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# Landscape-scale impacts of transportation infrastructure on spatial dynamics of two vulnerable ungulate species in Ghamishloo Wildlife Refuge, Iran

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ABSTRACT

Development of roads through protected areas can have deleterious effects on natural habitats containing species of conservation concern. During the past decades road construction has affected many former remote areas and led to fragmentation and isolation of wildlife populations. The present study focuses on the ecological impacts of Isfahan's West Freeway, which passes through Ghamishloo Wildlife Refuge; an IUCN category IV protected area, in Isfahan Province. The two key affected species, both classified as vulnerable by IUCN, the goitered gazelle (*Gazella subgutturosa subgutturosa*) and the wild sheep (*Ovis orientalis isphahanica*) were subject to impact analyses. We used habitat evaluation procedure (HEP) as a habitat-based impact assessment methodology which considers habitat quality and quantity. Habitat quality was measured as habitat suitability index (HSI) for each species. By literature review and field observations, five variables defining habitat suitability were identified and suitability maps for both species generated. Habitat units (HUs) were derived from multiplying the HSI for each species by the habitat area before and after freeway construction. The results showed that due to the construction of the freeway, about 14% of the HUs for goitered gazelle and about 9% of the HUs for wild sheep were lost. In addition, for quantifying landscape pattern change due to freeway construction, various landscape metrics were calculated for the species distribution polygons for two times before and after freeway construction. Results obtained through quantifying landscape metrics showed that mean nearest neighbor (MNN) and number of patches (NP) metrics increased. On the other hand, CONTAG metric decreased in both goitered gazelle and wild sheep distribution polygons, demonstrating the negative effect of freeway on these species distribution polygons integrity. According to the results of this study, mitigation and compensation activities should be considered in Ghamishloo Wildlife Refuge. Our study demonstrated that HEP method combined with quantifying landscape metrics might provide a powerful tool for assessing ecological impact of technical infrastructures on populations of far-ranging species of conservation concern.



## 1. Introduction

Modern human-dominated environments are subject to frequent and intense environmental perturbations (Mcdonald et al., 2009). Transportation infrastructure that enhances connectivity among human settlements often results in decreased connectivity among remaining natural habitats and wildlife populations (Forman and Alexander, 1998). Habitat fragmentation and the creation of barriers by transportation infrastructures reduce landscape connectivity, which is suspected to be one of the most important factors causing wildlife population declines (Borda-de-Água et al., 2011; Forman et al., 2003). Road networks affect wildlife habitats in different ways. First, road construction directly leads to a habitat loss. Second, maintenance and use of roads reduce habitat quality for wildlife by increasing distance between remaining habitat patches (Goodwin and Fahrig, 2002), and via additive barrier and mortality effects (Ascensao and Mira, 2006; Eigenbrod et al., 2008; Hoskin and Goosem, 2010; Jaeger et al., 2005; Shepard et al., 2008). This may hamper dispersal, which is critical for the long-term population viability of wildlife species (Debinski and Holt, 2000; Laurance et al., 2002; Lienert, 2004). By altering habitat area and spatial distribution of habitat patches, road networks affect the structure and spatial heterogeneity of a landscape. Development of roads in protected areas and ecological sensitive regions can have deleterious effects on wildlife populations (Lian et al., 2011). In addition to these primary impacts, roads may also provoke

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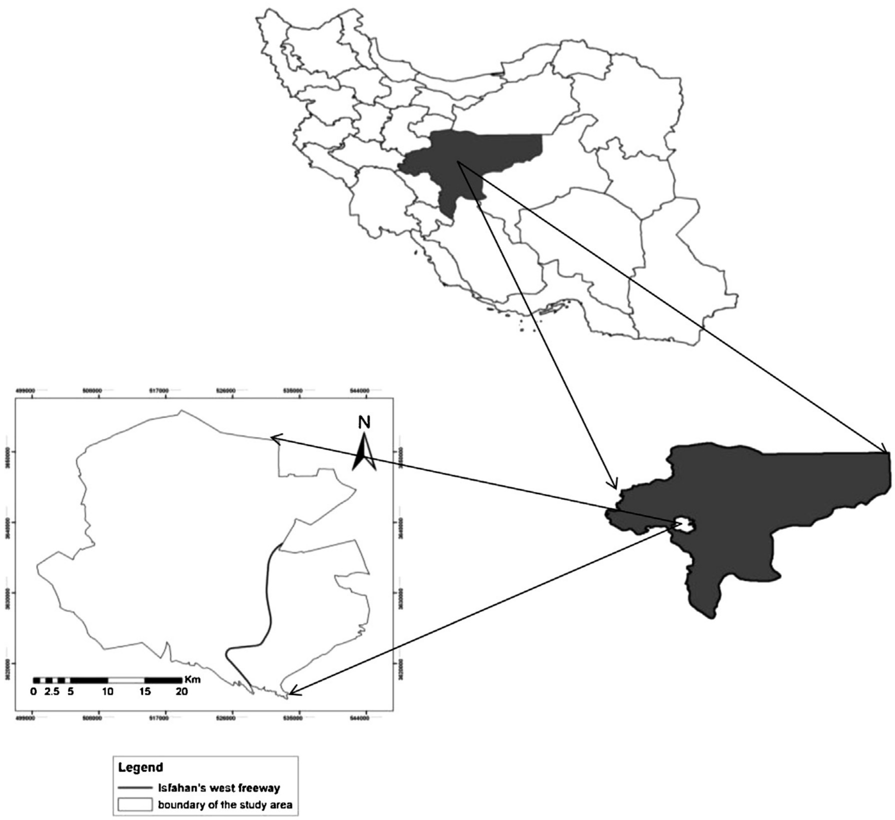


**Fig. 1.** Study area.

various secondary effects on protected areas. They may facilitate access to hunters, poachers and uncontrolled tourism (Gratson and Whitman, 2000). In addition new roads commonly promote economic development which may compromise conservation goals.

Far-ranging mammals such as large herbivores are particularly sensitive to habitat fragmentation because they need unrestricted access to large continuous habitat (Bolger et al., 2008). Fragmentation of habitat into small, non-contiguous patches may result in dramatic population declines (Simmons et al., 2010). Furthermore, small and isolated subpopulations are Eigenbrod et al., 2008; vulnerable to demographic, genetic, and environmental stochasticity (Fahrig, 2003).

Not withstanding these negative ecological impacts, road networks grow and get denser worldwide due to increasing socioeconomic needs for high mobility (Coffin, 2007; Shanley and Pyare, 2011). In Iran, road construction in ecologically sensitive habitats, i.e. protected areas and national parks, has been increasing during the past decades and ecological impacts have become highly visible (Momen Bellah Fard, 2009; Monavari and Mirsaeed, 2008).

In most cases, the ecological value of existing wildlife habitat has been considered of secondary importance in the face of compelling economic and social arguments for road construction. Assessment of ecological impacts of road construction is commonly hampered by a lack of appropriate data. Thus appropriate studies quantifying habitat loss and landscape pattern changes are essential. Further, there is a lack of studies on their impacts on animal species distribution and migration.

Here we provide quantitative data on habitat loss and landscape fragmentation due to Isfahan's West Freeway, which passes through Ghamishloo Wildlife Refuge, I.U.C.N category IV, Habitat/Species Management Area, in Isfahan Province of Iran. The two key affected species in the study area were goitered gazelle (*Gazella subgutturosa subgutterosa*) and wild sheep (*Ovis orientalis isphahanica*), both classified as Vulnerable (VU) on the IUCN Red List (Mallon, 2008; Valdez, 2008). The following questions were investigated in this study:

(1) How did habitat changes due to road construction affect the distribution of goitered gazelle and wild sheep?
(2) How does an existing freeway affect habitat quality and quantity of the large herbivores in Ghamishloo Wildlife Refuge?
(3) How landscape metrics such as MNN (mean nearest neighbor); NP (number of habitat patches) and degree of landscape fragmentation have been changed due to road disturbance effects?

## 2. Materials and methods

### 2.1. Study area

Our study area, Ghamishloo Wildlife Refuge is located 45 km northwest of Isfahan City, Iran (Fig. 1). Ghamishloo is located at 50°59′43″ to 51°28′09″ eastern longitude and 32°40′05″ to 33′02′24″ northern latitude and covered an area of approximately 113′653 ha. This area is covered with plains, mountains and rolling hills. The climate in this region is semi-arid and continental, with average temperatures ranging from −18.5 to 41.5 °C (hot dry summers, and cold dry winters), and mean annual precipitation of 180–190 mm.

The lowest elevation of the area is 1687 m above sea level in the southern part of the region. The bedrock mainly consisted of various sediments of Quaternary and Mesozoic age. Vegetation cover is sparse in the valleys and increases at the higher elevations. The vegetation of the area is typical drought tolerant shrub-steppe communities including *Artemisia* sp., *Astragalus* sp., Asteraceae, Brassicaceae, Poacea and etc. The area benefits from a naturally diverse terrain resulting in a rich fauna and flora. In total, more than

600 vascular plant species, 37 mammal species, 82 bird species, 32 reptile species have been recorded (Hajehforooshnia et al., 2011). The focal large herbivores in the study region are *G. subgutturosa*, and *O. orientalis isphahanica*, both classified as Vulnerable (VU) on the IUCN Red List (Mallon, 2008; Valdez, 2008). *O. orientalis isphahanica* has a restricted distribution mainly around Isfahan in central Iran. Ghamishloo Wildlife Refuge, which harbours one of the largest populations of this vulnerable sub-species, is of high conservation concern.

### 2.2. The data-base used

The data sources used in this study were composed of a digital elevation model (DEM) of the area, topography map at a scale of 1:25,000 prepared by NGO (National Geographical Organization), data collected during the field visits and information obtained from different references. Data for wild sheep and goitered gazelle locations before and after road construction were obtained from expert knowledge (interrogating wildlife/game wardens) and also field surveys that took place at least monthly, in all four seasons of 2011, and from different references, unpublished data and personal communications with wildlife guards of Ghamishloo Wildlife Refuge, local people and wildlife ecologists who have worked in this area. During the field monitoring the locations of goitered gazelle and wild sheep were recorded by GPS. We only recorded data when a correct assessment of animal or their sign was possible.

### 2.3. Ecological impact assessment

The ecological impact assessment of the Isfahan west freeway was performed using the two following approaches:

a. HEP (habitat evaluation procedure).
b. Quantifying landscape metrics.

#### 2.3.1. Habitat evaluation procedure (HEP)

HEP was developed by the U.S. Fish & Wildlife Service as a habitat-based approach for assessing impacts of proposed projects on wildlife (Farmer, 1980). HEP can be used for quantifying impacts of proposed projects on wildlife habitat by comparing the relative value of the same area at different times. HEP is based on the assumption that habitat for wildlife species can be described by a habitat suitability index (HSI), which ranges from 0 to 1, where an index of 0.0 represents unsuitable habitat, whereas an index of 1.0 represents optimal habitat (Farmer, 1980).

In this study, HEP was applied for quantifying habitat condition prior to road construction, and after development of the freeway in the study area. The HSI was determined through a combination of various suitability index (SI) values for relevant habitat variables. An SI value represents a value of interest (the measured habitat condition of the variable) relative to a standard of comparison (the optimum habitat condition of the variable) (Farmer, 1981). The HSI was multiplied by the area of available habitat to obtain habitat units (HUs), a measure of both habitat quality and quantity.

*2.3.1.1. Delineation of model.* The model is applicable throughout the Ghamishloo Wildlife Refuge and through all seasons of the year. By literature review (e.g., (Maleki Najafabadi et al., 2010; Mallon and Kingswood, 2001; Nowzari et al., 2007), field observations (recorded presence points for goitered gazelle and wild sheep throughout the year), and collecting experts' knowledge, five independent variables describing habitat suitability were identified, i.e. vegetation cover, slope, elevation, distance to water and distance to freeway, and related to four habitat components (food, cover, water and human impact). After classifying each variable, a quality value was assigned to each category (according to the percent of species presence points and literature review). These categories as well as the suitability indices for five variables are shown in Tables 1 and 2 (for goitered gazelle) and Tables 3–5 (for wild sheep).

**Table 1**
Suitability index for vegetation cover variable used in the Gazelle habitat suitability index model.

| Group | Vegetation types | Suitability index |
|---|---|---|
| 1 | Type 4 & 6 (Ar-No Sc-St) *Scariola Orientalis–Stipa barbata*, *Artemisia Sieberi–Noaea mucrunatu* | 1 |
| 2 | Type 1, 2 & 7 (An-Ar Ar-Ac As-Pr) *Astragalus* spp.–Perennial grasses, *Artemisia Sieberi–Scariola Orientalis*, *Anabasis apylla–Artemisia siebri–Astragalus* spp. | 0.75 |
| 3 | Type 5 (Ar-La) *Artemisia Sieberi–Launae acanthodes* | 0.5 |
| 4 | Type 3 (Ar-As) *Artemisia Sieberi–Astragalus* spp. | 0.25 |
| 5 | Type 8 (rock) | 0 |

Suitability maps were generated for each variable by assigning a suitability index (scale 0–1) to conditions for each variable. Colored spectrum ranged from green to red, green color indicating highest and red color indicating least suitability.

An overall HSI value was calculated using a mathematical formula representing hypothesized relationship among the individual SIs based on expert knowledge and literature. The output value indicates the habitat suitability index of each cell for the species and is represented on the final HSI map.

*2.3.1.2. Determining the habitat units (HUs).* Habitat unit (HU) was derived from multiplying the HSI for each of evaluation species by the habitat area (HU = HSI × size of habitat) in two time steps (before and after freeway construction). For determination of habitat loss, buffer zones on both sides of the freeway were considered, and levels of habitat loss through overlying road map, ecosystem map and buffer zone, were calculated.

#### 2.3.2. Quantifying landscape metrics

For quantifying landscape-scale impacts of Isfahan's West Freeway on Ghamishloo Wildlife Refuge, points of species presence and their distribution before and after freeway construction were determined. This resulted in four maps showing the distribution of goitered gazelle and wild sheep before and after freeway construction. Using these maps, the distribution polygons of species in separate layers were prepared. Then using FRAGSTATS 3.3, various metrics including MNN (mean nearest neighbor), NP (number of patches) and CONTAG (contagion), were extracted in the two conditions (before and after the freeway). Contagion measures both patch type interspersion (i.e., the intermixing of units of different patch types) as well as patch dispersion (i.e., the spatial distribution of a patch type) at the landscape level.

## 3. Results

### 3.1. Habitat evaluation procedure (HEP)

#### 3.1.1. Goitered gazelle

Based on a literature review five habitat suitability variables were identified for the goitered gazelle. A final habitat suitability map was prepared based on formula 1, which was adopted from Farmer (1981), Ashley and Berger (1999) and Larson et al. (2003), and classified based on Table 6. Goitered gazelle occurrence in each HSI category before and after freeway construction is shown in Fig. 2A.

$$\mathrm{HSI} = \frac{\mathrm{MIN}(\mathrm{SI}_1, \mathrm{SI}_2, \mathrm{SI}_4) + \mathrm{SI}_3}{2} \times \mathrm{SI}_5 \qquad (1)$$

**Table 2**
Suitability index for variables used in the Gazelle habitat suitability index model.

| Group | Suitability degree | Slope | | Elevation | | Distance to water supplies (m) | | Distance to freeway | |
|---|---|---|---|---|---|---|---|---|---|
| | | Category (percent) | Percent of presence points (%) | Category (m) | Percent of presence points | Category (m) | Percent of presence points (%) | Category (m) | Percent of presence points (%) |
| 1 | 1 | 0–10 | 78 | 1700–1900 | %41 | 0–4000 | 60 | >3000 | 91 |
| 2 | 0.6 | 10–20 | 12 | 1900–2100 | %38 | 4000–8000 | 32 | 2000–3000 | 5 |
| 3 | 0.3 | 20–30 | 7 | 2100–2300 | %16 | 8000–10,000 | 6 | 1000–2000 | 3 |
| 4 | 0 | >30 | 3 | >2300 | %5 | >10,000 | 2 | 0–1000 | 1 |

**Table 3**
Suitability index for vegetation cover variable used in the wild sheep habitat suitability index model.

| Group | Vegetation type | Suitability index |
|---|---|---|
| 1 | Type6 (*Scariola Orientalis–Stipa barbata*) | 1 |
| 2 | Type4 (*Artemisia Sieberi–Noaea mucrunatu*) | 0.8 |
| 3 | Type7 (*Astragalus* spp.–Perennial grasses) | 0.6 |
| 4 | Type1, type2 & type5 (*Anabasis apylla–Artemisia siebri–Astragalus* spp., *Artemisia Sieberi–Scariola Orientalis*, *Artemisia Sieberi–Launae acanthodes* | 0.4 |
| 5 | Type3 (*Artemisia Sieberi–Astragalus* spp.) | 0.2 |
| 6 | Type8 (rock) | 0 |

As shown in Fig. 3A, part of northern and eastern sections of the study area was found to be the best habitat for goitered gazelle populations. These areas cover 8475 ha (Table 7).

The HEP assessment resulted in a total of 56,019 HUs for goitered gazelle before freeway construction and 48,309 HUs after freeway construction. These results showed that due to the presence of the freeway, 7710 (HUs) or about 14% of the original HUs for *G. subgutturosa* were lost.

### *3.1.2. Wild sheep*

Based on a literature review five habitat suitability variables were identified for the wild sheep. A final habitat suitability map was prepared based on formula 2 which was adopted from Farmer (1981), Smith et al. (1991), Bodie et al. (1995) and Larson et al. (2003), and classified based on Table 6. Wild sheep occurrence in each HSI category before and after freeway construction is shown in Fig. 2B.

$$\mathrm{HSI} = \frac{(\mathrm{SI}_1, \mathrm{SI}_2, \mathrm{SI}_4) + \mathrm{SI}_3}{2} \times \mathrm{SI}_5 \quad (2)$$

As the map shows (Fig. 4A) some sections in north, center and west of Ghamishloo Wildlife Refuge are considered the best suitable habitat for wild sheep populations that equals 24,667 ha (Table 8).

The HEP assessment resulted in a total of 72,445 HUs for wild sheep before freeway construction and 66,157 HUs after freeway construction. The results showed that due to the presence of the freeway, 6288 (HUs) or about 9% of the original HUs for *O. orientalis* were lost.

## *3.2. Landscape metrics*

The landscape-scale impacts of Isfahan's West Freeway on Ghamishloo Wildlife Refuge was assessed by comparing two scenarios (before and after freeway construction). With regard to the species distribution polygons in these two scenarios (Figs. 5 and 6), respective metrics were calculated. Results obtained through quantifying landscape metrics showed that mean nearest neighbor (MNN) metric increased, demonstrating the negative effect of freeway on these species distribution polygons integrity. The MNN metric considerable addition is about 94 m for goitered gazelle (from 1382.39 m, come to 1287.94 m) and about 790 m (from 2635.65 m, come to 1845.43 m) in wild sheep distribution polygons. The number of patches (NP) increased from 22 units to 26 for goitered gazelle and from 16 units to 17 for wild sheep, which indicates the presence of the species in new regions or modification of their distribution places.

On the other hand, CONTAG metric decreased in both goitered gazelle and wild sheep distribution polygons. It decreased from 54.8 (before freeway construction) to 53.2 (after freeway construction) for goitered gazelle and from 54.7 to 52.4 for wild sheep, respectively. Lower values of CONTAG generally characterize landscapes with many small and dispersed patches. Whereas, higher

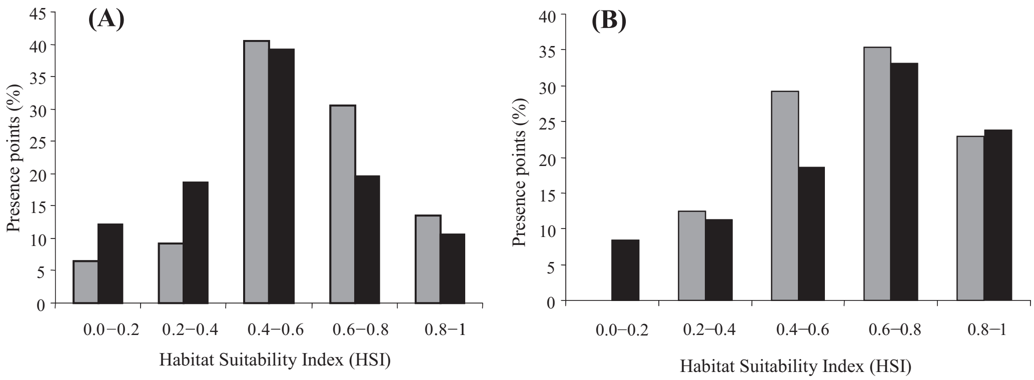


**Fig. 2.** The relationship between the species occurrence vs. HSI before (grey bars) and after (black bars) freeway construction (A) for *Gazella subgutturosa*, (B) for *Ovis orientalis isphahanica*.

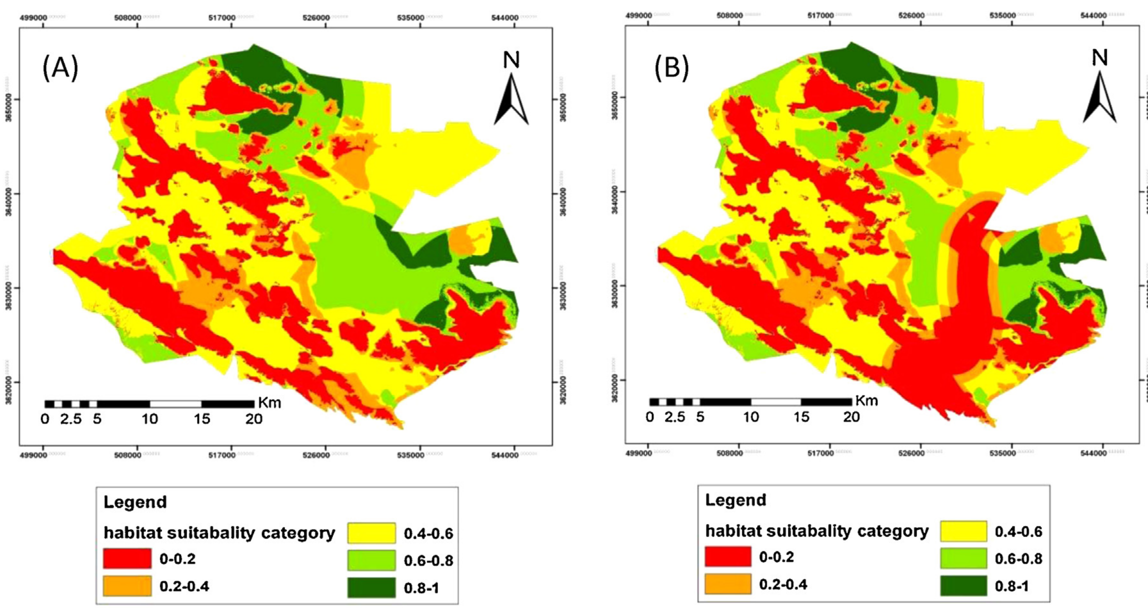


**Fig. 3.** Final habitat suitability map for *Gazella subgutturosa*: (A) before freeway construction, (B) after freeway construction.

**Table 4**
Suitability index for variables used in the wild sheep Habitat Suitability Index Model.

| Group | Suitability degree | Slope | | Distance to water supplies (m) | | Distance to freeway | |
|---|---|---|---|---|---|---|---|
| | | Category (percent) | Percent of presence points (%) | Category (m) | Percent of presence points (%) | Category (m) | Percent of presence points (%) |
| 1 | 1 | 0–20 | 80 | 0–4000 | 75 | >3000 | 86 |
| 2 | 0.6 | 20–30 | 13 | 4000–6000 | 18 | 2000–3000 | 8 |
| 3 | 0.3 | 30–40 | 7 | 6000–8000 | 6 | 1000–2000 | 5 |
| 4 | 0 | >40 | 0 | >8000 | 1 | 0–1000 | 2 |

**Table 5**
Suitability index for elevation variable used in the wild sheep habitat suitability index model.

| Group | Elevation | Suitability index | Percentage of presence points (%) |
|---|---|---|---|
| 1 | 1700–1900 | 0.5 | 19 |
| 2 | 1900–2100 | 0.75 | 30 |
| 3 | 2100–2300 | 1 | 42 |
| 4 | 2300–2500 | 0.25 | 9 |
| 5 | >2500 | 0 | 0 |

**Table 6**
Habitat suitability index verbal equivalency.

| Suitability index | Verbal equivalent |
|---|---|
| 0–0.2 | Very poor |
| 0.2–0.4 | Poor |
| 0.4–0.6 | Average |
| 0.6–0.8 | Good |
| 0.8–1 | Excellent |

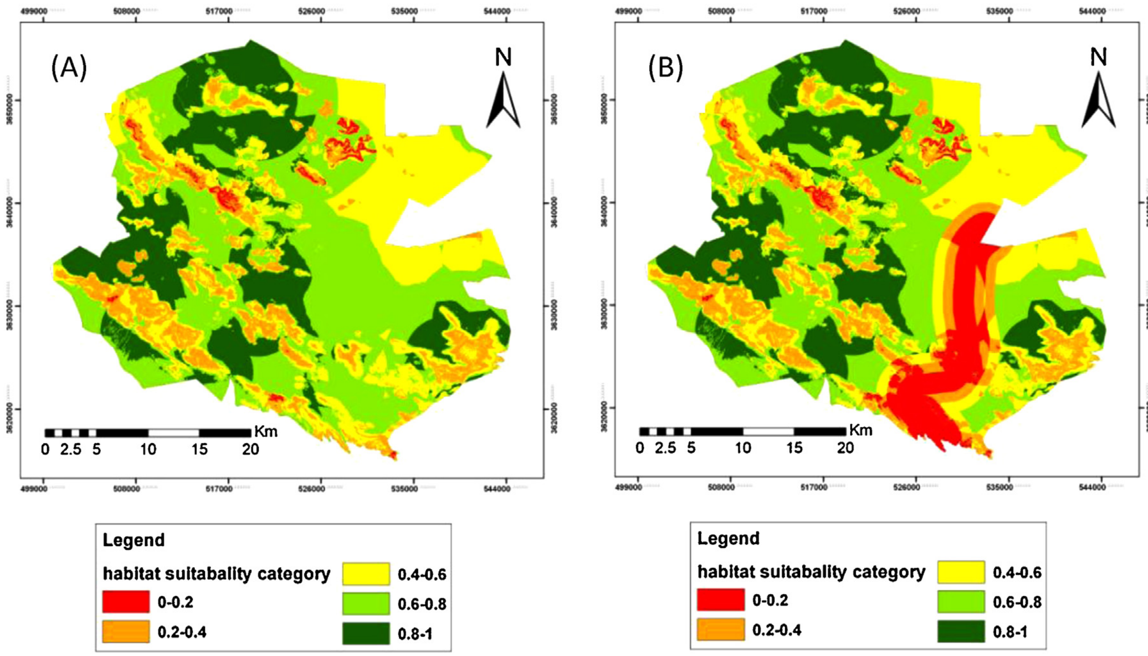


**Fig. 4.** Final habitat suitability map for *Ovis orientalis isphahanica*: (A) before freeway construction, (B) after freeway construction.

values of contagion may result from landscapes with a few large, contiguous patches, thus, a landscape in which the patch types are aggregated into larger, contiguous patches will have greater contagion than a landscape in which the patch types are fragmented into many small patches.

The difference between the landscape parameters revealed the increasing distance between available habitat patches, the additive barrier of roads, limit dispersal possibilities of species and decrease landscape connectivity in the study area. For instance, the increase of 43% in MNN for wild sheep indicated stronger isolation in this species than in goitered gazelle where MNN only increased about 7%. Comparison of the species distribution polygons before and after freeway construction reveals that after freeway construction goitered gazelle and wild sheep could not use 13% and 31% of their habitat any longer (Figs. 5 and 6).

## 4. Discussion and conclusion

We examined the impact of a freeway passing through Ghamishloo Wildlife Refuge on habitat integrity for *G. subgutturosa* and *O. orientalis isphahanica*. Our results demonstrate that the freeway not only reduced the area of the original habitat in the refuge for the two vulnerable ungulate species (Figs. 5 and 6) but also further represents a barrier and restricts gene flow between remaining habitat patches. Remaining habitat patches now represent islands in terms of limited area, isolation and distance from each other (Fahrig, 2003). In addition to the physical occupation of land use and maintenance of the road caused disturbance and thus further reduced the quality of the remaining habitat (Tables 7 and 8). This affected the spatial distribution of the two large herbivore species in the study area. Figs. 5B and 6B show that the nearest distance

**Table 7**
Comparison of each HSI category area for *Gazella subgutturosa* before and after freeway construction.

| Category | Before freeway area (ha) | After freeway area (ha) | Difference between two situations (before & after freeway) |
|---|---|---|---|
| Very poor | 29,821 | 37,798 | +7977 |
| Poor | 13,720 | 15,133 | +1413 |
| Average | 38,158 | 35,217 | −2941 |
| Good | 23,229 | 17,487 | −5742 |
| Excellent | 8475 | 7768 | −707 |

**Table 8**
Comparison of each HSI category for *Ovis orientalis* before and after road construction.

| Category | Before freeway area (ha) | After freeway area (ha) | Difference between two situations (before & after freeway) |
|---|---|---|---|
| Very poor | 982 | 9469 | +8487 |
| Poor | 13,178 | 17,123 | +3945 |
| Average | 30,054 | 27,814 | −2240 |
| Good | 44,521 | 34,659 | −9862 |
| Excellent | 24,667 | 24,338 | −329 |

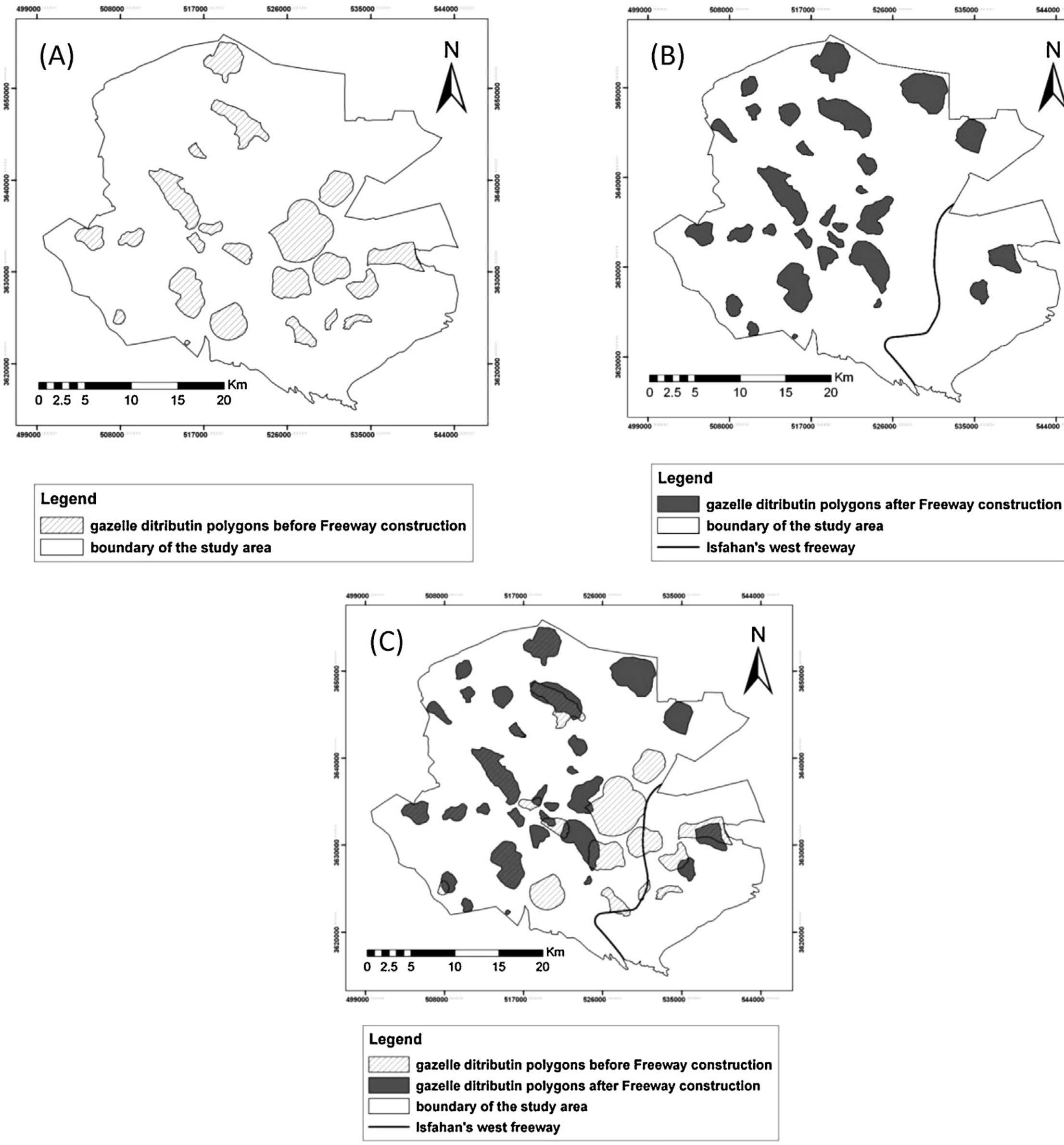


**Fig. 5.** Distribution polygons of *Gazella subgutturosa* in Ghamishloo Wildlife Refuge: (A) before freeway construction, (B) after freeway construction, (C) both (A) and (B).

between occupied polygons on two sides of the freeway increased to 9 km for goitered gazelle and 7 km for wild sheep. Due to disturbance from the freeway (Figs. 5B and 6B) goitered gazelle and wild sheep could not use 13 and 31%, respectively, of their former habitat any longer.

In general, the results of HEP showed that the goitered gazelle lost more habitat units than the wild sheep. Therefore the goitered gazelle is more vulnerable to the effects of highway than the wild sheep. These effects are aggravated particularly for gazelles because during the critical seasons when water or food availability is insufficient within the protected area, they have to roam into surrounding unprotected areas.

The underlying problem of landscape-scale ecological impact assessment studies is that road impacts show a lagged response because the different effects of roads on wildlife populations occur at different time scales (Forman et al., 2002). Habitat loss is the immediate effect. The results obtained in the present work show a large scale deterioration of habitat quality after the construction of the freeway. 6449 ha of good and excellent habitats for goitered gazelle and also 10,191 ha for wild sheep were lost (Tables 7 and 8). On the other hand, very poor and poor habitats for goitered gazelle and wild sheep increased by 9390 ha and 12,432 ha, respectively. Thus for goitered gazelle only 25,255 ha or 79.6% of the originally good/excellent habitat remained, and for wild sheep this figure was 58,997 ha or 85%.

Isolation of the south-eastern part of the wildlife refuge by the freeway, increasing accessibility from every side and shrinking and disappearing habitat patches for both species (Figs. 5 and 6) demonstrated that this part of the wildlife refuge, could no longer be used by wildlife after the construction of the freeway. As a matter of fact, 22,561 ha were lost. So 11,209 HUs for goitered gazelle and 13,682

**Table 9**
Area of Habitat suitability categories for *Gazella subgutturosa* and *Ovis orientalis*.

| Suitability category | Gazelle habitat area (ha) | *Ovis* habitat area (ha) |
|---|---|---|
| 0–0.2 | 5306 | 21 |
| 0.2–0.4 | 3007 | 2241 |
| 0.4–0.6 | 4171 | 7659 |
| 0.6–0.8 | 5914 | 10,012 |
| 0.8–1 | 3944 | 2409 |

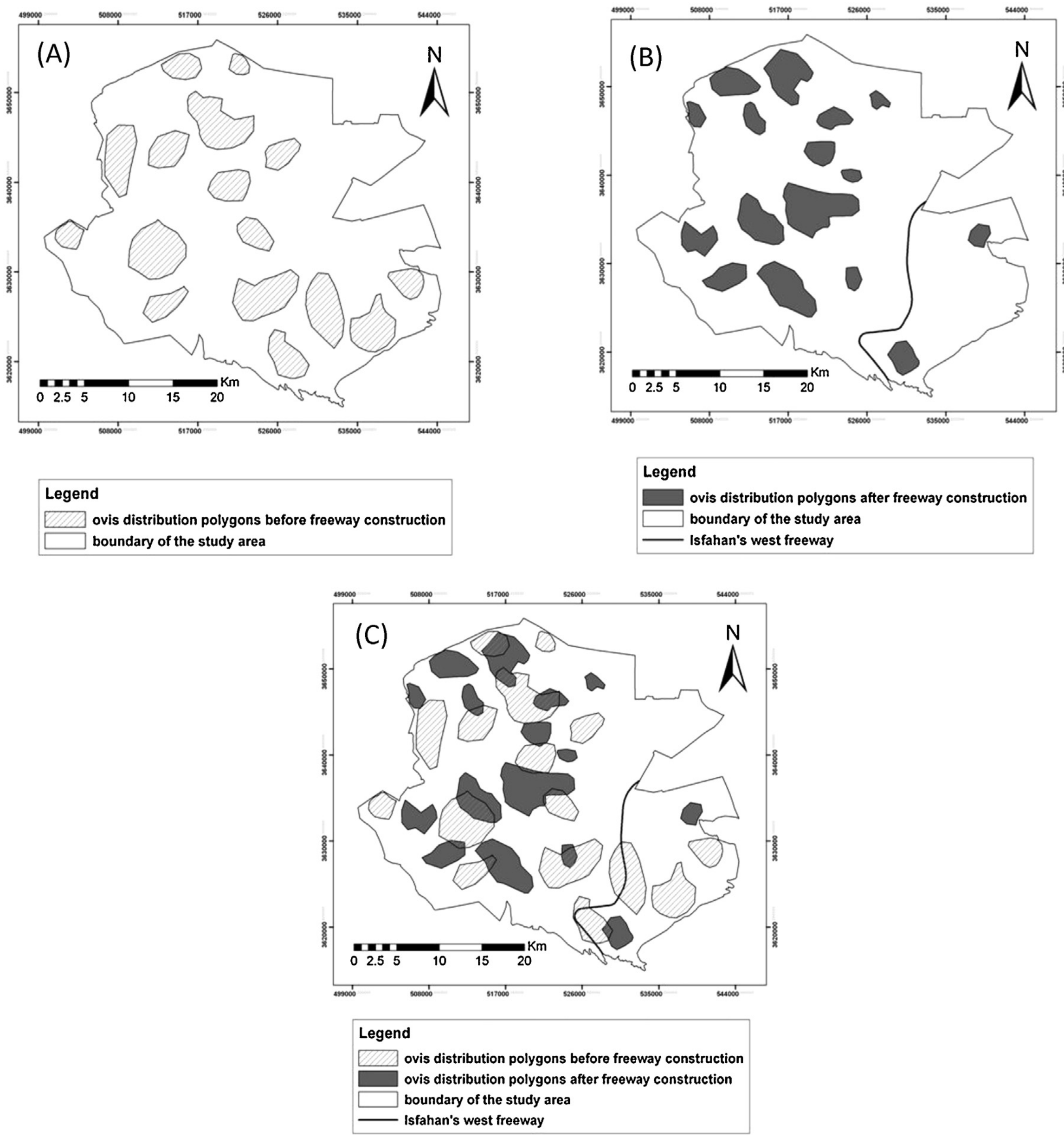


**Fig. 6.** Distribution polygons of *Ovis orientalis isphahanica* in Ghamishloo Wildlife Refuge: (A) before freeway construction, (B) after freeway construction, (C) both (A) and (B).

HUs for wild sheep became unusable. In the case of goitered gazelle, 3,944 ha of its potentially best habitat (of a total of 7768 ha) lies east of freeway (Table 9). Thus 51% of the high quality habitat for this species became unavailable through the construction of the road. For wild sheep this figure is 10% or 2409 ha.

Further the road increased the accessibility of wildlife habitat (Figs. 5 and 6) to poachers and livestock. The movement of domestic livestock and their keepers with motorbikes and vehicles make the habitat insecure for wildlife (M. Farahmand and Z. Taki, pers. comm.). In addition to this the livestock keepers may also be the potential poachers, particularly in wild sheep habitat which mainly consists of rolling hills and mountains. According to Bashari and Hemami (submitted for publication) accessibility to human interference, particularly poaching, is a crucial determinant for habitat suitability for wild sheep.

The effects of roads as barriers, reducing landscape connectivity, will likely take several decades to become fully visible (Findlay and Bourdages, 2000). Kuehn et al. (2007) already demonstrated genetic effects of transportation infrastructure in a widespread ungulate species at an intermediate time scale. Further research will have to figure out the long term impacts of freeways on wildlife populations and determine its effects on genetic diversity.

Maleki Najafabadi et al. (2010) found that availability of vegetation as food, topography and distance to water were the main factors determining habitat suitability for wild sheep in Mooteh Wildlife Refuge. Some studies, however, did not consider roads as a crucial factor for habitat suitability (Pahlevani, 2004). Our study revealed negative effects of the freeway on accessibility of high-quality habitat patches (Figs. 5 and 6) in Ghamishloo Wildlife Refuge for wild sheep and goitered gazelles and thus presents a conservation concern for these vulnerable species. According to our results, mitigation and compensation activities should be considered in Ghamishloo Wildlife Refuge. In accordance with the HU formula (area × HSI), road impacts on wildlife population might be mitigated by securing high quality but not yet protected habitat along the northern and western border of the wildlife reserve.

Our study demonstrated that HEP method combined with quantifying landscape metrics may provide a powerful tool for assessing ecological impact of technical infrastructures on wildlife populations and thus allow retrospective assessment for a region-wide management of far-ranging wildlife species with of conservation concern.

## Acknowledgements

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