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Road expansion: A challenge to conservation of mammals, with particular emphasis on the endangered Asiatic cheetah in Iran

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ABSTRACT

Anthropogenic activities, including road expansion, are one of the main drivers of biodiversity loss in Iran. Central and northeastern Iran have been among the most vulnerable areas where expanding anthropogenic activities (in particular construction of road networks) have come into conflict with conservation and management of the endangered Asiatic cheetah (*Acinonyx jubatus venaticus*), along with other large mammals. The present study aimed to determine hotspot locations along an extremely high-risk road for mammals in northeast Iran (Touran Biosphere Reserve [TBR]) and propose mitigation measures for mammals such as the Asiatic cheetah. Using a spatially-explicit algorithm to estimate collision incidences, we adopted the kernel density estimation (KDE) and the distance method with respect to EDGE (evolutionarily distinct and globally endangered) and home range values for all locations. Also, a habitat suitability map was prepared to create habitat patches and applied to corridor modeling for the Asiatic cheetah. We investigated locations of 73 wildlife–vehicle collisions (WVCs) and crossing data from 2005–2016, that included Persian gazelles (*Gazella subgutturosa*), Asiatic cheetahs, striped hyenas (*Hyaena hyaena*), golden jackals (*Canis auerus*), red fox (*Vulpes vulpes*), European hare (*Lepus europaeus*), caracal (*Caracal caracal*), and grey wolves (*Canis lupus*). Our results showed that, based on the two methods, hotspot locations and the Asiatic cheetah corridor coincided. The corridor between TBR and Miandasht Wildlife Refuge was illustrated. This corridor is about 55 km length and 656 km^2 area, which connects two population patches within these protected areas. Asiatic cheetah vehicle collisions mostly occurred where a road crossed this corridor at the border of the TBR. The mitigation strategies proposed in this study for large mammals, particularly the Asiatic cheetah, are as follows: retrofit and installation of culverts in hotspots; installation of fences for crossing carnivores; and, roadside vegetation clearance in critical seasons for the Persian gazelles along the Semnan-Mashhad road.

1. Introduction

Human–wildlife conflicts including wildlife–vehicle collisions (WVCs) present significant challenges to conservation and management of mammals in human-dominated landscapes (Lima, Blackwell, DeVault, & Fernández-Juricic, 2015; Neumann et al., 2012). The adverse effects of roads on wildlife, such as habitat fragmentation and habitat loss, are well-known particularly on large carnivores due to their large area requirements, low population densities and direct persecution by humans (Colchero et al., 2011; Crooks, 2002; Grilo, Bissonette, & Santos-Reis, 2009; Stewart et al., 2016). WVCs have been widely recognized as a major impediment to management and conservation of certain carnivores (Grilo et al., 2009); for instance, the Florida panther (*Puma concolor*; Taylor, Buergelt, Roelke-Parker, Homer, & Rotstein, 2002), the Iberian lynx (*Lynx pardinus*) in Spain (Ferreras, Gaona, Palomares, & Delibes, 2001), and the ocelot (*Leopardus pardalis*) in Texas (Haines, Tewes, Laack, Grant, & Young, 2005; Hewitt, Cain, Tuovila, Shindle, & Tewes, 1998; Tewes & Hughes, 2001). Furthermore, WVC can act synergistically with other disturbance factors, contributing to increase the fragmentation and isolation of threatened species. For example, Cullen et al. (2016) showed that jaguar (*Panthera onca*) populations are being threatened by a combination of factors, namely habitat loss, habitat fragmentation, and proximity to roads. (Espinosa, Celis, & Branch, 2018).

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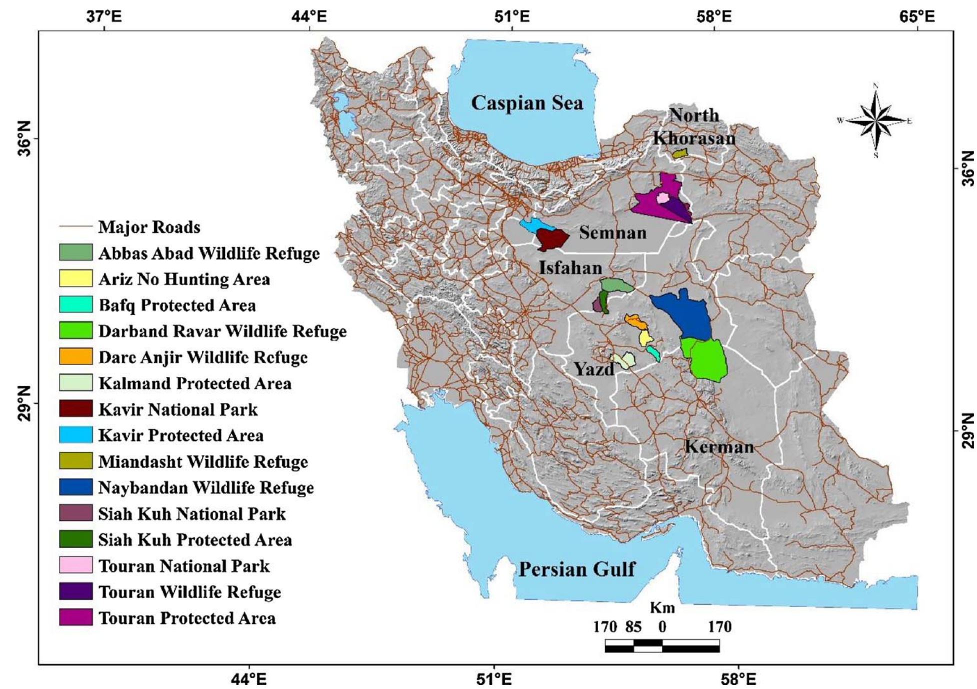

Fig. 1. Protected areas with cheetah occurrences in Iran.

WVCs are mainly a particular conservation concern for endangered species populations that are already at risk of extinction (Downs et al., 2014). In Iran, WVCs are also well documented for a variety of large mammals including carnivores (Mohammadi & Kaboli, 2016). Among these is one of the most threatened felid species in the world (Farhadinia et al., 2013; Mohammadi & Kaboli, 2016). Prior to the 1940s, it was estimated that around 400 Asiatic cheetahs (*Acinonyx jubatus venaticus*) roamed throughout eastern Iran and in the west near the Iraqi border (Farhadinia et al., 2013). However, during the 2000's, only 82 cheetahs were detected by camera-tracking in their habitats (TBR, Kavir National Park, Khosh Yeilagh Wildlife Refuge, Naybandan Wildlife Refuge, Bafgh Protected Area, Dareh Anjir Wildlife Refuge, Siah Kouh National Park, Ariz No Hunting Area, Abbas Abad Wildlife Refuge, Darband Ravar Wildlife Refuge, Miandasht Wildlife Refuge (Fig. 1)) in Iran (Farhadinia et al., 2017).

Over the past three decades, Iran has been the last refuge for Asiatic cheetahs, occurring throughout several protected areas, including the provinces of North Khorasan, Yazd, Semnan, Kerman and Isfahan (Farhadinia et al., 2017) (Fig. 1). After years of developing road networks in Iran, protected areas with high biodiversity and the corridors that connect them have been severely impacted (Mohammadi & Kaboli, 2016). Yazd and Semnan Provinces in central and northeast of Iran have been among the most problematic areas as a result of expanding anthropogenic activities (including construction of road networks), which leads to human-wildlife conflicts (Mohammadi & Kaboli, 2016).

Road densities within and at the border of the Asiatic cheetah protected areas are shown in the supplementary material (Table S1). Reports indicate that 14 Asiatic cheetahs were killed in vehicle accidents in these regions over the course of 10 years (CACP, 2015) (Fig. 2).

An important step in mitigating the impacts of roads on wildlife is to focus on road-kill hotspots (Litvaitis & Tash, 2008). Road-kill hotspots have typically been identified along roadside habitats attractive to wildlife (e.g., mineral licks, food resources), or wildlife movement corridors (Litvaitis & Tash, 2008). Roads with high traffic volumes and/or high-speed vehicles are associated with increased road-kills (Danks & Porter, 2010; Grilo et al., 2009; Jaarsma & Willems, 2002). Studies suggest that mitigation planning based on sound science can effectively reduce WVCs (Clevenger, Chruszcz, & Gunson, 2001; Rytwinski et al., 2016). As a result, planning and implementation of mitigation measures

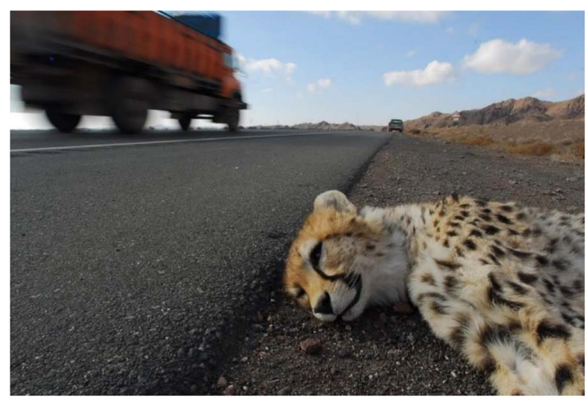

Fig. 2. Female Asiatic cheetah killed on the Semnan – Mashhad road due to a vehicle collision in November 2015.

has proliferated worldwide (Beckmann & Hilty, 2010). Unfortunately, few WVC-related studies have been carried out in Asia and even fewer in Iran (Gubbi, Poornesha, & Madhusudan, 2012; Lateef, 2010; Mohammadi & Kaboli, 2016; Moqanaki & Cushman, 2016; Saeki & Macdonald, 2004).

The objectives of our study are the following: 1) collect field data on incidence of WVCs and road crossings in Semnan-Mashhad highway in the northeast of Iran; 2) develop models that identify potential areas of conflict between wildlife movement and road systems; 3) validate models using field data collected; 4) culvert monitoring for wildlife track detection in crossing hotspots; and, 5) recommend mitigation measures to reduce WVCs including mammals, such as Asiatic cheetahs.

2. Material and methods

2.1. Study area

Touran Biosphere Reserve (TBR) is located south of Shahrud and 28 km southeast of Biarjomand, and covers an area of 1,464,992 ha (Fig. 3). In 1976, it was declared as a protected area and in 1977, UNESCO's Man and Biosphere Program (MAB) decided to designate the

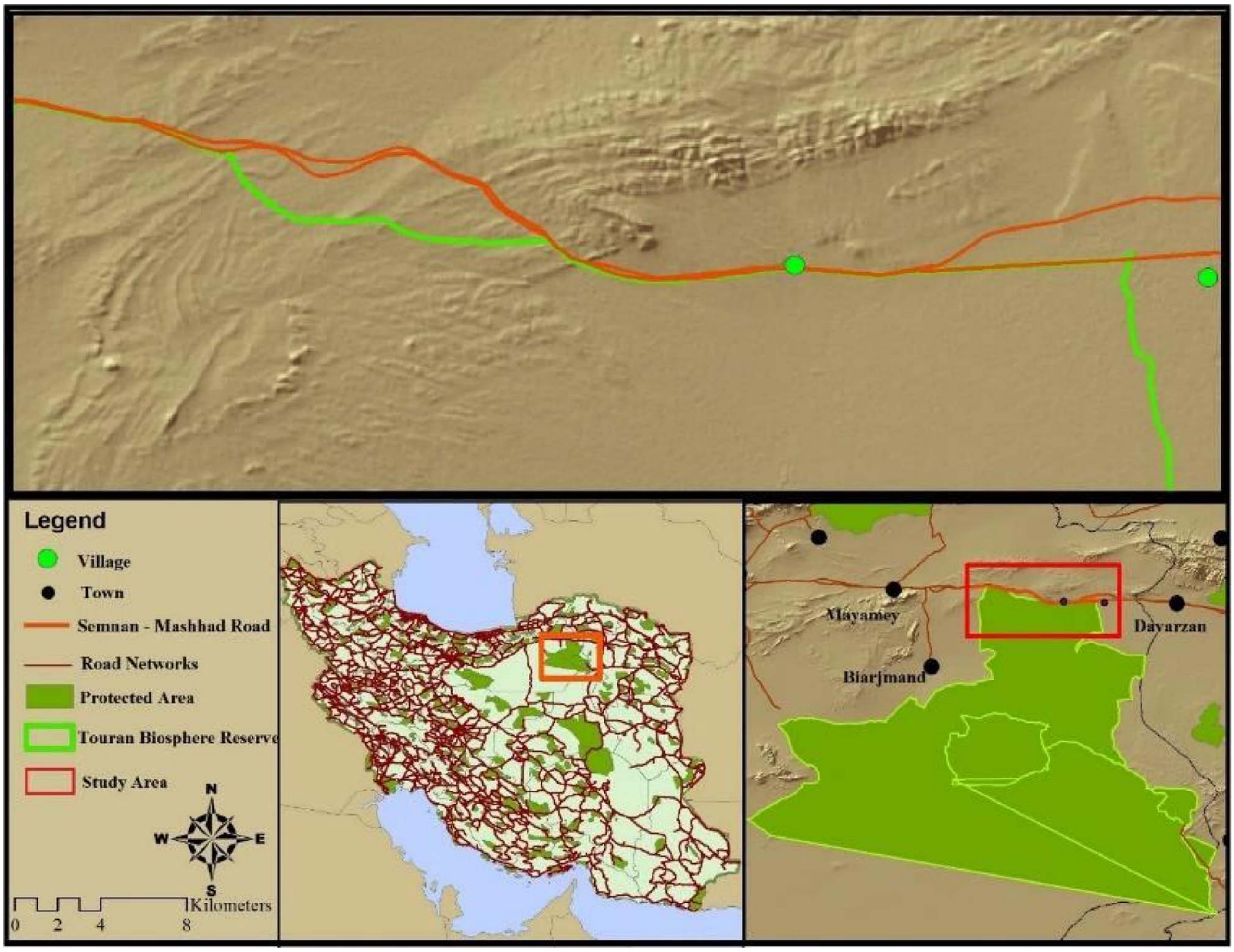

Fig. 3. Touran Biosphere Reserve in north east of Iran.

area as a biosphere reserve on account of its unique endemic fauna and flora, which includes a great number of large mammals such as Persian wild ass *(Equus hemionus),* Persian Gazelle (*G. subgutturosa*), Jebeer Gazelle (*G. bennettii*), Jungle cat (*Felis chaus*), Sand cat (*F. margarita*), Leopard (*Panthera pardus*) and most importantly the Asiatic cheetah. TBR is the second largest biosphere reserve in the world and consists of three areas of Wildlife Refuge, National Park, and Protected Area (CACP, 2015). Rangeland is the most dominant ecosystem type in TBR. It is among the most valuable habitats for Asiatic cheetah and appears to be a source for cheetah population in Iran (CACP, 2015). The Miandasht Protected Area, Behkade Protected Area and Golestan National Park are located in the east and north of TBR and act as peripheral core areas for the cheetah population (CACP, 2015). The climate of the region is cold arid (as determined by the Ambrege method). The area encompasses a range of mountains, ridges, plains, sand dunes and sand sheets (CACP, 2015).

The Semnan-Mashhad road is at the border of the TBR, about 45 km of which crosses the northern border of the reserve (Fig. 3). The 12 m wide, 2-lane highway has a traffic volume of 6728 and 719 vehicles per day for private and commercial vehicles, respectively. The speed limit is 90 km/h. The highway has lanes that are separated by concrete and guardrail in some sections of the road (Iran Transportation Organization, 2013). Roadside vegetation is predominantly *Zygophyllum eurypterum*, *Artemisia sieberiits* and *Ephedra intermediate* (CACP, 2015).

2.2. Wildlife-vehicle collision (WVC) data collection

We monitored a 20 km section of the Semnan-Mashhad road that borders the TBR. In this 20 km section, we surveyed a 30 m buffer (on either side of the road, corresponding to a 60 m × 20 km area) for road-killed mammals every morning during two periods: late summer (20 August–29 September); and, early autumn (10 October–25 November) of 2014 and 2015. We inspected each side of the road separately on foot and all carcasses of mammals were recorded using a handheld GPS (Garmin GPS Map 62S). In order not to double-count carcasses, we removed the carcasses after recording.

We also obtained WVCs location data from 2011 to 2015 from Semnan province, Department of Environment. We acquired anecdotal data related to mammals crossing the road over a 1-year period in TBR with the contribution of a number of experienced local people who were trained prior to data collection (data included direct observation of mammals in the vicinity of the road and crossing the road). We estimated the probability of a mammal getting killed as it attempts to cross a road, based on an equation used in previous studies (Gibbs & Shriver, 2002; Hels & Buchwald, 2001; Litvaitis & Tash, 2008; Row, Blouin-Demers, & Weatherhead, 2007).

$$P_{killed} = 1 - e^{-Na/v} \quad (1)$$

This equation attempts to ascertain the probability of an animal getting killed (P_{killed}) while crossing the road, given the traffic intensity N (number of vehicles per 24 h) (vehicles/lane/min), the kill zone a (m), and the velocity of the individual v (m/min) while crossing the road (Hels & Buchwald, 2001; Litvaitis & Tash, 2008). In this study, we considered *v*: 480 m/min, *a*: 12 m and *n*: 4 vehicles/lane/min. We applied the value obtained from this equation to the crossing data

2.3. WVCs hotspots

Here, we determined WVCs hotspots based on two methods, the Distance Method and the Kernel Density Estimation (KDE) technique and compared both methods (Anderson, 2009; Krisp & Durot, 2007; Williamson, McLafferty, Goldsmith, Mollenkopf, & McGuire, 1998; Xie & Yan, 2008).

2.3.1. Distance method

This method was separately applied for each data set (crossing points and WVCs data). As the distance from each point increases, each cell value will gradually increase and the fuzzy raster map will depict the distribution of all points (Quddus, Noland, & Ochieng, 2006; Quinn, Alexander, Heck, & Chernoff, 2011; Wang, Lao, Wu, & Corey, 2010). In this approach, in order to distinguish mortalities of each mammal and to weight each point, we considered two different ecological values for each point: (1) evolutionarily distinct and globally endangered (EDGE); and, (2) home range radius.

2.3.1.1. EDGE. The evolutionarily distinct and globally endangered (EDGE) species is an approach for conservation prioritization of species (Isaac, Turvey, Collen, Waterman, & Baillie, 2007), in which based on the evolutionary distinctiveness and extinction risk according to the equation derived by Isaac et al. (2007), species are prioritized for effective management and conservation (Isaac, Redding, Meredith, & Safi, 2012, Isaac et al., 2007; Jetz et al., 2014).

In this study, we prepared a list of mammals killed on the studied road and prioritized them based on the EDGE method (Isaac et al., 2007). Then, we converted the EDGE values to relative values between 0 and 1. Finally, the relative weight for each mammal was achieved using the relative values (Table 1).

2.3.1.2. Home range radius. This method is based on the home range radius of each mammal, including Persian gazelle (Durmus, 2010), Asiatic cheetah (CACP, 2015), striped hyena (Wagner, Frank, & Creel, 2008), golden jackal (Admasu, Thirgood, Bekele, & Karen Laurenson, 2004), red fox (Trewhella, Harris, & McAllister, 1988), European hare (Reitz & Léonard, 1994; Smith, Alves, Ferrand, & Hackländer, 2008), caracal (Avenant & Nel, 1998), and grey wolf (Mattisson et al., 2013). Similar to the previous method, we provided relative values between 0 and 1. Therefore, the relative weight for each mammal can be achieved using the relative values (Table 2).

All procedures of identifying potential hotspot locations followed the following steps: 1) Preparing a raster map using both data sets (crossing points and WVCs) based on Euclidean Distance; 2) Providing a fuzzy map using the raster map to categorize cell values between 0 and 1; 3) Applying EDGE and home range radius values to separately weight mortality points for each map; 4) Inverting each cell value to exhibit both values (EDGE and home range radius) for each point; 5) Overlaying the entire map to prepare hotspot locations and 6) Using contour lines for prioritization of hotspot locations.

Table 1
Prioritized list of mammals based on the EDGE method.

	EDGE	IUCN Categories	EDGE/ Total	Relative weight
Acinonyx jubatus venaticus	5.78	CR	0.250	5
Hyaena hyaena	3.76	NT	0.150	3
Capra aegagrus	3.34	VU	0.130	2.6
Ovis orientalis	3.24	VU	0.120	2.4
Gazella subgutturosa	2.72	VU	0.110	2.2
Caracal caracal	2.41	LC	0.100	2
Lepus europaeus	2.01	LC	0.070	1.4
Canis aureus	1.52	LC	0.055	1.1
Vulpes vulpes	1.51	LC	0.055	1.1
Canis lupus	1.45	LC	0.050	1
	Total: 21.95		**1**	

Table 2
Values of each mammal based on home range radius.

	Home range (Km^2)	Radius of home range (Km^2)	Radius of home range / Total	Relative weight
Acinonyx jubatus venaticus	170	7.5	0.280	40
Hyaena hyaena	80	5.2	0.196	28
Canis lupus	70	4.7	0.178	25
Caracal caracal	30	3	0.113	16
Gazella subgutturosa	15	2.1	0.080	11
Ovis orientalis	10	1.7	0.064	9
Vulpes vulpes	3	1	0.038	5.4
Canis aureus	3	1	0.038	5.4
Lepus europaeus	0.7	0.2	0.007	1
		Total 26.4	**1**	

2.3.2. Kernel density estimation (KDE)

KDE placed a grid over the WVCs and crossing points; a 10 × 10 m grid cell was used to include the entire distribution of WVC points in the study area. A crucial step in KDE methodology was to determine the proper bandwidth for our study (Anderson, 2009; Krisp & Durot, 2007; Williamson et al., 1998; Xie & Yan, 2008). First, we determined the bandwidth using the nearest neighbor distance algorithm (Williamson et al., 1998), and then computed point weights within the kernel radii. Central point's play a more important role in determining the density value of the cell because the closer a point is to the center, the more weight it will be given. We calculated the final value for each grid cell by summing the values of circle surfaces associated with each point (Silverman, 1986).

2.4. Habitat corridor for Asiatic cheetah

A habitat suitability map of the Asiatic cheetah was prepared using MaxEnt software version 3.3.3k (Phillips, Anderson, & Schapire, 2006) to create habitat patches and apply to corridor modeling. MaxEnt is a general-purpose method for characterizing species habitat associations using presence-only data, and has proven to be robust and precise compared to other methods (Elith et al., 2006). We used 10,000 as the number of pseudo-absence points (Phillips & Dudík, 2008). For the training data set, 75% of the presence points were randomly chosen to produce the model, while the remaining 25% was used as test data (Pearson, Raxworthy, Nakamura, & Peterson, 2007). We used the area under the ROC curve (AUC) to evaluate model performance. AUC ranges from 0.5 to 1, in which 0.5 shows no discrimination between presence points and pseudo-absence points and 1 shows the highest level of discrimination (Phillips et al., 2006).

A total of 365 presence points were obtained from CACP (2015) in TBR and Miandasht Wildlife Refuge, as well as nearby surroundings. Environmental layers, including (1) digital elevation model (DEM) and (2) topographic position map as topographic layers, (3) land cover, (4) distance to river and (5) distance to springs as layers representing food and water needs, (6) distance to road, (7) distance to village and (8) distance to pasture as human disturbance, All layers had a 30 m × 30 m resolution. Topographic position was derived from DEM in four categories (Majka, Jenness, & Beier, 2007); in 200 m radius neighborhood, a 30 × 30 m cell was classified as canyon bottom if cell elevation was at least 12 m lower compared to the neighbourhood average, ridge-top if cell elevation was at least 12 m higher compared to the neighbourhood average, flat-gentle slope if the cell is neither a canyon bottom nor a ridge-top and slope < 6°, and steep slope if the cell is neither a canyon bottom nor a ridge-top and slope > 6°. Elevation and slope thresholds were chosen based on methods used by Atwood et al. (2011). Land cover maps (FRWMO (Forest, Range & Watershed Management Organization of Iran), 2010) initially including 45 classes were converted to 11 classes based on the similarities between classes. Other maps were created by the Department of Environment (DoE) of Iran. Distance to these feature maps was calculated using the Euclidean distance tool in the Spatial Analyst extension of ArcGIS 10.2. The habitat suitability map created by MaxEnt was rescaled from a 0–1 range to the 0–100 range.

A habitat suitability map was used to provide potential population patches and potential stepping stone patches (Majka et al., 2007). A 200 m radius neighborhood was chosen to assess each cell of the habitat suitability map. Potential stepping-stone patches were selected based on at least 10 km^2 of contiguous cells with a neighborhood suitability of > 30. A threshold of 30 was chosen based on the equal training sensitivity and specificity logistic threshold in MaxEnt results (Liu, Berry, Dawson, & Pearson, 2005) and a threshold of 10 km was chosen based on home range of the Asiatic cheetah (CACP, 2015). Potential population patches were selected based on at least 50 km^2 of contiguous cells with a neighborhood suitability of > 30. A 50 km^2 area is large enough to support about five cheetahs to create a population (CACP, 2015).

Corridor modeling was done using CorridorDesigner software (Majka et al., 2007) in Arc GIS 10.2. The corridor was illustrated between TBR and Miandasht Wildlife Refuge. CorridorDesigner used population patches within each protected area as termini and the corridor was illustrated using the least cost method (Almasieh, Kaboli, & Beier, 2016).

2.5. Culvert usage

Using the track-pad technique, the most appropriate technique in wildlife track detection (Mateus, Grilo, & Santos-Reis, 2011), 10 box-type drainage culverts (n = 4, width: > 2–3 m × height: 1-2.50 m; n = 3, width: 3–4.10 m × height: 2–3 m; n = 3, width: > 4 m × height > 3 m) in crossing hotspot locations were monitored during winter (November-January) and summer (June–September) of 2015. To detect mammal tracks, we covered the width of all culverts with a thin layer of marble dust, approximately 1cm deep and 150 cm in length (Mata, Hervas, Herranz, Suarez, & Malo, 2005).

Animal tracks were detected over a 2–3-day interval between visits. Drainage culverts were sampled during seven consecutive days. This sampling period was selected as it is the driest period of the year and when culverts are least likely to be flooded and marbled dust is not washed away.

3. Results

3.1. Wildlife-vehicle collisions

Our results showed that 14 Asiatic cheetah were killed on the roads of Iran during 2005–2016 (CACP, 2015) (Table 3). Among these, seven Asiatic cheetahs were killed on Semnan-Mashhad road. In this study, 71 WVC observations were made of mammalian species, including: Persian gazelle (n = 5); Asiatic cheetah (n = 7); striped hyena (n = 4); golden jackal (n = 10); red fox (n = 20); European hare (n = 20); caracal (n = 3); and, grey wolf (n = 4). Also, 40 road crossings by mammalian species were recorded, including: Persian gazelle (n = 9); grey wolf (n = 17); red fox (n = 9); and, golden jackal (n = 5). Using the nearest neighbor distance algorithm, the bandwidth of 500 m was determined to be the most effective in estimating the density of WVCs. The probability of a mammal getting killed while crossing the road was 0.18 which means 18 percent of the species that cross the road will be killed by vehicles collisions.

Table 3
Road mortalities of the Asiatic cheetah during 2005–2016 (CACP, 2015).

Road	Year	Sex	Season
Calmand - Bahadoran	2005	Female	January
Bafgh- Bahabad	2006	Unknown	December
Calmand - Bahadoran	2006	Male	February
Calmand - Bahadoran	2008	Male	February
Calmand – Bahadoran	2009	Male	October
Calmand – Bahadoran	2009	Female	December
Yazd – Tabas road	2012	Male	May
Semnan – Mashhad road	2011	Female	December
Semnan – Mashhad road	2011	Cub	December
Semnan – Mashhad road	2011	Cub	December
Semnan – Mashhad road	2015	Cub (Female)	November
Semnan – Mashhad road	2015	Female	November
Semnan – Mashhad road	2016	Female	December
Semnan – Mashhad road	2016	Male	May

Based on the distance method, and considering the EDGE and home range radius values, hotspot locations were determined (Fig. 4), which covered an overall length of 12 km (Fig. 4). Also, when we considered home range radius values of other large mammals such as the grey wolf and the Persian gazelle, vehicle collisions coincided with hotspot locations near Abbas Abad village. The final map of hotspot locations was prioritized based on quantitative values of Euclidean distance cells (Figs. 4 and 5). Asiatic cheetah mortalities are located in hotspot locations (1 and 2) with high priority for urgent monitoring. Another hotspot location (3: medium priority for future monitoring) is located near Abbas Abad village (Fig. 5). Based on KDE, we obtained two hotspot locations (Fig. 6).

3.2. Habitat patches and corridor for Asiatic cheetah

Our MaxEnt model showed an AUC of 0.97 which represents high accuracy of the model. Two modeled population patches were obtained from the habitat suitability model; each patch within each protected area (Fig. 7). The population patches within TBR and Miandasht Wildlife Refuge were about 3447 km^2 and 996 km^2, respectively. There were four modeled stepping-stone patches between the two protected areas, covering an area of about 153 km^2.

The corridor between TBR and Miandasht Wildlife Refuge is shown in Fig. 7. This corridor is about 55 km length and 656 km^2 area, which connects two population patches within these protected areas. Asiatic cheetah vehicle collisions (n = 7) and other mammal collisions such as golden jackal (n = 7), red fox (n = 5), European hare (n = 10) occurred where a road crossed this corridor at the border of the TBR.

3.3. Use of culverts by mammals

Most crossings were associated with the red fox, golden jackal, European hare, the grey wolf and the striped hyena (Table 4). Two records of Asiatic cheetah crossing were reported in medium and large culverts (n = 1, width: 2.20 m × height: 1.60 m × length: 12 m; n = 2, width: 3.10 m × height: 2.70 m × length: 12 m) (Table 4, Fig. 8). The majority of crossings were detected in medium and large box culverts (Table 4).

4. Discussion and conclusions

Populations of the Asiatic cheetah are distributed over a wide area in Iran and individuals constantly travel across vast distances through central parts of the country (in four parks and reserves including Dareh-Anjir Wildlife Refuge, Ariz Non-hunting Area, Bafq Protected Area, and Siah-Kouh National Park). Hence, populations of this subspecies are forced to get across several roads within these protected areas

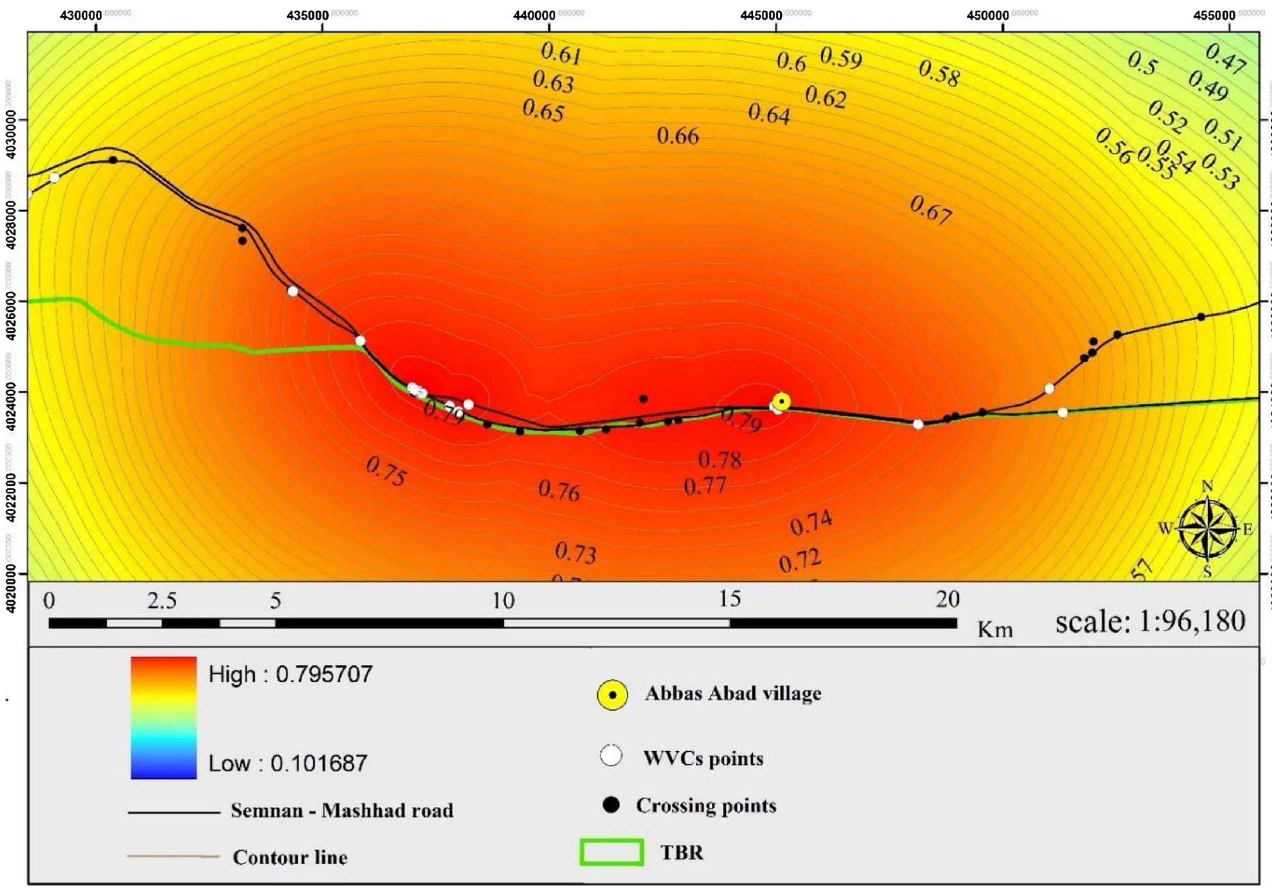

Fig. 4. Hotspot locations of WVCs based on the distance method with reference to EDGE and home range radius values on Semnan-Mashhad road (high values (red zones) indicate highly-significant locations of WVCs hotspots and low values (yellow zones) indicate locations of minor significance in terms of WVCs). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(Farhadinia et al., 2013).

The population patch within TBR was about 3.5 times larger than the population patch in Miandasht Wildlife Refuge, an indication of better habitat suitability for the Asiatic cheetah in TBR. In other words, contiguous cells with suitability > 30 were 3.5 times higher in TBR than Miandasht Wildlife Refuge. Two of the four stepping-stones were included in the modeled corridor, which covered about 11% of the corridor area (78 km^2 stepping-stones of 656 km^2 corridor). These stepping-stones should facilitate movement of Asiatic cheetah individuals within the corridor, acting as stopovers, particularly for long movements of cheetahs within corridors (Almasieh et al., 2016; Moqanaki & Cushman, 2016). Efforts should be made to maintain or restore habitat within the Asiatic cheetah corridor, ensuring functional habitat connectivity between stepping-stone patches and within the corridor. The two stepping-stone patches outside the corridor with an area of 75 km^2 could potentially be important habitat should efforts be made to create suitable habitat conditions to improve connectivity with the corridor and in the matrix proper. A regional population conservation strategy needs to focus on reducing cheetah mortality on the Abbas Abad Road, through use of existing culverts and construction of new passages, and ensuring travel habitat exists within the corridor.

Previous studies have shown that high rates of mortality may occur within habitat corridors and well-connected areas (Grilo, Ascensao, Santos-Reis, & Bisonette, 2011). Our results revealed that the modeled corridor and vehicle-collisions of the Asiatic cheetah overlapped significantly (Fig. 7). Indeed, Semnan-Mashhad road has bisected this corridor as well as suitable habitats of the species. Mortalities of other mammals, such as the grey wolf, red fox and golden jackal mostly occurred close to Abbas Abad village road due to their scavenging behavior. In areas where roads are barriers to movement, culverts and crossing structures may serve as corridors to travel across roads (Lister, Brocki, & Ament, 2015). Today, studying the adverse effects of roads on species mobility and the potential for passage structures in alleviating those impacts is a key conservation issue (Lister et al., 2015; Tigas, Van Vuren, & Sauvajot, 2002). Most studies documented that large mammals, especially large carnivores, used crossing structures in a way that ensured habitat connectivity (Gagnon, Dodd, Ogren, & Schweinsburg, 2011; Sawaya, Clevenger, & Kalinowski, 2013). For this reason, determining the precise location of implementing mitigation measures is important (Beckmann & Hilty, 2010; Clevenger & Wierzchowski, 2006; Landguth, Hand, Glassy, Cushman, & Sawaya, 2012).

There are many culverts in the identified hotspot. However, only a few of them have appropriate dimensions for the species to cross. Our road-kill data showed that in hotspot locations (1 and 2) of the Asiatic cheetah, there are six drainage culverts; two of which have high openness ratios (Table 4). Also, our study is the first to report on mammal use of below-grade passage structures in Iran and the first documented passage by Asiatic cheetahs.

Most crossings of drainage culverts were recorded from European hare, red fox, golden Jackal, grey wolf. Two records of the Asiatic cheetah crossings were recorded from medium and large culverts (Table 4). The distance between the two culverts is about 300 m. The floor of both culverts used by Asiatic cheetah had a substrate of soft clay soil, and they are used by livestock only in autumn, which together with the fact that visibility of both culverts is suitable (i.e. Asiatic cheetahs can see the end of culverts) might be promoting its use by cheetahs.

In a study in Banff National Park from 1996 to 2000, 22 crossing structures were monitored year-round along 45 km stretch of a highway (Gloyne & Clevenger, 2001). Their results showed that cougars preferred to cross open-span underpasses compared to other types of

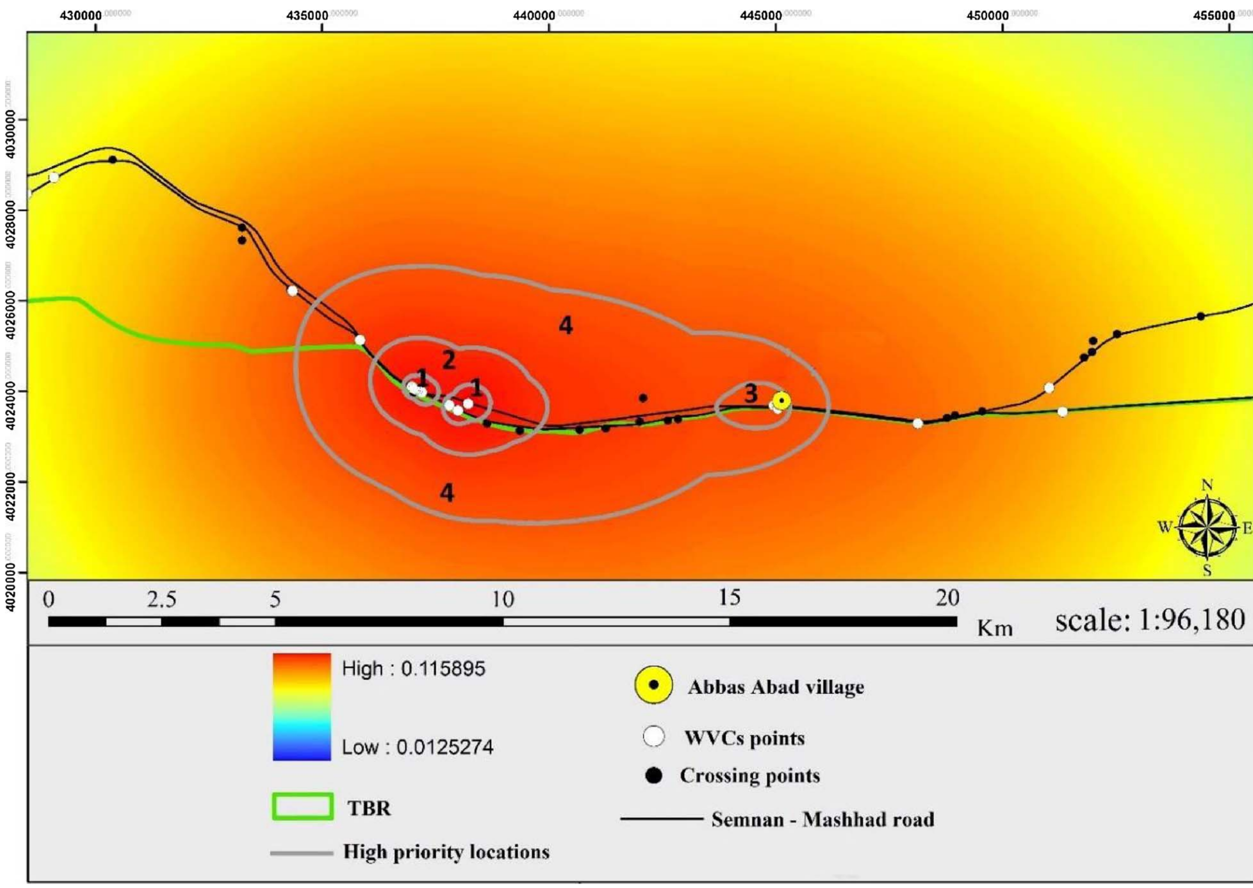

Fig. 5. Prioritization of WVCs hotspot locations on Semnan-Mashhad road (Locations 1 and 2 show high-priority hotspots, locations 3 and 4 show medium-priority hotspots for future monitoring).

crossing structures. Moreover, they found that crossing structure use by cougars (including underpasses) was highest during winter and lower in summer, and largely based on seasonal altitudinal migrations and habitat use of their prey species. In our study, the Asiatic cheetah used culverts during both summer and winter seasons, suggesting that their prey and food resources are available year-round. Some large carnivores such as grey wolves prefer large, open structures with good visibility, for instance landscape bridges, wildlife overpasses or viaducts (Clevenger & Waltho, 2005). Red foxes and golden jackals generally experience high levels of road-related mortality (Markolt, Szemethy, Lehoczki, & Heltai, 2012). Studies showed that to encourage red fox and golden jackal use of underpasses and culverts, they should be designed relative to the species' body size (Grilo et al., 2009; Markolt et al., 2012). Other studies showed that crossing structures and the proximity of suitable habitats disposed these species to vehicle collisions (Grilo et al., 2009; Markolt et al., 2012).

Small and medium-sized mammals, particularly prey species, tend to use passages of a size that allow for their movement, but may limit movement of their larger predators (Clevenger et al., 2001). Construction of wildlife crossings along fenced roads can provide safe road conditions for drivers and mitigate barrier effects on entire wildlife communities (Foster & Humphrey, 1995; Rytwinski et al., 2016). However, rarely is a single crossing structure design effective for a wide range of wildlife species, although due to their large size, viaducts and land bridges meet community level needs (Clevenger & Huijser, 2011; Lister et al., 2015). Wildlife species are capable of using a wide range of crossing structure types (Clevenger & Waltho, 2005; Grilo, Bissonette, & Santos-Reis, 2008; Mata et al., 2005). Our data bear this out as well (Table 4). Asiatic cheetahs used small and medium-sized underpasses, red foxes, golden jackals and striped hyenas used medium-sized underpasses, and wolves used mostly large passage structures. Therefore, a wide range of wildlife crossing types and designs should be used in order to facilitate passage by most species in the affected area. By placing a mix of crossing design types in the 12 km hotspot area, it will help reduce mortality and maintain connectivity for cheetahs and other species we documented in this study area.

Road networks can create suitable habitats for wildlife with a higher availability of food compared to the surrounding environments (Meunier, Verheyden, & Jouventin, 2000; Munguira & Thomas, 1992). Due to our field experiment during winter, when vegetation cover is abundant along the edge of the road, especially in plain areas, Persian gazelles are drawn to these edges, leading to an increase mortality risk from vehicles. Most mortalities of Persian gazelles occurred near Abbas Abad village. In this regard, due to the increase in mortality of this species during critical seasons, mitigation method such as roadside vegetation clearance could be considered as an effective measure in reducing mortality rates. When certain mammals forage along the edge of high-traffic roads, there is an unavoidable risk of vehicle collisions, which provides abundant carrion and attracts scavengers to the road area (Clevenger & Huijser, 2011). Striped hyena, red fox and golden jackal are scavengers and feed on the remains of domestic and other animals that have died due to road accidents (Qarqaz, Abu Baker, & Amr, 2004). Therefore, roads can attract scavengers because of the possibility of the presence of dead animals (Knight & Kawashima, 1993; Santos, Carvalho, & Mira, 2011; Tourani, Moqanaki, & Kiabi, 2012). In view of this behavior, most mortalities associated with these species in this area occurred near Abbas Abad village.

Wildlife warning signs are meant to control WVCs by increasing drivers' awareness and thus reducing vehicle speed (Huijser, Mosler-Berger et al., 2015). Most studies on the effectiveness of signs in reducing WVCs could not ensure their effectiveness (e.g., Bullock, Malan, & Pretorius, 2011; Coulson, 1982; Meyer, 2006; Pojar, Prosence, Reed,

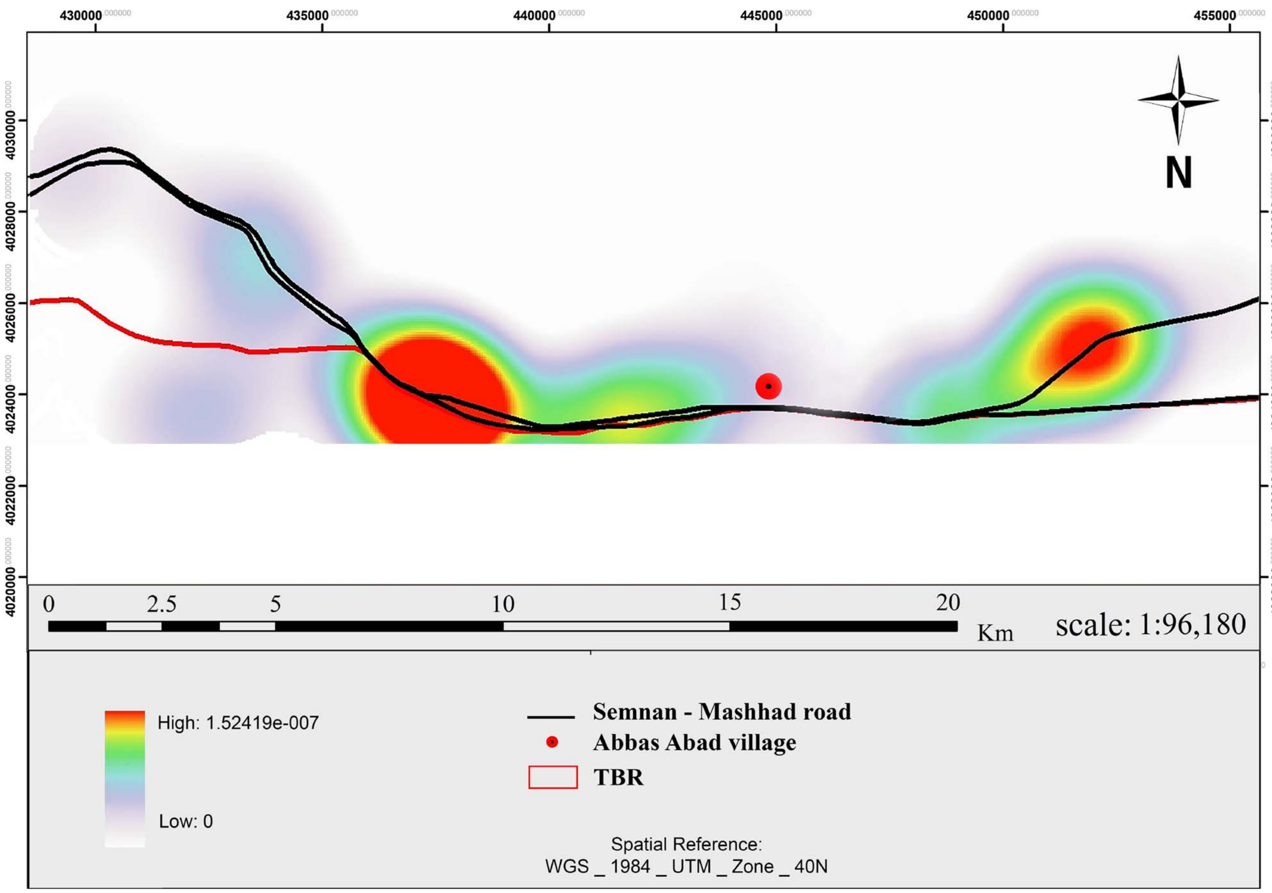

Fig. 6. Hotspot locations of WVCs based on Kernel Density Estimation with discriminate presence points and WVCs.

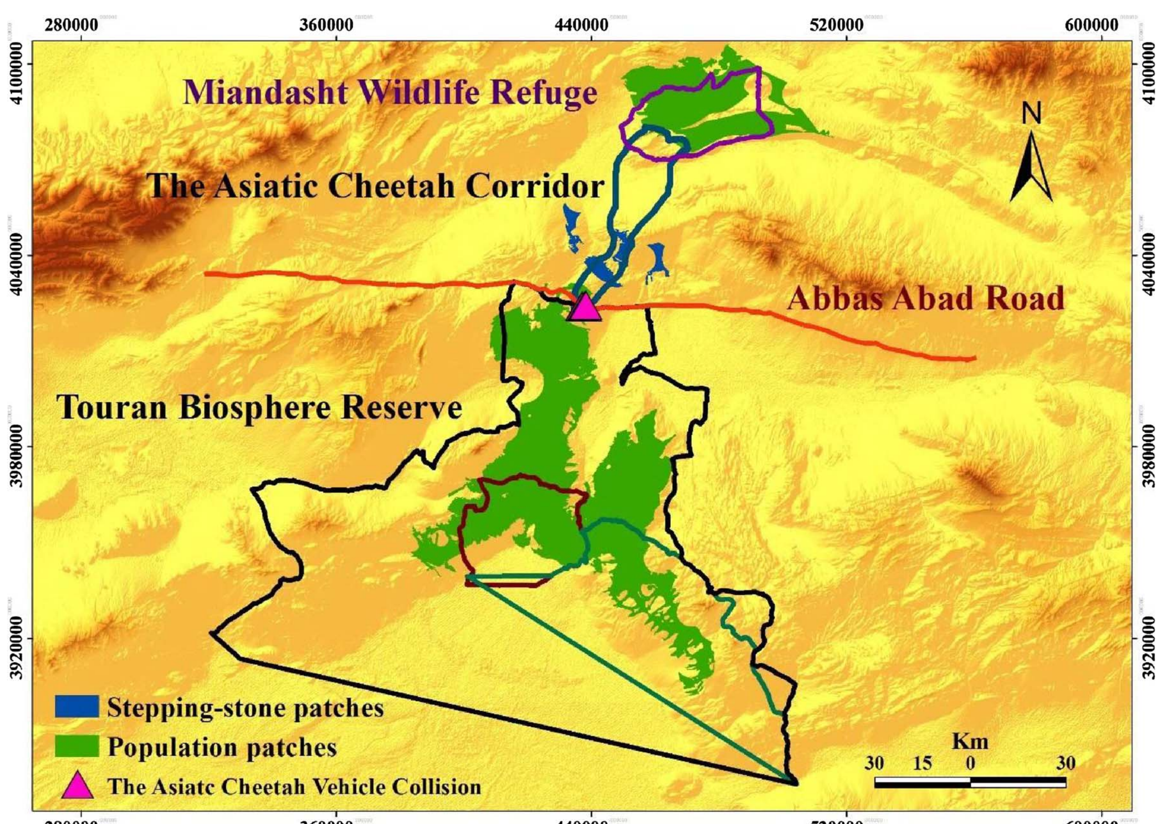

Fig. 7. Modeled population patches, modeled stepping stone patches and the modeled corridor between TBR and Miandasht wildlife refuge.

Table 4
Attributes of 10 culverts used by mammals in Touran Biosphere Reserve.

	Culverts									
Culvert Attribute	1	2	3	4	5	6	7	8	9	10
Width	2.20	2.40	2.70	2.80	3.10	3.50	4.10	4.20	4.30	4.30
Height	1.60	1.80	1.90	2.50	2.70	2.90	3.00	3.10	3.35	3.45
Length	12	12	12	12	12	12	11	11	12	12
Openness	0.29	0.36	0.42	0.58	0.69	0.84	1.11	1.18	1.2	1.2
Species										
Red fox	0	0	1	1	1	20	40	0	0	0
Golden Jackal	0	0	0	1	2	12	25	10	0	0
Grey wolf	0	0	0	0	2	3	5	6	8	4
European hare	0	0	1	3	2	5	0	5	0	0
Striped hyena	0	0	0	0	1	1	2	0	0	0
Asiatic cheetah	1	0	0	0	1	0	0	0	0	0
Total	1	0	2	5	9	41	72	21	8	4

Fig. 8. The Asiatic cheetah has crossed the medium culvert (width: 2.20 m, height: 1.60 m, length: 12 m).

Fig. 9. Asiatic cheetah warning sign designed by the CACP project.

& Woodard, 1975; Rogers, 2004). One study found warning signs reducing WVCs by 34% promptly after installment (Found & Boyce, 2011). Other studies have used signage at fence openings where a crosswalk was painted on the road and resulted in 37–43% decreases (Huijser, Kociolek et al., 2015). Animal-detection systems with or without fencing have proven most effective recently at reducing WVCs by > 50% (Huijser, Kociolek et al., 2015).

The CACP project designed eight Asiatic cheetah warning signs (Fig. 9), for increasing public awareness. Cheetah mortality rates and critical location must be assessed before installment of signs in order to measure their effectiveness in reduction of Asiatic cheetah vehicle collision. Moreover, wildlife fencing and crossing, if designed and maintained properly, are able to minimize vehicle collisions significantly (80–97%) (Huijser et al., 2016). Studies showed that wildlife fencing implemented along short road sections (< 5 km) were less effective in reducing collisions with large mammals than fencing implemented along long road sections (> 5 km) (Huijser et al., 2016). In our study total length of hotspots location was 12 km. In this section there are culverts with suitable dimensions for use by large carnivores, but some culverts are too small, so fencing with plans to retrofit culverts is recommended. Once these structures are retrofitted, systematic monitoring over a minimum of five years should produce useful information to guide the design of crossings for Asiatic cheetahs in future transportation projects in their range. Moreover, use of fencing in hotspot locations might be needed to guide mammals toward the crossing structures. Also, maintenance and monitoring of the crossings should be considered for effective mitigation measures.

In our study, we determined hotspot locations for mammals, particularly

the endangered Asiatic cheetah. We suggest that future studies examine road and environmental factors that may best explain why and where collisions occur. There also are critical gaps in our understanding of road impacts on the population viability of Asiatic cheetahs and other mammals in Iran. Addressing these information needs with focused research should be a high priority as transportation infrastructure expands throughout the country. Spatially explicit individual-based modelling approaches can be an important conservation tool to evaluate how roads affect the population viability of Asiatic cheetahs and other mammals (Grilo et al., 2009; Paula & Desbiez, 2013). This information will help create predictive models of mortality risk and population fragmentation that will identify where Asiatic cheetahs are most threatened by new and improved road systems in Iran. This science-based information will help transportation practitioners in Iran make informed decisions regarding transportation planning that will minimize impacts on Asiatic cheetahs and other sensitive species.

Conflict of interest

The authors declare that they have no conflict of interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jnc.2018.02.011.

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