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

Hossein Madadi[a,e], Hossein Moradi[a,*], Alireza Soffianian[a], Abdolrassoul Salmanmahiny[b], Josef Senn[c], Davide Geneletti[d]

[a] Department of Natural Resources, Isfahan University of Technology, Isfahan 84156-83111, Iran
[b] Department of the Environment, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran
[c] Swiss Federal Research Institute WSL, Zürcherstrasse 111, 8903 Birmensdorf, Switzerland
[d] Department of Civil, Environmental and Mechanical Engineering, University of Trento, via Mesiano, 77, 38123 Trento, Italy
[e] Department of Environmental Science, Behbahan Khatam Alanbia University of Technology, Behbahan 63616-47189, Iran

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A B S T R A C T

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

* Corresponding author.
E-mail address: hossein.moradi@cc.iut.ac.ir (H. Moradi).

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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