Environmental Impact Assessment Review 65 (2017) 147–155

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

journal homepage: www.elsevier.com/locate/eiar

Degradation of natural habitats by roads: Comparing land-take and noise effect zone

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ARTICLE INFO

Keywords:
Wildlife habitat
Habitat fragmentation
Habitat loss
Noise propagation
Effect zone
Road ecology

ABSTRACT

Roads may act as barriers, negatively influencing the movement of animals, thereby causing disruption in landscapes. Roads cause habitat loss and fragmentation not only through their physical occupation, but also through traffic noise. The aim of this study is to provide a method to quantify the habitat degradation including habitat loss and fragmentation due to road traffic noise and to compare it with those of road land-take. Two types of fragmentation effects are determined: structural fragmentation (based on road land-take only), and functional fragmentation (noise effect zone fragmentation, buffer using a threshold of 40 dB). Noise propagation for roads with a traffic volume of more than 1000 vehicles per day was simulated by Calculation of Road Traffic Noise (CRTN) model. Habitat loss and fragmentation through land-take and noise effect zone were calculated and compared in Zagros Mountains in western Iran. The study area is characterized by three main habitat types (oak forest, scattered woodland and temperate grassland) which host endangered and protected wildlife species. Due to topographic conditions, land cover type, and the traffic volume in the region, the noise effect zone ranged from 50 to 2000 m which covers 18.3% (i.e. 516,929.95 ha) of the total study area. The results showed that the habitat loss due to noise effect zone is dramatically higher than that due to road land-take only (35% versus 1.04% of the total area). Temperate grasslands lost the highest proportion of the original area by both land-take and noise effect zone, but most area was lost in scattered woodland as compared to the other two habitat types. The results showed that considering the noise effect zone for habitat fragmentation resulted in an increase of 25.8% of the area affected (316,810 ha) as compared to using the land-take only (555,874 ha vs. 239,064 ha, respectively). The results revealed that the degree of habitat fragmentation is increasing by considering the noise effect zone. We conclude that, although the roads are breaking apart the patches by land-take, road noise not only dissects habitat patches but takes much larger proportions of or even functionally eliminates entire patches.

1. Introduction

Transportation infrastructures represent a major driver for loss and fragmentation of natural habitat for wildlife species (Geneletti, 2003; Bruschi et al., 2015). Since the mid-1990s, while these linear infrastructures significantly grew, their ecological impacts have received increasing attention (Jaeger et al., 2007; Parris and Schneider, 2009). According to Jaeger et al. (2005), linear infrastructures affect wildlife populations in four different ways. Roads may reduce habitat area and quality, increase wildlife mortality due to collisions with vehicles, prevent accessibility to resources on the other side of the roads and thus subdivide wildlife population. Therefore, roads gradually deteriorate the quality of habitats on their both sides (Fischer and Lindenmayer, 2007). Habitat degradation by roads includes two aspects. First the habitat loss caused due to the land physically occupied by the road, (Geneletti, 2003; Geneletti, 2006), and the land on both sides of the road affected by nuisances, such as traffic noise above a species specific threshold causing the wildlife to avoid this land (Forman and Deblinger, 2000; Boarman and Sazaki, 2006; Liu et al., 2008; Eigenbrod et al., 2009; Shanley and Pyare, 2011). Second, the habitat fragmentation (Wilcove et al., 1986). Similarly, to habitat loss, habitat fragmentation by roads is occurring in two extents: loss in structural

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http://dx.doi.org/10.1016/j.eiar.2017.05.003
Received 17 October 2016; Received in revised form 9 May 2017; Accepted 11 May 2017

connectivity due to road construction and reducing and severance of larger habitat patches (structural habitat fragmentation), and loss in functional connectivity of meta-populations due to traffic noise and other nuisances deterring wildlife from the vicinity of roads (functional habitat fragmentation) (Fahrig and Rytwinski, 2009).

Several studies on the negative ecological effects of roads and other linear infrastructures focused on the fragmentation due to land-take (Bruschi et al., 2015; van der Ree et al., 2011; Liu et al., 2008; Fahrig and Rytwinski, 2009). Others focused on the road effect zone due to noise pollution (Reijnen et al., 1995; Forman, 2000; Jaeger et al., 2005; Fahrig and Rytwinski, 2009). The type and intensity of the habitat degradation depend on road avoidance behavior and sensitivity of wildlife species to road impacts, road size, and traffic volume (Jaeger et al., 2005). The noise effect zone may range from a few tens to hundreds of meters (Geneletti, 2003). The “road effect zone” was first analyzed by Reijnen in the Netherlands based on the study on the composition of bird communities in forests and agricultural grassland in areas affected by roads (Reijnen et al., 1995). Traffic noise was frequently found to be the major factor defining the road effect zone (Forman, 2000; Forman and Deblinger, 2000; Parris and Schneider, 2009; Eigenbrod et al., 2009; Boarman and Sazaki, 2006; Liu et al., 2008). Shannon et al. (2015) reviewed 242 peer-reviewed articles published between 1990 and 2013 on the effects of noise on wildlife and concluded that terrestrial wildlife starts to respond begin at noise levels of approximately 40 dB.

Generally, roads facilitate the accessibility for poachers to wildlife habitats. Thus, in contrast to most countries in western Europe and North America, in countries with prevailing illegal hunting, wild animals relate car noise from roads to poachers and thus avoid the vicinity of roads (Bashari and Hemami, 2013). Therefore, extensive areas on both sides of the road are functionally lost as grazing habitat for species targeted by poachers, such as ungulates, and road crossing becomes extremely rare.

In the present study, we examine the habitat degradation through habitat loss and fragmentation due to the road networks in the three habitats types within the Irano-Anatolian Biodiversity Hotspot in Lorestan province, Iran.

In particular, this study seeks to answer the following questions: 1) How much habitat was lost due to road land-take, i.e. the area occupied by the road, vs. the noise effect zone, the area affected by car noise on both sides of the road? 2) What is the degree of habitat fragmentation caused by the roads land-take? 2) How does the noise effect zone change the degree of habitat fragmentation? 3) How does the degree of fragmentation differ among the different habitat types, such as oak forests, scattered woodlands, and temperate grasslands?

2. Materials and methods

To define and quantify the habitat loss and fragmentation caused by land-take and noise effect zone of roads, noise propagation of the road network in Lorestan Province was simulated. The population size of the province was estimated at 1,754,243 people in 2011 (Statistical Center of Iran, 2011). There are 23 urban areas as well as 3000 villages which are connected by 214 km of highways, 1203 km primary roads, 1044 km secondary roads, and 4900 km of rural roads. The total area of the province is 28,294 km^2, characterized by three main habitat types: oak forest, scattered woodland, and temperate grassland (Fig. 1). Oak forest habitat is the area covered dominantly by Persian oak trees (*Quercus brantii*) with a canopy density of 50–75%. The clearly distinct scattered woodland habitat consists of scattered trees and various shrubs of variable size. The temperate grassland habitat consists of several grass species, herbs and dwarf shrubs and represents the most valuable grazing grounds for wild ungulates in the region.

2.1. Noise effect zone modeling

Based on the literature, the roads with a volume of higher than 1000 vehicles per day were considered in this study as they act as significant barriers and sources of mortality for many species (Helldin et al., 2010; Seiler, 2005; Hels and Buchwald, 2001).

Data on traffic volume of Lorestan Province for 2014 were provided by the National Road Maintenance and Transport Organization (Iran Road Maintenance and Transportation Organization, 2014). To estimate traffic noise, we used the model Calculation of Road Traffic Noise (CRTN) (Tang and Wang, 2007; Attenborough et al., 2006: Li et al., 2003; Department of Transport Welsh Office, 1988), which is widespread and easy to apply in a GIS environment.

Calculation of road traffic noise was the next step. Any road in a road network has different noise levels due to different traffic volumes. Each road segment acts as a separate noise source. Noise propagation for the entire road network is predicted by combining noise propagations of all individual segments. Accordingly, the anticipated one-hour noise level for each point within the road network was calculated using Eq. (1) (Attenborough et al., 2006).

$$L_{10,i} = L_{Basic,i} + \Delta L_{pV.i} + \Delta L_{q.i} + \Delta L_{G,i} + \Delta L_{D,i} + \Delta L_{GC,i} + \Delta L_{Sh,I} + \Delta L_{sg,i} \quad (1)$$

where L_{Basic} is the basic hourly noise level; $\Delta L_{pV.i}$ is the mean traffic speed adjustment; $\Delta L_{q.i}$ is the traffic flow adjustment; $\Delta L_{G,i}$ is the gradient adjustment; $\Delta L_{D,i}$ is the distance adjustment; $\Delta L_{GC,i}$ is the ground cover adjustment; $\Delta L_{Sh,i}$ is the shielding adjustment and $\Delta L_{sg,i}$ is an adjustment for finite length of road segment (all units in Eq. (1) are in the decibel (dB)). According to the national standard of noise in Iran, expressed in terms of L_{eq}, the noise level simulated by CRTN (L_{10}) was converted to L_{eq} as described in (Abbott and Nelson, 2002).

For road schemes consisting of more than one segment, the predicted level at the reception point was calculated by combining the basic hourly levels predicted for *N* segments using Eq. (2) (Attenborough et al., 2006; Li et al., 2002; Department of Transport Welsh Office, 1988):

$$L_{eq}^{tot} = 10 \log_{10} (\Sigma_{i=1}^{N} 10^{L_{eqj/10}}) \quad (2)$$

where,

$L_{eq}{}^{tot}$: the sound level for the road network

$L_{eq}j$: the sound level for jth road segment

N: number of road segments in the road network

The noise propagation was simulated using open source QGIS software (QGIS Development Team, 2015).

2.2. Habitat loss

Habitat loss was quantified in two extents: habitat loss due to the land-take (physical habitat loss), and habitat loss due to noise effect zone (functional habitat loss) (Fig. 2). Physical habitat loss is based on the road network width multiplying by road network length. However, functional habitat loss is based on the proportion of habitat patches located within the 40 dB limits on both sides of the roads. Functional habitat loss may include complete loss of original habitat patches if they were situated with the 40 dB threshold or partial loss if the habitat patches extended beyond that threshold. The different patch types (see Fig. 2) were analyzed and quantified separately.

2.3. Habitat fragmentation

Habitat fragmentation caused by linear transport infrastructure can be measured by the infrastructure fragmentation index (IFI) (De Montis et al., 2017; Bruschi et al., 2015; Sangiorgi and Irali, 2012; Geneletti and Dawa, 2009; Zucca et al., 2008; Romano, 2002; Di Ludovico and Romano, 2000). In terms of fragmentation of wildlife habitats, IFI is

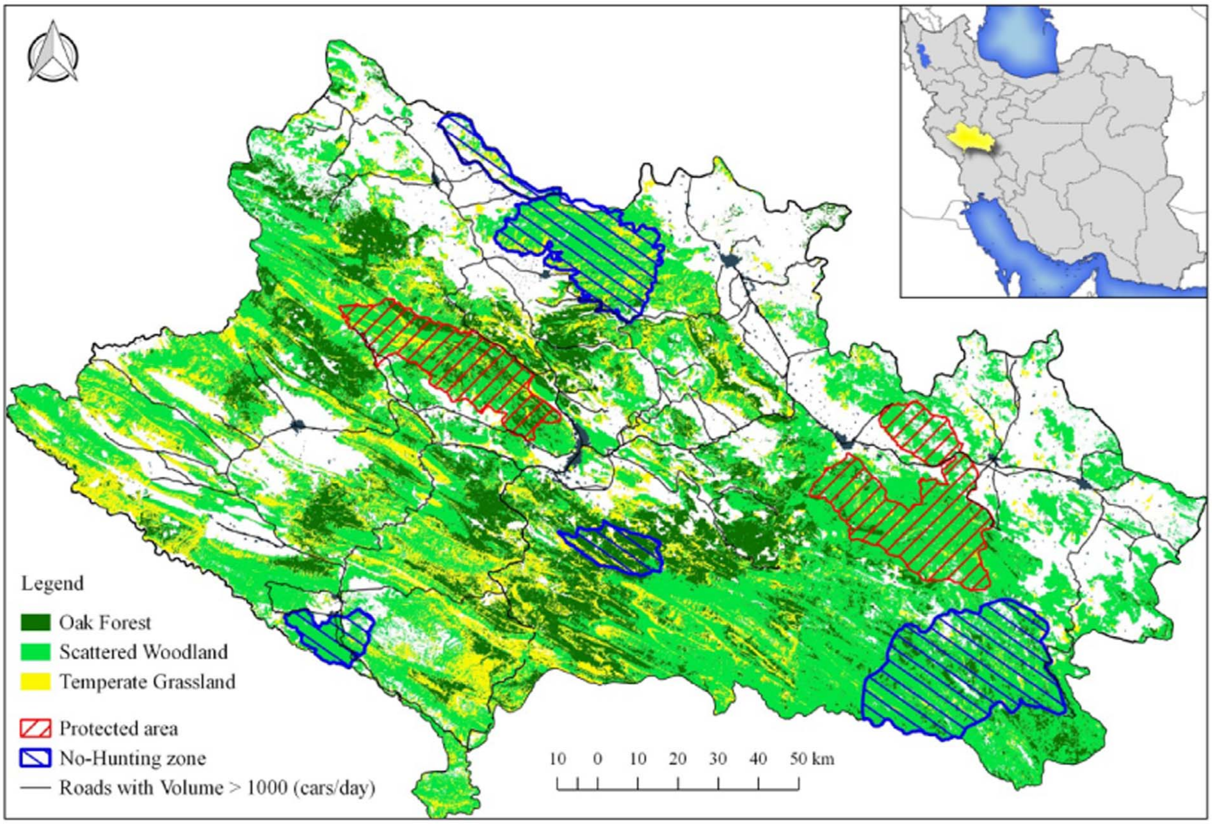

Fig. 1. Map of Lorestan Province with its location in Iran, the three habitat types, the protected areas, and the network of major roads.

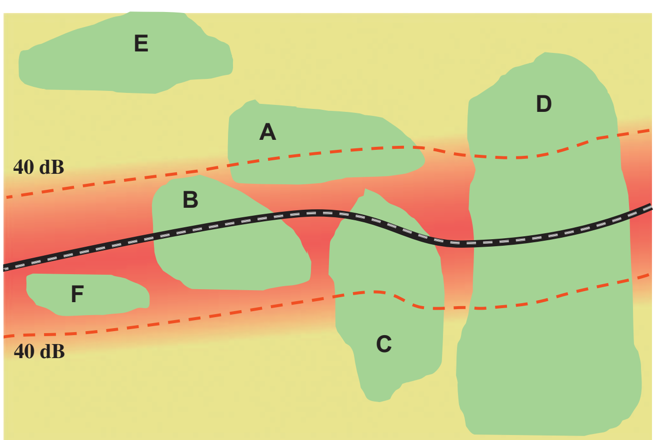

Fig. 2. The concept for structural and functional habitat degradation as used in this study. The original habitat patches are indicated in green within the yellow matrix. The road is shown in black, the noise effect zone in red, and the dotted lines indicate the threshold for noise affecting wildlife. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

used to calculate the level of habitat vulnerability (Romano, 2002; Geneletti and Dawa, 2009). The fragmentation level caused by roads (structural fragmentation) or by 40 dB noise level line (functional fragmentation) in each habitat patch can be calculated using Eq. (3).

$$FI = \frac{(\sum_{i=1}^{i=n} L_i * O_i) * N * Pt}{At} \quad (3)$$

where L_i: length of the i-th road infrastructure or noise level threshold line of 40 dB (meter); O_i: occlusion coefficient of the i-th infrastructure, depending on the type of infrastructure and traffic flow; N: number of shares in which the territorial unit is fragmented by the set of infrastructures; Pt: territorial unit perimeter (m); At: territorial unit area (m^2). IFI obtained from Eq. (3) is a dimensionless number. The barrier coefficient (O_i) of any road is a function of its physical characteristics and its traffic volume (Romano, 2002; Geneletti and Dawa, 2009). The simplified form of calculating the barrier coefficient can be found in ($O_i = n/60$) where n is the number of vehicles per hour. This relation shows that if the traffic volume is equal to or > 60 vehicles per hour, road traffic acts like a fence and completely blocks the road (Romano, 2002; Biondi et al., 2003). The maximum value of O_i is equal to 1. Freeways and highways with broader width, continuous fences, higher traffic volumes and continuous traffic flows have a poor permeability for wildlife populations. In contrast, secondary and local roads with narrower width, lower traffic volumes and discontinues traffic flows show a higher permeability (Bruschi et al., 2015). For traffic volume of > 1000 vehicles per day the minimum barrier coefficient is equal to 0.69 based on the traffic volume per hour which is used for this study.

The region in which IFIs were computed was limited to the potential road effect distance. For this, we took the 5 km as the road effect distance. As Benítez-López et al. (2010) stated this can be up to 1 km and 5 km for birds and mammals, respectively.

To solve the problem a hexagonal grid was used, which for ecological studies is more suitable than a rectangular grid (Birch et al., 2007). Therefore, the study area was divided into hexagonal grids with 5 km from the grid center to the middle of each side of the hexagonal. In this case, the area of each hexagonal is 86.6 km^2. As a result, the entire Lorestan province was divided into 327 hexagonal grids. The degree of fragmentation was calculated for each patch within each hexagonal using Eq. (4), (Bruschi et al., 2015). Then, based on the normalized functional fragmentation, quantiles were assigned to the five qualitative fragmentation classes very low, low, moderate, high and very high.

$$IFI_N \frac{\sum_{i=1}^{i=n} V_i * S_i}{\sum_{i=1}^{i=n} S_i} \quad (4)$$

where,

IFI_N: normalized degree of habitat fragmentation of each hexagonal

V_i: degree of habitat fragmentation of the i-th hexagonal

S_i: area of each patch within the i-th hexagonal

Values of IFI_N were classified within 5 classes as:

a) Very low: lower or equal to the 20th quantile

b) Low: higher than the 20th quantile and lower than the 40th quantile

c) Moderate: higher than the 40th quantile and lower than the 60th quantile

d) High: higher than the 60th quantile and lower than the 80th quantile

e) Very high: higher than 80th quantile

2.4. Comparing structural versus functional habitat fragmentation

We calculated the degree of fragmentation caused by land-take only, and by the noise effect area using Eq. (3), and then compared the results. The map resulting from the differences between these degrees of fragmentation shows the areas that are most affected by the traffic noise rather than the physical structure of the road and vice versa. To do this, first the land-take and noise effect zone fragmentation values were normalized using Eq. (5) and then, their difference was obtained using Eq. (6).

$$NIFI_i = [X_i - (Ns\text{-}IFI)_{min}]/[(Ns\text{-}IFI)_{max} - (Ns\text{-}IFI)_{min}] \quad (5)$$

where, $NIFI_i$ is the normalized degree of habitat fragmentation (land-take or noise effect zone), X_i is degree of habitat fragmentation (land-take or noise effect zone), and $(Ns\text{-}IFI)_{max}$ is the maximum of degree of habitat fragmentation caused by noise effect zone.

$$ND = \log(NIFI_i)_f - (NIFI_i)_s \quad (6)$$

where, ND is the normalized difference of the habitat fragmentation for each patch, $(NIFI_i)$ is the normalized noise effect zone habitat fragmentation for each patch, and $(NIFI_j)$ is the normalized land-take habitat fragmentation for each patch.

3. Results

3.1. Noise effect zone

Fig. 3 shows the traffic noise propagation in the road network of Lorestan province. Evidently, the road noise footprint is spatially heterogeneous. In areas with a higher road density, traffic noise level is higher and the road effect zone broader. Furthermore, high traffic volume caused a broader road effect zone, depending on the topography and land cover. Different habitat types with their species were affected differently by traffic noise. Fig. 4 shows the percentage of different habitat types within 5 km distance from the road affected by the traffic noise.

Our results revealed that 18.3% (i.e. 516,929.95 ha) of the total study area is affected by a traffic noise higher than 40 dB. Scattered woodland was affected most by road traffic noise (Fig. 4). This is because of the dominance of scattered woodland as compared to the other habitat types. In the noise level of 40 to 50 dB, scattered woodland with 90,462.7 ha (17.5%) and oak forests with 25,846.5 ha (5%) had the biggest and smallest area affected. The extent of the highest noise level (> 60 dB) was lowest in oak forest (1% or 4910 ha).

3.2. Habitat loss

Table 1 shows the area of structural and functional habitat loss for the three different habitat types. The results showed that the habitat loss due to noise effect zone is dramatically higher than that due to road land-take only (35% versus 1.04% of the total area). Temperate grasslands lost the highest proportion of the original area by land-take and noise effect zone. However, the area of the three habitat types, and also, the length of the roads within them are different. Thus, most area was lost in scattered woodland as compared to the other two habitat types.

Table 1 shows the different types of habitat loss caused by land-take and road noise effect zone. In the study area, habitat loss (habitat reduction) of type A patches (affected by the noise effect zone but not land-take, see Fig. 2), are mostly in scattered woodlands. Type D patches are largest in temperate grassland, and type F patches are smallest in scattered woodlands.

The results further indicate that type D patches in temperate grasslands are most heavily affected by noise effect zone as their size decreased from an original range of about 1400–22,000 ha to a present range of about 84–622 ha.

3.3. Habitat fragmentation

Fig. 5 and Fig. 6 show the degree of habitat fragmentations due to land-take and noise effect zone in natural areas of Lorestan province, respectively. The habitat areas that were not affected by any of the two conditions got a zero value and are shown in light green.

The results show that considering the noise effect zone for habitat fragmentation resulted in an increase of 25.8% of the area affected (316,810 ha) as compared to using the land-take only (555,874 ha vs. 239,064 ha, respectively).

3.4. Structural versus functional habitat fragmentation

Table 2 indicates the total areas and the proportions affected by of land-take versus noise effect zones within the five different classes of habitat fragmentation. Considering the effect of land-take, 95,757 ha are fragmented at very low and low degrees and 143,307 ha at medium to very high degrees. Considering the noise effect zone 105,248 ha are in lower degree classes, but 450,626 ha are in medium to very high degrees of fragmentation. The results showed that the proportion of habitat affected in the study area by the road noise effect zone is much higher than road land-take (45.2% versus 19.4%).

Fig. 7 shows the degree of fragmentation in the three habitat types for the five classes of fragmentation. The results revealed that the degree of habitat fragmentation is increasing by considering the noise effect zone. The natural habitats were affected relatively little and similarly by both land-take and noise effect zone in the very low to medium classes. In contrast to that, the amount of fragmented habitats due to noise effect zone, especially in scattered woodlands (Fig. 7b), increased dramatically in the higher classes as compared to the land-take.

Fig. 8 shows the spatial distribution of differences between degree of fragmentation due to noise effect zone and land-take. The results indicate that natural habitats were affected significantly further by traffic noise than by land-take. The results further indicated that traffic volume in combination with topography, land cover type, and road network density are leading to much higher fragmentation than road land-take alone.

4. Discussion

Traffic noise modeling is an effective tool to quantify the amount of habitats functionally lost for wildlife due to noise from roads. However, functional habitat loss is depending on the species sensitivity to noise, habitat type, and topography (Reijnen et al., 1995; Forman et al., 2002; Eigenbrod et al., 2009). According to our results, 35.3% of the natural areas in Lorestan Province are facing functional habitat loss due to road traffic noise. Although, the roads are breaking apart the patches by

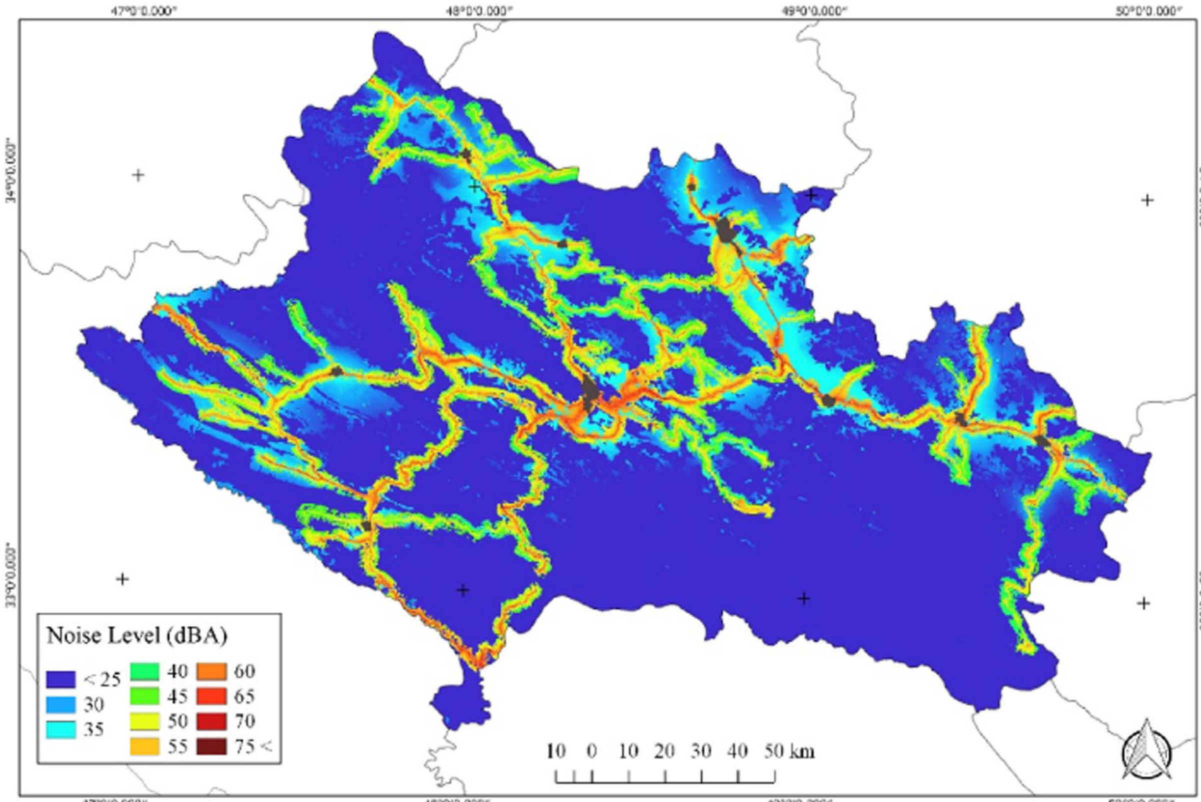

Fig. 3. Propagation of noise due to road traffic, topography and land cover for roads with > 1000 vehicles per day.

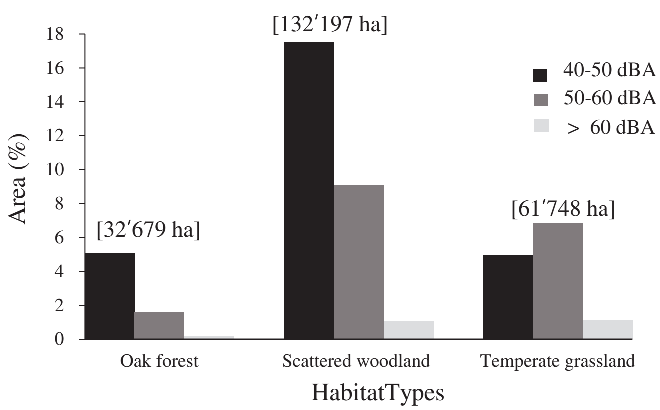

Fig. 4. The three habitat types affected by the three traffic noise levels.

Table 1
The area of structural and functional habitat loss for different habitat types.

Habitat loss type	Habitat type	Habitat loss (ha)	Habitat loss (%)
Structural habitat loss	Oak forest	953.5	0.22
	Scattered woodland	2574.2	0.22
	Temperate grassland	2101.2	0.60
Total structural habitat loss		5628.9	1.04
Functional habitat loss	Oak forest	31,398.8	7.2
	Scattered woodland	132,910.2	11.5
	Temperate grassland	58,542.3	16.6
Total functional habitat loss		222,851.3	35.3

land-take, road noise not only dissects habitat patches but takes much larger proportions of or even functionally eliminates entire patches (Fig. 2). Whereas, the proportion of habitat affected by land-take was 19.4% functional habitat fragmentation amounted to 45.2%.

Low but continuous noise will significantly change habitat conditions and may trigger biological responses and physiological stress in residing wildlife (Shannon et al., 2015). Therefore, knowing the width of the road effect zone can be a key element for effective wildlife conservation. Due to the topographic conditions and the traffic volume in our study region, the road effect zone ranges from 50 to 2000 m based on a noise level threshold of 40 dB (Fig. 3). The width of the road effect zone for birds in the Netherlands ranged between 40 and 1500 m depending on the bird species and the volume of road traffic (Reijnen et al., 1995).

Previous studies (Nega et al., 2013; Helldin et al., 2013; Parris and Schneider, 2009; Jaeger et al., 2007; Reijnen et al., 1995) used noise propagation modeling to calculate the proportion of habitat loss and compared losses in different habitat types and for different species. In this study we used noise propagation modeling to estimate both habitat loss and degree of fragmentation.

Our results are based on 40 dB as the general noise threshold for wildlife (Shannon et al., 2015). However, different noise thresholds depending on the species and the habitat type were used in other studies. Nega et al. (2013) estimated that 37% of the protected areas were affected by the traffic in the Twin Cities Metro Region (TCMR) in Minnesota by using 50 dBA noise threshold. But Helldin et al. (2013) found that 13.5% of all Important Bird Sites (Grimmett and Jones, 1989) were negatively affected by traffic noise in West Götland, Sweden, when applying a 45 dBA noise effect zone. Similarly, Reijnen and Foppen (2006) estimated the noise effect zone affecting 19% of bird habitat area in Netherlands when using a 42 dBA threshold. Several studies (Helldin et al., 2013; Parris and Schneider, 2009; Jaeger et al., 2007; Reijnen et al., 1995), however, only considered traffic volume and cars speed to estimate the noise effect zone, but not topography or

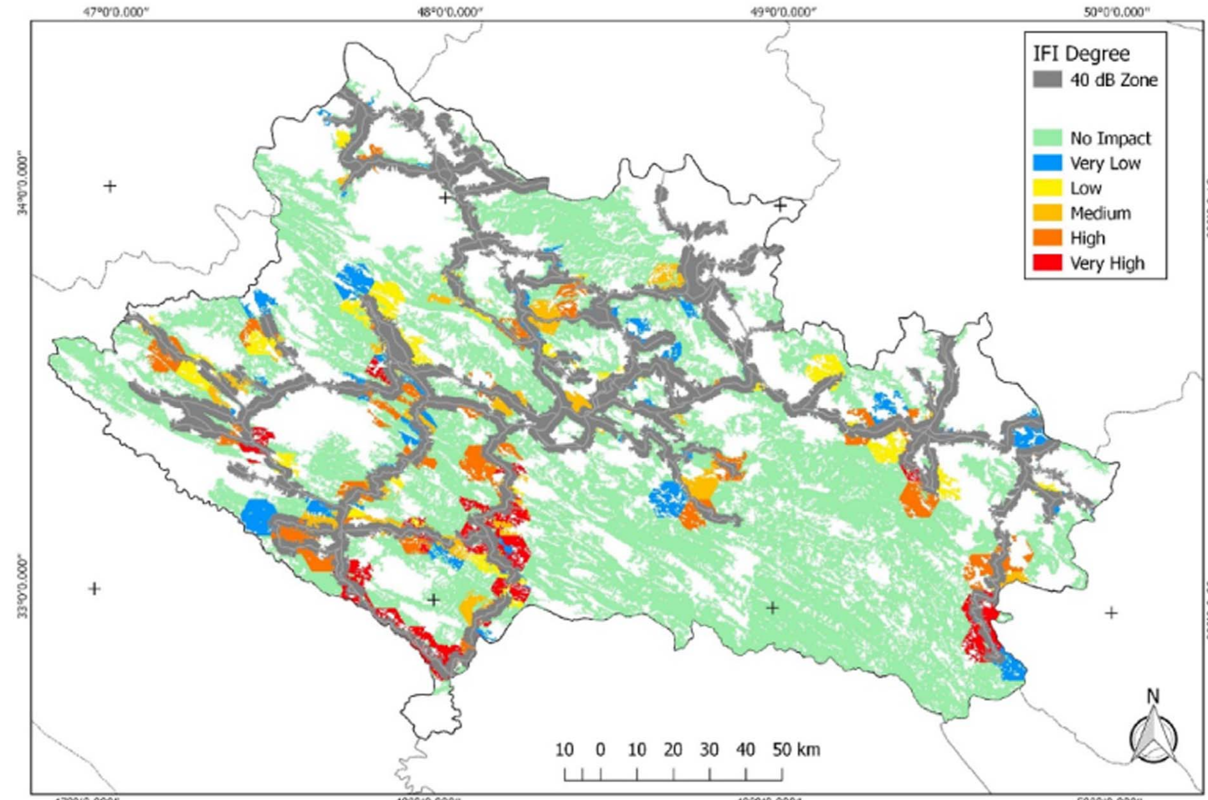

Fig. 5. Degree of habitat fragmentation due to road land-take. The white color within the study area indicates agricultural land or developed areas.

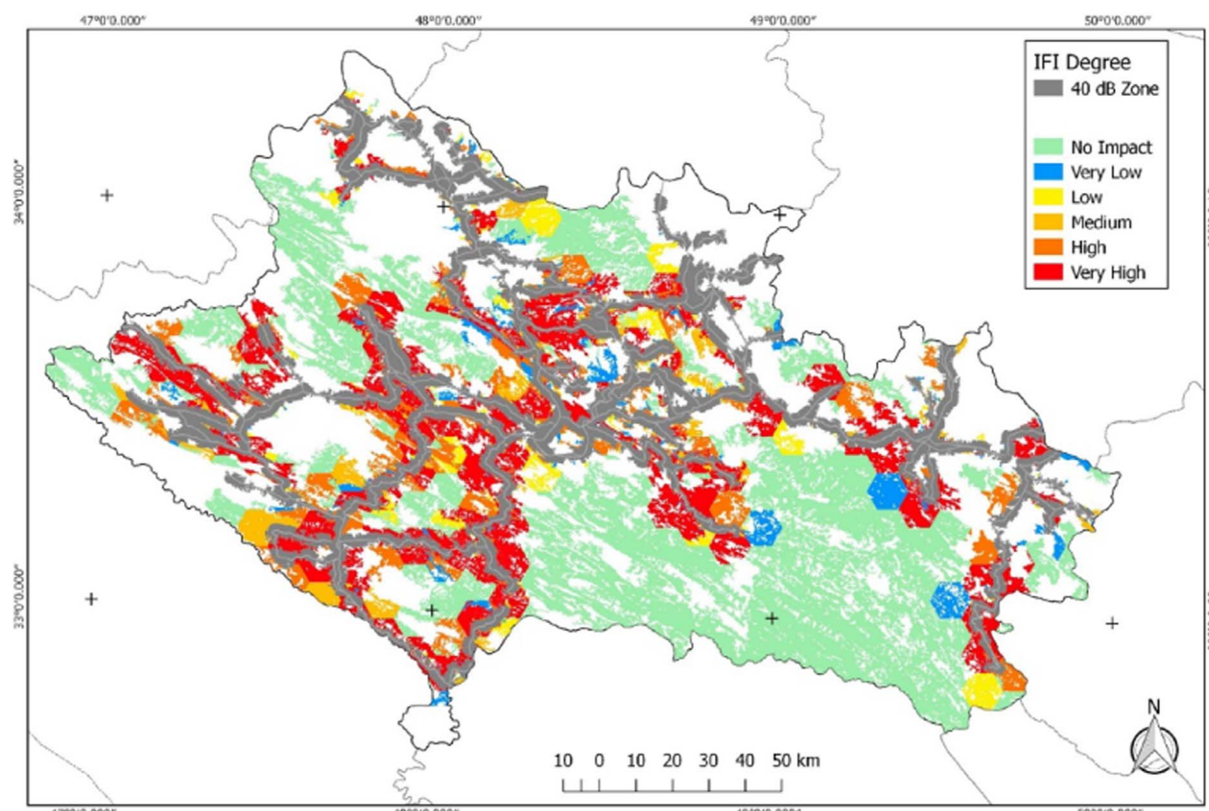

Fig. 6. Degree of habitat fragmentation due to road noise effect zone. The white color within the study area indicates agricultural land or developed areas.

Table 2
Number of patches (PN), mean patch size (MPS), and the mean patch size of the habitat remnants (RMPS).

	Habitat type	PN	MPS (ha)	Remnant MPS (ha)	ΔMPS
A	Oak forest	239	334.19	71.30	262.9
	Scattered woodland	443	122.03	26.60	95.4
	Temperate grassland	391	252.70	49.73	203.0
B	Oak forest	41	32.42	0	–
	Scattered woodland	107	44.51	0	–
	Temperate grassland	63	49.26	0	–
C	Oak forest	16	786.78	32.58	754.2
	Scattered woodland	64	337.37	26.75	310.6
	Temperate grassland	32	1272.92	92.12	1180.8
D	Oak forest	22	8317.46	193.69	8123.80
	Scattered woodland	42	1482.86	84.11	1398.70
	Temperate grassland	40	21,972.75	622.61	21,350.10
F	Oak forest	135	28.50	0	–
	Scattered woodland	204	23.27	0	–
	Temperate grassland	138	28.81	0	–

land cover type.

Structural and functional habitat fragmentations are varying within a range of 2% and 19%, respectively (Table 3). The steep increase in the higher classes in the functional habitat fragmentation relates to the presence of type A habitat patches (Fig. 2) and was strongest in scattered woodlands. Number of patches of type A was higher than that of the other types (Table 2). This patch type is not being affected by structural fragmentation, in contrast type B patches (the less numerous type A patches only contributed to structural fragmentation). On the other hand, mean patch size in type A patches are smaller than in type C and D, which means that, based on the Eq. (3), having smaller area resulted in a higher degree of fragmentation. Therefore, presence of type A habitat patches in higher numbers and smaller areas resulted in a steep increase in the higher classes of functional fragmentation (Fig. 7b). In contrast to type A, habitat patches of type D were the largest patches, and their influence was lower than that of type A patches. First, the number of type D patches was very low. Second, after breaking apart the area of the remnants was still big enough. Therefore, both structural and functional fragmentation were low in temperate grasslands and remained within a narrow range across the fragmentation classes (Fig. 7c). This shows the importance of larger patch size as a driver for fragmentation in the face of disturbances.

Based on our results, particularly types B, C, and D habitat patches lost their structural connectivity to other patches (Fig. 2), and type A, C and D habitat patches had their functional connectivity reduced. Particularly patches of scattered woodland lost their functional connectivity and became most isolated. Habitat loss was highest here and mean size of the remnant patches (mostly type A and type C habitat patches) was about 26 ha as compared to 122 ha (type A) and 337 ha (type D) before the fragmentation (Table 2). If we assume that "degree of fragmentation" is the inverse of "connectivity" (Wulder and Franklin, 2006; Turner et al., 2001), the Infrastructure Fragmentation Index IFI values in type D habitat patches (affected by both land-take and noise effect zone) for structural fragmentation range from 0.1 up to 1336, and those for functional fragmentation range from 1.2 up to 23,236.6. These ranges show that the connectivity between remnants is cut off significantly heavier by noise effect zone than road land-take. Kindlmann and Burel (2008) in a review of connectivity measures concluded that "a major challenge in connectivity research today is to develop functional connectivity measures that incorporate both species-species movement behavior and landscape structure". So, there is a good chance to compare IFI index with other connectivity measures and improve this index with the connectivity concept in future studies.

Road density variation throughout the study area has resulted in mesh size varying across the study area (Fig. 1). Thus, in areas with higher density of roads we have smaller mesh size as well as larger degree of fragmentation and vice versa (red and pink area versus light green area, Fig. 8). Our results revealed that the mesh size created by the noise effect zone was smaller than by land-take. Therefore, the sensitivity of the species to noise and their avoidance behavior can play a key role for determining mesh size. In other words, the more sensitive an animal reacts to the noise the smaller effective mesh size will result.

The main advantage of quantifying the degree of habitat fragmentation is that mitigation measures to reduce negative impacts of disturbance on sensitive wildlife species can be implemented more effectively in identified critical areas. Hence, e.g. for the construction of noise barriers, patches with a higher fragmentation level should have higher priority. If species do not show specific noise avoidance behavior but do avoid road surface or cars (Fahrig and Rytwinski, 2009; van Langevelde and Jaarsma, 2005; Jaeger et al., 2005), patches with a higher degree of fragmentation due to land-take may be more suitable for future under- and overpasses.

5. Conclusion

We believe that insufficient focus on the quantitative ecological impacts of roads especially at the landscape scale resulted in weak EIA practices. In this study we estimated habitat loss and fragmentation due to road networks from both structural and functional aspects. Thus, traffic noise modeling can be applied in ecological impact assessment of roads and will increase chances for successful implementation of mitigation measures of roads. In other words, this approach can help to assess the ecological impacts throughout the EIA process from the planning to the construction and operation phase of linear infrastructural projects. This approach can fill the gap between EIA and GIS-based models considering topography to produce the quantitative rather than qualitative assessments at both local and landscape scale.

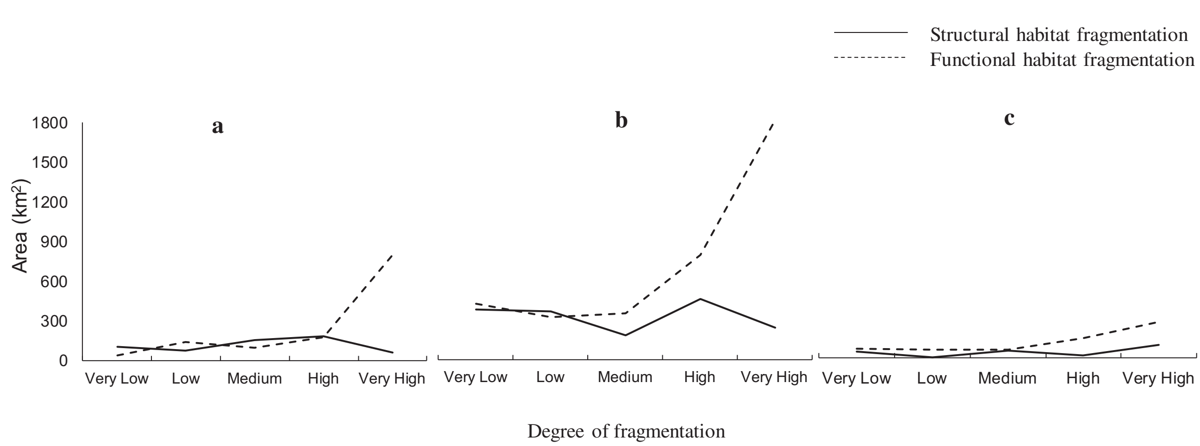

Fig. 7. Comparison of habitat areas affected by land-take vs. noise effect zone for the five classes of fragmentation: (a) oak forest (b) scattered woodland, and (c) temperate grassland.

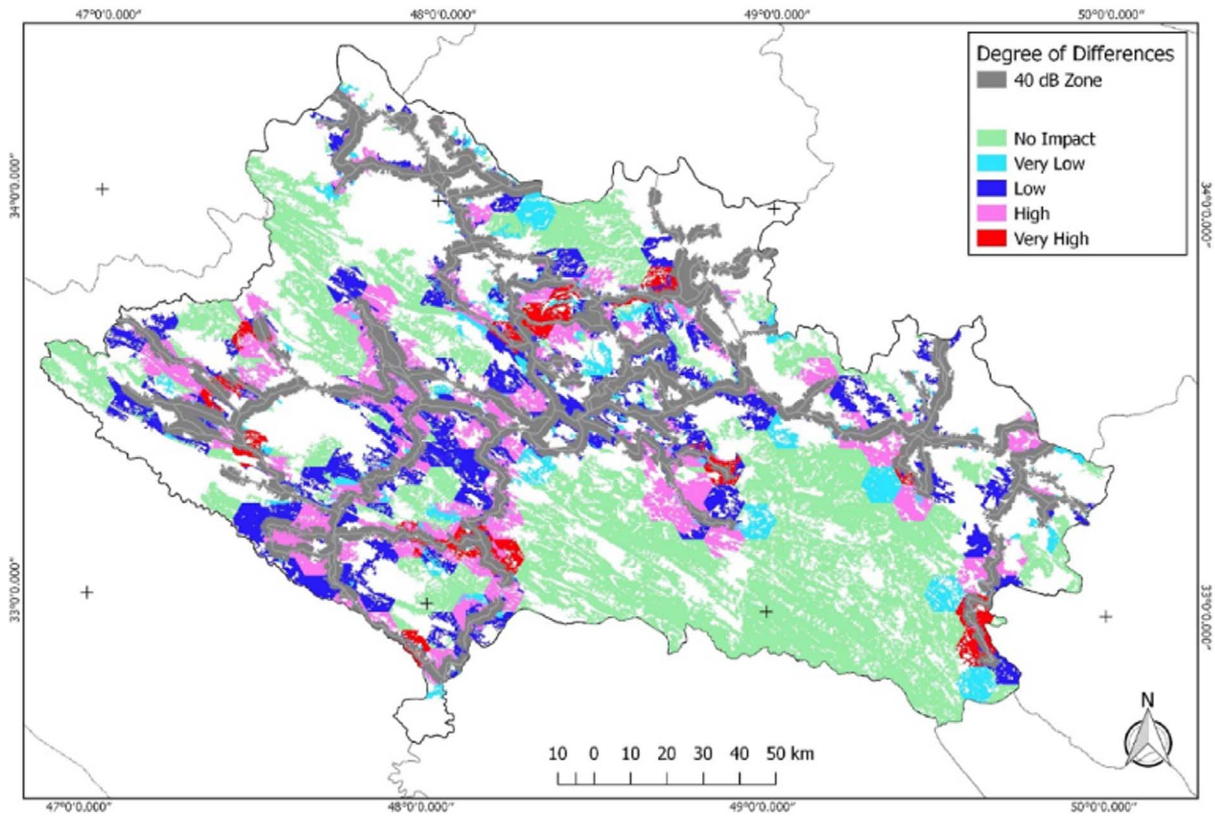

Fig. 8. Normalized difference between habitat fragmentation due to noise effect zone versus land-take.

Table 3
The area and the proportion of fragmentation by land-take and road effect zone in natural habitats of Lorestan Province.

Degree of fragmentation	Land-take habitat fragmentation		Noise effect zone habitat fragmentation		Differences	
	Area (ha)	Proportion (%)	Proportion (%)	Area (ha)	Area (ha)	Proportion (%)
Very low	52,322	4.3	53,369	4.3	1047	0.1
Low	43,435	3.5	51,879	4.2	8444	0.7
Medium	39,520	3.2	49,700	4.0	10,180	0.8
High	64,236	5.2	118,498	9.6	54,262	4.4
Very high	39,551	3.2	282,428	23.0	242,877	19.7
Total fragmented	239,064	19.4	555,874	45.2	316,810	25.8

In EIA practices, assessing the cumulative impacts is a major concern. We believe that the approach developed in this study can be applied as a cumulative impact assessment approach for the linear infrastructural projects.

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