installation of signs in close proximity to the WVC hotspots. Therefore, 8 locations were identified for installing warning signs alongside the North-South and South-North directions of the study site (Figure 3). In addition, the current design of wildlife warning signs for Asiatic cheetahs did not follow acceptable standards of the

Table 1. Distance of wildlife warning signs from the nearest hotspots in Kalmand-Bahadoran Protected Area.

Distance of wildlife warning signs from the nearest hotspots (m)	Wildlife warning sign code
1,366	1
4,761	2
7,641	3
9,838	4
6,681	5
1,046	6

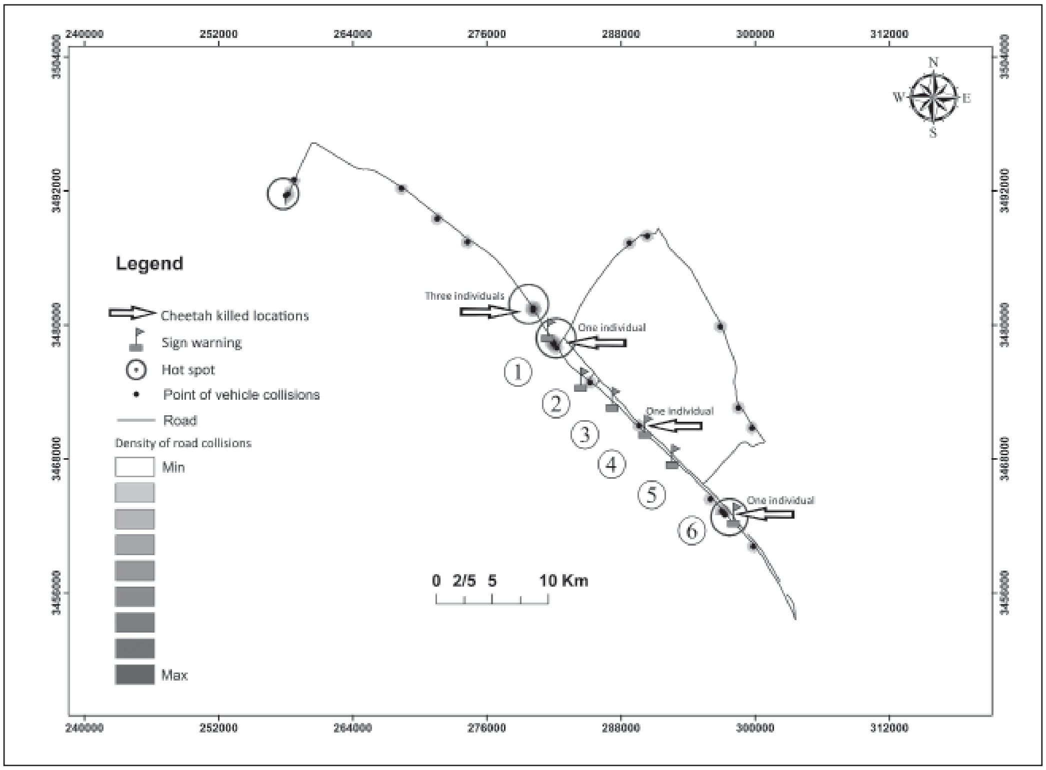

Figure 2. Locations of wildlife warning signs already installed in Kalmand-Bahadoran Protected Area and detected WVC hotspots (bandwidth: 850 m).

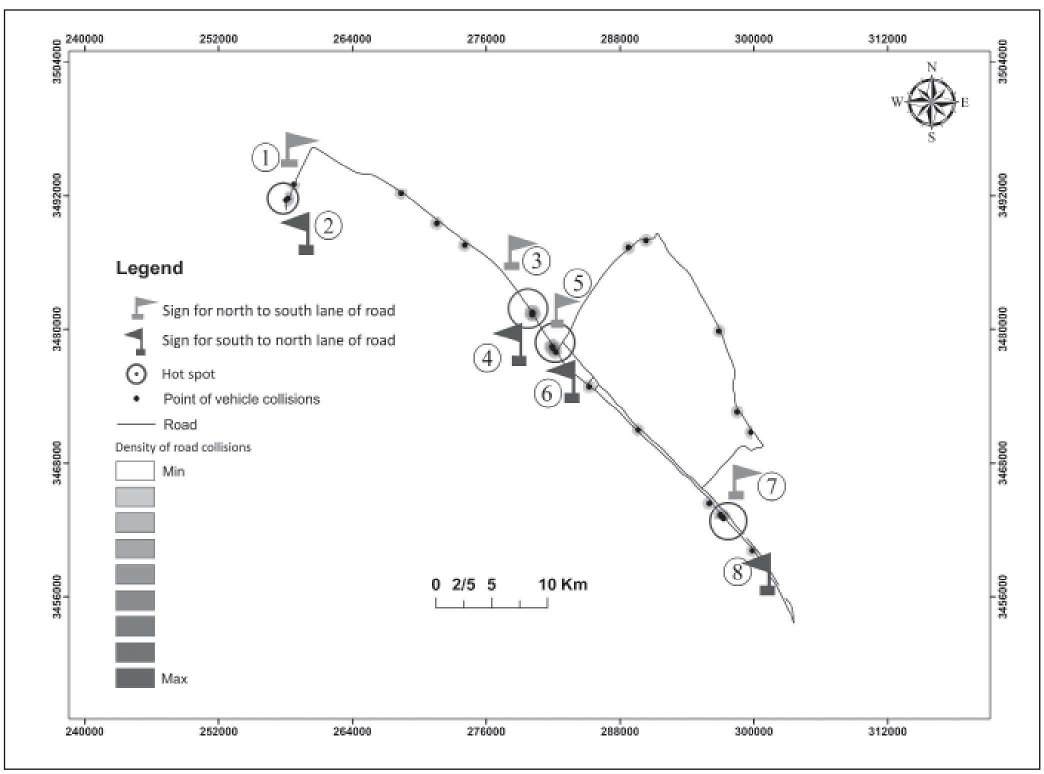

Figure 3. Proposed optimal locations of wildlife warning signs in Kalmand-Bahadoran Protected Area, Yazd-Kerman transit road, and Tange-Chenar road.

warning tabloids (Figure 4). Therefore, a new design was proposed to improve warning sign effectiveness (Figure 5).

Discussion

Overlaying Asiatic cheetah vehicle collisions on hotspot locations

All 6 Asiatic cheetah vehicle collisions matched on 3 hotspots in the runway of Kalmand-Bahadoran. Four out of 6 WVCs were recorded in the winter, which is the mating season for the Asiatic cheetah. Territory sizes increase during the mating season, requiring them to pass through the Yazd-Kerman transit road. The population of Asiatic cheetahs is distributed over a vast area in Iran. Farhadinia et al. (2013) reported that the Asiatic cheetahs travel long distances in central Iran within 4 reserves: Dare-Anjir Wildlife Refuge, Bafq Protected Area, Ariz No-hunting Area, and Siah-Kouh National Park/Protected Area. This implies that the subspecies must pass through a number of roads within the protected areas. There are >100 culverts of small and medium height and width in the Yazd-Kerman transit road. Half of those exist in hotspot locations of Asiatic cheetah collisions. Unfortunately, insufficient light, noise pollution, and unsuitable width or height in these culverts contribute to the problem. Furthermore, the bedding of many of these culverts are not appropriate for passing of the Asiatic cheetahs, striped hyenas, and caracals.

Important factors that affect Persian gazelle and striped hyena vehicle collisions

The goitered gazelle had the highest number of mortalities among the species in this area. Almost 6 out of the total mortalities (12) we identified occurred on the Mehdi Abad village road. Half of the mortalities occurred on the Yazd-Kerman transit road for this species, matching with the 3 hotspot locations. Large herbivores are particularly sensitive to the habitat fragmentation because they need unrestricted access to the large continuous habitat (Bolger et al. 2008). In fall and winter, when green fodder is scarce, goitered gazelles forage in farms and orchards. We often observed this in Mehdi Abad village road. Pistachio orchards, located in the Mehdi Abad

Figure 4. Existing wildlife warning signs for Asiatic cheetahs on Yazd-Kerman transit road and Kalmand-Bahadoran Protected Area.

Figure 5. Proposed design for wildlife warning signs for the Asiatic cheetahs in Yazd-Kerman transit road and Kalmand-Bahadoran Protected Area.

village, attract gazelles to cross the road to feed on them. Also in winter, vegetation cover at the edge of the road increases, especially in the plain areas. This will in turn attract Persian gazelles to the edge of this road, increasing the risk of species mortality.

The third species with a considerable mortality from WVC was the striped hyena, a scavenger that feeds on the remains of livestock and other animals, including due to road accidents (Qarqaz et al. 2004). Therefore, roads can attract scavengers like striped hyenas because of the possibility of the presence of dead animals. The significant reduction of the striped hyena population in Iran is attributed to the poisoning, illegal killing, and WVCs, which confirms the critical role of human activities in striped hyena mortality (Tourani et al. 2012). Three hyena deaths occurred near Mehdi Abad village road. This can be attributed to a higher mortality rate of red foxes, jackals, and Persian gazelles near this rural area as well as the inefficient dump site attracting this species leading to a higher mortality rate. Furthermore, 2 animal deaths occurred on the Yazd-Kerman transit road near Mehdi Abad village (matched with the 2 hotspots). In summary, all of the WVC mortalities of hyena occurred near this village due to scavenging behavior, carcasses of dead animals (through vehicle collisions), and the dump site near the village.

Mismatch of present Asiatic cheetah warning signs and determined hotspots

The results of this study showed the existing wildlife warning signs installed on the Yazd-Kerman transit road were not matched with WVC hotspots identified by KDE method. We proposed to change the locations to match the hotspots. In addition, the design of the warning signs for the Asiatic cheetahs did not meet the conventional standards of size, color, direction, and distance to the road. We propose to change the background color for the wildlife warning signs from the standard retro-reflective yellow to a retro-reflective fluorescent yellow for animals that are typically active at dusk and dawn. Based on the mean speed of the vehicles in our study area (90 km/h), we propose that the size of the warning signs be 90×90 cm and located at a 2-m distance to the edge of the road.

Management implications

The current study was conducted at a local scale of the Kalmand-Bahadoran Protected Area, Yazd Province, Iran. Further studies should focus on regional patterns of WVCs across the protected areas in different study locations. Our findings could be practically employed to protect the Asiatic cheetahs along with other threatened species in this area. There are more than 100 culverts with small and medium height and width in the runway of Kalmand-Bahadoran, some of which are overlaid with the collision locations of Asiatic cheetahs. Unfortunately, the insufficient light, noise pollution, and unsuitable width, height, or bedding of these culverts reduce the willingness of Asiatic cheetahs and other large carnivores to use these culverts. Potential mitigation strategies proposed include wildlife warning sign usage, increasing public awareness, traffic devices to reduce vehicle speed in dangerous areas, utilization of warning lights for drivers, and improved crossing structures. The establishment of a road monitoring network is of high importance for systematic WVC data collection and hotspot analysis.

Acknowledgments

We thank Dr. Afsaneh Motamed-Khorasani, a member of the American Medical Writer Association (AMWA), from Neometrix Consulting Inc., Toronto, Ontario, Canada, for reviewing and editing this work.

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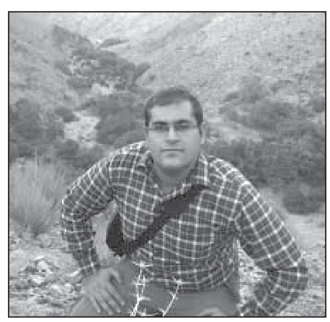

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