

## **Applying a Systematic Conservation Planning Tool and Ecological Risk Index for Spatial Prioritization and Optimization of Protected Area Networks in Iran**

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### **Abstract**

One of the key purposes of conservation selection strategies is to design a network of sites to support relevant biodiversity components and, therefore, decrease the risk of populations becoming isolated. To this end, it is important to be aware of the habitat locations of the target species and the threats of human activities, in order to identify areas of a high conservation priority. This paper takes the Chaharmahal and Bakhtiari province (Iran) as a case study, to highlight a network optimization for six target species of conservation concern, including the Persian leopard, *Panthera pardus* Pocock, wild sheep, *Ovis orientalis* Gmelin and wild goat, *Capra aegagrus* Erxleben. To run the optimization, we first generated the following input data: we modelled suitable habitats, using the InVEST model (Integrated Valuation of Environmental Services and Tradeoffs) and simulated the ecological impact of road networks (Spatial Road Disturbance Index (SPROADI), Kernel Density Estimation (KDE) and the Landscape Ecological Risk Index (ERI)). A visual inspection of the input data revealed that a large percentage of the study area constitutes a suitable habitat for the target species, however, the disturbances caused by the road demonstrate that the central and north-eastern regions of the study area are significantly affected. Indeed, approximately 10% and 25% of the study area are in the high and medium risk categories, respectively. Optimization using Marxan, shows that the north-western and southern regions of the study area should be given high conservation priority, necessary for an efficient conservation network. Habitats located in the north-central region should act as stepping-stone areas or corridors between the isolated regions in the north-east and the well-connected areas in the north-west and south. Overall, the findings of the present study show that the current network of protected areas is not contradictory to that suggested by Marxan, but has deficiencies in terms of size and stepping-stones.

Key words: InVEST, suitable habitats, road networks, ERI, conservation priority, Marxan.

## 1. Introduction

One of the key goals of conservation selection strategies is to design a practical network of sites which supports entire components of biodiversity. One of the essential aspects of this strategy is to decrease the environmental risks to crucial habitats and significant species (Schill & Raber, 2009). As stated by recent assessments, approximately 32.8% of the global protected areas network and up to 60% of the ecosystem services, have been degraded worldwide (Jones et al., 2018; Lanzas et al., 2019). To this end, several legal frameworks, aiming for more biodiversity conservation, such as the 2010 international agreements of the Convention on Biological Diversity (CBD High-Level Panel, 2014), which called for the preservation of at least 17% of terrestrial and inland water and the restoration of 15% of degraded ecosystems until 2020, have emerged, so as to meet the Aichi Biodiversity Targets (CBD High-Level Panel, 2014). Moreover, the preliminary assessment of the post-2020 Aichi Biodiversity Targets stated that at least 30% of the Earth should be covered by well-connected systems of protected areas and other effective, area-based conservation measures (OECMs) by 2030 (OECD, 2019). Although not all human activities could be considered threats to habitats and biodiversity, the direct and indirect impact of human activities are eventually responsible for the majority of changes in the ecological processes that support biodiversity. Accordingly, it is necessary to understand the relationship between anthropogenic threats and ecological health, and then identify the areas which have the highest priority in terms of conservation and have provided valuable insights into conservation planning (Schill & Raber, 2009).

Reserve planning is often carried out in an opportunistic way. Frequently, non-commercially used remnant land is put together to form a non-systematic network of protected sites. In order to make a more comprehensive assessment of conservation areas, systematic conservation planning approaches have emerged. Prioritizing conservation areas is an essential step in systematic conservation planning, which enables the efficient and effective implementation of conservation management, in order to conserve habitats or biodiversity (Schuster, 2014; Mo et al., 2019). Spatial conservation prioritization corresponds to the technical phase of systematic conservation planning and is typically implemented using site selection software, based on optimization algorithms, such as Zonation (Moilanen et al., 2009; Honeck et al., 2020), Marxan (Game & Grantham, 2008) and C-Plan (Pressey et al., 2009). The most important application of these types of software is the evaluation of an ecological infrastructure's value and the optimization of spatial conservation allocation or spatial impact avoidance, by balancing multiple biodiversity features, such as habitats, species and ecosystem services (Di Minin et al., 2014). Using the Chaharmahal and Bakhtiari province, and a set of target species as an example, we applied systematic conservation planning using a set of innovative indices that express suitable habitats as well

as fragmentation threats. The Chaharmahal and Bakhtiari province has a network of protected areas for a large variety of animal species. However, this existing network and the adjacent, non-protected habitats have neither been checked systematically for effectiveness, nor for a potential extension. This, however, is urgent, as the north-east of the province is developing rapidly, both in terms of road and settlement expansion.

To select the target species, we consulted the Iranian and the IUCN Red List of threatened species and selected a key set of threatened species. These were complemented with other important species by focusing on (a) the food chains (herbivores and carnivores), (b) the availability of sufficient and uniform data and information throughout the province and (c) the species susceptible to fragmented habitats and road networks. Therefore, the Persian leopard, *Panthera pardus* Pocock 1927, an endangered species was selected as a target species (Stein et al., 2020), as well as the wild sheep, *Ovis orientalis* Gmelin, 1774 and wild goat, *Capra aegagrus* Erxleben, 1777, both considered vulnerable species (Weinberg et al., 2020), according to the IUCN Red List of Threatened Species. In addition, the flagship species, Brown bear, *Ursus arctos* Linnaeus, 1758 and Persian squirrel, *Sciurus anomalus* Gmelin, 1778 were selected as target species because of their key role in preserving oak forests in the central region of the Zagros mountain ranges; the Eurasian badger, *Meles meles* Linnaeus was also selected due to the high number of vehicle collisions recorded for this species.

The research questions in our analysis were as follows:

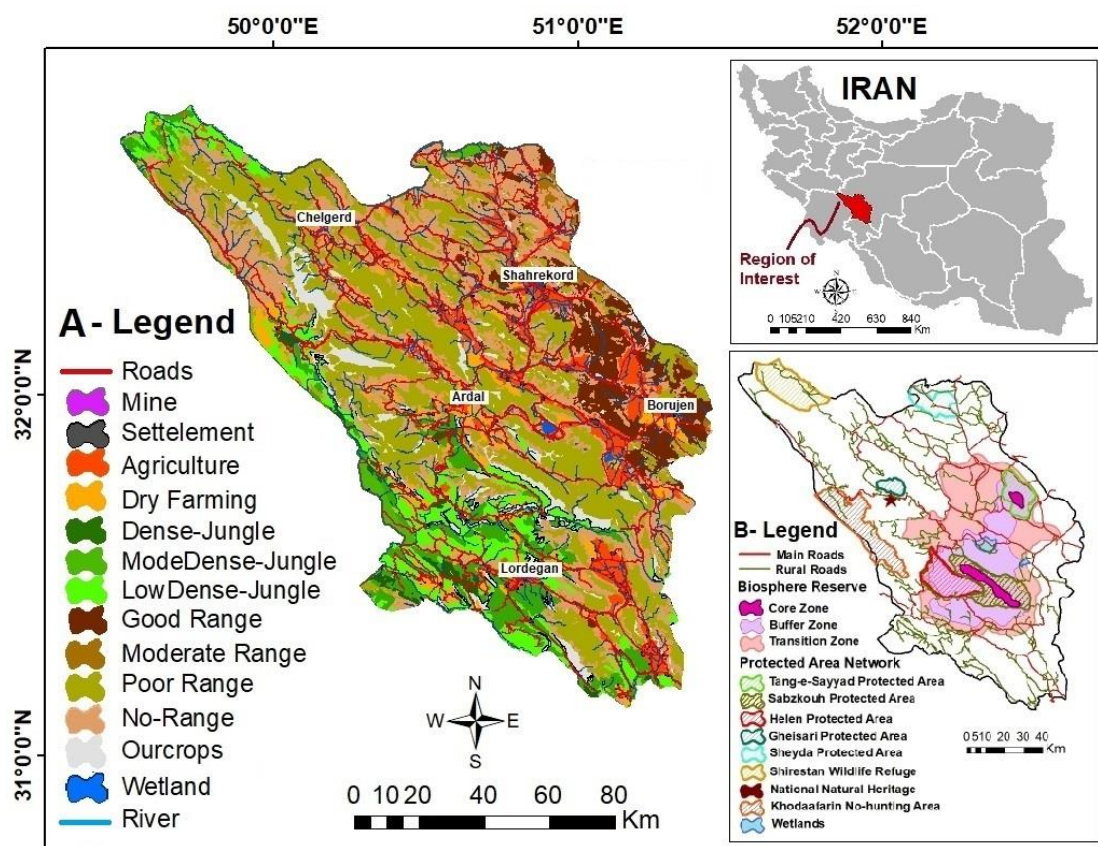
- where are the suitable habitat patches for the respective target species?
- in which areas is species movement between habitat patches threatened?
- what would an optimized network of protected areas look like?
- how does the existing network compare with the optimal network, and how would additional protected areas best complement the existing network?

## **2. Materials and method**

### **2.1. Study area**

The case study – the Chaharmahal and Bakhtiari (Ch and B) province, with an approximate area of 16,332 km<sup>2</sup> and an average height of 2153 m, located in the central region of the Zagros mountain range in Iran, has a rough terrain and its climate varies considerably. This causes significant ecosystem diversity and provides suitable habitats for a great variety of plant and animal species, including wild sheep (*Ovis orientalis*) and the Persian leopard (*Panthera pardus*), classified as vulnerable and endangered species on the IUCN Red List of Threatened Species, respectively (Jafari et al., 2018). This province supports more than 1200 plant species (Mozaffarian, 2019), 62 mammal species, 170 bird species, 35 reptile species, five amphibian species and 22 fish species

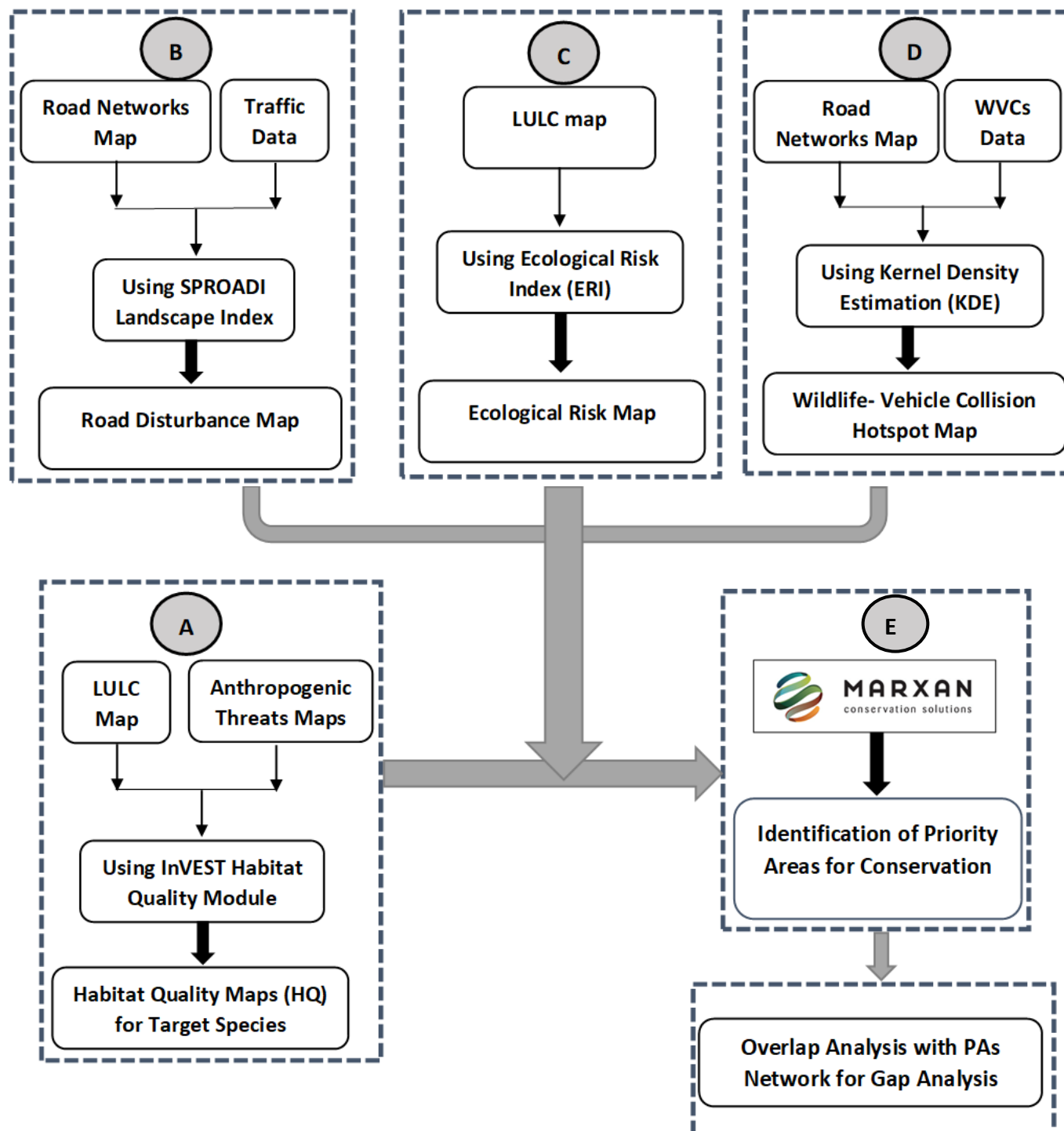
(Jafari & Azizi, 2015). In addition, this province has great potential for ecotourism development (Afghari, 2021). Based on the land use and land cover map (LULC), created by the Forests, Range and Watershed Management Organization in 2004, around 55.6% (908,000 ha), 20.57% (336,000 ha) and 9.6% (156,617 ha) of the areas of the Ch and B province, are rangelands, forests and agricultural lands, respectively, and approximately 14.23% (232,583 ha) of these areas are outcrops, rivers, wetlands and human settlements. Around 11.63% of the areas of this province are considered as a protected areas network, including one national, natural monument (*Fritillaria imperialis*), one national park (Tang-e-Sayyad), one wildlife refuge (Shirestan) and five protected areas (Tang-e-Sayyad, Sabzkouh, Helen, Sheyda and Gheisari). In 2015, the central regions of this province, including the Sabzkouh and Tang-e-Sayyad protected areas were declared a biosphere reserve by UNESCO's Man and Biosphere Programme (MAB), due to their unique endemic flora and fauna. The central regions of the Sabzkouh protected area and the Tang-e-Sayyad protected area were considered the "core zones" and the areas between them were the "buffer zone" (Fig. 1). However, these natural habitats and valuable species are negatively affected by human activities, particularly road networks, which cause habitat fragmentation and habitat loss. To this end, it is essential to identify the priority areas of conservation planning in the Ch and B province.



**Fig. 1.** Location of the study area; A- Land use/cover map, B- Location of road networks and protected areas network

## 2.2. Method

Our analysis can be subdivided into the steps presented in Fig. 2. Each component constitutes an independent modelling compartment that will be described in the following paragraphs.



**Fig. 2.** General research methodology flowchart

### 2.2.1. Habitat quality modelling of target species (see Fig. 2a)

We did not have species' occurrence maps, only expert descriptions of occurrence and detailed habitat requirements. The latter were used to generate habitat quality maps for each of the six species, using LULC layers and the InVEST habitat quality module (Tallis et al., 2011). As stated by Terrado et al. (2016), this module uses the assumption that habitat quality is implicitly linked to species' richness, an assumption that is well accepted, but is nevertheless not as accurate as species' counts. We estimate the quality of habitat for each grid of the LULC as a function of 1) the suitability of each type of LULC to provide appropriate habitats for target species, 2) varying types of human threats, which have an adverse impact on habitat quality and 3) the delicacy of each type of LULC to each threat (Tallis et al., 2011; Terrado et al., 2016). We are well aware of the limitations of our study results, due to the lack of spatially consistent occurrence data. However, we feel that the habitat suitability maps, based on habitat requirements, yield a more consistent spatial pattern of suitable areas than pure expert assessments, which are often biased towards specific areas where experts have conducted field surveys.

An LULC map of the Ch and B province was obtained from the regional land cover map and was classified into 15 varying key categories, matching each habitat type (Fig. 1a). Mines, agricultural lands, dry farming lands, road networks and settlements were considered to be the main sources of degradation in the study area. Subsequently, the habitat quality index was calculated by the following equation (1):

$$HQ_{xj} = H_j(1 - (D_{xj}^z / (D_{xj}^z + k^z))) \quad (1)$$

The  $HQ_{xj}$  is the habitat quality of cell, x, in land type, j. A comparative amount of habitat suitability ( $H_j$ ) is between 0 and 1, where 1 is ascribed to each LULC type with maximum suitability for the target species. One of the most notable attributes of this model is its capability to take into account the sensitivity of each LULC type in relation to diverse threats. For this purpose, each threat source was mapped as a raster, in which the grid cell value revealed the intensity of the threats and normalized between 0, the lowest threat and 1, the highest threat.  $D_{xj}$  constitutes the total level of threats of cell, x, in land type j; k and z are the half-saturation constant and the scaling parameter, respectively (Eqn. 1 & 2).

$$D_{xj} = \sum_{r=1}^R \sum_{y=1}^{Y_r} (W_r / \sum_{r=1}^R W_r) \left( 1 - \left( \frac{D_{xy}}{D_{max}} \right) \right) r_y B_x S_{j_r} \quad (2)$$

The negative effects of the threats in grid cell,  $x$ , in land type,  $j$  ( $D_{xy}$ ), were mediated by a) the distance between the grid cell and the threat sources. ( $D_{xy}$  represents the distance between the grid cells,  $x$  and  $y$ .  $D_{max}$  is specified as the maximum distance); b) the comparative seriousness of the threat (the significance of the threats by comparison with one another was defined as  $W_r$ ) and c) the relative delicacy of the land use type,  $j$ , in relation to each threat ( $S_{jr}$ ) (Tallis et al., 2011; Terrado et al., 2016; Nematollahi et al., 2020).

Generally, the adverse effects of the threats on the habitats are reduced as the distance from the threat sources increases, therefore, the grid cells located at a greater distance from the degradation sources would experience a lower impact.  $W_r$ , ranging between 0 and 1, represents the comparative destructiveness of the threat sources to all sorts of habitats. In addition, this module has taken into account the comparative sensitivity of each habitat type in relation to a threat ( $S_{jr}$ ), indicating that the more sensitive a habitat type is to a threat, the more affected it is by the threat. In this case study, the  $H_j$  and the threat variables were specified, based on expert knowledge and a literature review (Terrado et al., 2016; Sallustio et al., 2017). Subsequently, 15 experts were asked to assign values to each parameter of the module. The functioning of the InVEST habitat quality module, the variables and the structure and meaning of the tables for completion, were explained in detail before expert scoring (Table S1 and Table S2 in Appendix A). In the case of existing inconsistencies in the responses of the experts, the mean, standard deviation and coefficient of variation values were calculated and utilized, to evaluate any inconsistency in the model (Terrado et al., 2016).

### 2.2.2. Ecological impact assessment of road networks (see Fig. 2b)

In this section of the study, the SPROADI landscape index was used to assess the ecological impact of road networks on natural habitats. This index, obtained by the equations, uses three sub-indices including traffic intensity (T), vicinity impact (V) and fragmentation grade (F), to calculate the cumulative effects of road networks on habitats (Freudenberger et al., 2013; Nematollahi et al., 2017; Nematollahi et al., 2020). The layers of traffic data and road networks, with the resolution of 1 km<sup>2</sup> were used as the basic layers in producing these indices (UNEP, 2001; Eigenbrod et al., 2009; Makki et al., 2013; Nematollahi et al., 2020).

### 2.2.3. Calculation of landscape ERI (see Fig. 2c)

Ecological risk signifies the feasibility of self-maintenance of an ecosystem in relation to exterior interferences, caused by human activities, including land use change and road network development at landscape scale (Gong et al., 2015; Mo et al., 2017; Mann et al., 2020). ERI is composed of various sub-indices, as shown in Table 1. A first package is the Landscape Disturbance Index (Ei) that quantifies the magnitude of outside

interferences on an ecosystem. It incorporates the Landscape Fragmentation Index ( $C_i$ ), the Landscape Splitting Index ( $S_i$ ) and the Landscape Dominance Index ( $D_i$ ) (Liu et al., 2012). These indices were weighted in accordance with previous studies, and then summed together to calculate  $E_i$ . The weights of 0.5, 0.3 and 0.2 were assigned to  $C_i$ ,  $S_i$  and  $D_i$ , respectively (Liu et al., 2012; Gong et al., 2015; Mo et al., 2017; Mann et al., 2020). In order to spatialize the landscape ERI, the study area was divided into 2720 sample units of a 2.5 km  $\times$  2.5 km square grid, according to the local condition of the landscape patches.

Since external interferences had altered the structure and function of the regional ecosystem, the regional landscape pattern changed. Therefore, a second package, the Frangibility Degree Index ( $F_i$ ) evaluated the internal ability of the landscape type, to preserve its stability in relation to outside stresses, that can be related to the stages of the natural succession process (Peng et al., 2015). In the first step, the study area is divided into six main groups of landscape type. Then, considering the condition of the study area, based on literature review and expert knowledge, the frangibility index was assigned to each landscape type from low (1= least frangibility and most resilient) to high (6= most frangibility and least resilient), i.e., water, forest land, grassland, outcrops, farmland and construction lands. In other words, water areas are better able to preserve their stability in relation to exterior interferences than construction lands (Mo et al., 2017; Mann et al., 2020). Finally, these indices were normalized to acquire the Landscape Frangibility Index ( $F_i$ ) and the combination of  $E_i$  and  $F_i$  constituted the ERI (Table 1).

**Table 1.** The formula for calculating the landscape metrics and the ERI

Landscape index	Formula	Descriptions
<b>Landscape fragmentation index (<math>C_i</math>)</b>	$C_i = n_i / A_i$	$n_i$ : number of patches of landscape type $i$ $A_i$ : total area of landscape type $i$
<b>Landscape splitting index (<math>S_i</math>)</b>	$S_i = D_i \cdot A / A_i$ , $D_i = (1/2) \cdot \sqrt{ni} / \sqrt{A}$	$D_i$ : distance index of landscape type $i$ $A$ : total area of the landscape
<b>Landscape dominance index (<math>D_i</math>)</b>	$D_i = (R + F) / 4 + L / 2$ , $R = n_i / N$ , $F = B_i / B$ , $L = S_i / S$	$N$ : total number of patches $B_i$ : sample number of patches $i$ $B$ : total number of samples $S_i$ : area of patch type $i$ $S$ : total area of all samples
<b>Landscape disturbance index (<math>E_i</math>)</b>	$E_i = aC_i + bS_i + cD_i$	$a, b, c$ : weights of indices $a = 0.5$ ; $b = 0.3$ ; $c = 0.2$
<b>Landscape ecological risk index</b>	$ERI = \sum_{i=1}^N \frac{S_{ki}}{S_k} \sqrt{E_i, F_i}$	$N$ : number of landscape types in the sample areas $S_{ki}$ : area of landscape type $i$ in sample area $k$ $S_k$ : total area of sample area $k$

#### 2.2.4. Calculation of wildlife-vehicle collision hotspot (see Fig. 2d)

In this part of the study, the KDE was used to identify the most hazardous spots along the road networks (Xie & Yan, 2008). This method has been used extensively in several studies on wildlife-vehicle collision (WVC) along road networks. For this purpose, 120 WVC location data including those of wild sheep, wild goat, Eurasian badger, brown bear and Persian Leopard were obtained from the Department of Environment (DoE) of the Ch and B province. The position of the collisions was recorded using a handled GPS device. Since a large grid size meaningfully affected the variation details of the kernel estimation's output, in the first step, a  $5 \times 5$  grid cell was used to cover all the distribution points of animal accidents on the roads. Subsequently, the bandwidth (radius) was determined using the Nearest Neighbour Distance algorithm and the weights were calculated for each point within the kernel radius. Basically, higher weights were assigned to the points closer to the centre; consequently, they contributed more to the total density value of the cell. By adding the values of overall circle surfaces for each location, the final grid values were computed (Silverman, 2018; Mohammadi & Kaboli, 2016).

#### 2.2.5. Identification of the priority areas using Marxan (see Fig. 2e)

To identify the priority areas, the optimization software, Marxan v 2.4.3, was used. Marxan is able to optimize a habitat network at the lowest costs. For this purpose, Marxan is able to solve the “minimum set problem” in areas where user-defined targets are achieved at the lowest feasible cost (Game & Grantham, 2008). Among the different types of techniques, the Simulated Annealing (SA) algorithm was used, due to its high computational performance in resolving intricate problems and its concurrent assessment of diverse objectives and costs, compared to other techniques (Pearce et al., 2008).

A crucial step was to subdivide the study region into a set of Planning Units (PUs), from which the Marxan optimization software could then select the most optimal for a potential conservation network. In accordance with Egli et al. (2017) we decided to use a neutral, regular mesh of hexagonal patches which was not already predetermined by existing conservation-administrative boundaries. The hexagonal shape allows for a more realistic representation of edge effects and connectivity than a square. The size of the hexagonal PUs is critical for the optimization results and, generally, should be no finer in terms of resolution than the input layers of value and costs, and no coarser than is practical for management decisions (Game & Grantham, 2008). Furthermore, it should not be too big to reflect the landscape heterogeneity of the terrain and the home ranges of the selected species. As a compromise, we selected a size of 625 ha for each hexagon.

The four main input files, including a basic input parameter file (input.dat), the PU file (pu.dat), the species file (spec.dat) and the PU versus the conservation feature file (puvspr.dat), were required to run Marxan (Game & Grantham, 2008; Götz, 2014; Zhang et al., 2014). In the absence of species' occurrence maps, the habitat quality layers of the six species, which were produced using the InVEST habitat quality module and based on the LULC layer, were used to create the spec.dat and puvspr.dat in the Boolean format (1=suitable habitats and 0=unsuitable habitats). The pu.dat possesses all the information associated with the PUs, including the costs of each PU in the reserve system. In this study, the SPROADI, ERI and WVC layers were overlayed to calculate the overall cost across the Ch and B province and to create the PU file. The term “cost” is used to express the total number of adverse effects of road disturbance on wildlife. The PU status is another variable considered in the PU file. The value of 0 was assigned to this variable, indicating that the PUs were not locked in the initial reserve system (Game & Grantham, 2008). In addition, Marxan required a series of parameters including the Species Penalty Factor (SPF) and the conservation target.

The conservation target was one of the most important parameters of this model. It constituted the extent of the suitable habitats of each species across the entire study area, intended to be included in the final solution. In this case study, three different scenarios were designed to prioritize the selected reserve system. Each of these three scenarios differed in terms of the conservation percentage of suitable habitats. These scenarios are presented in Table 2.

Scenario I, the “literature-based scenario” was designed based on the national conservation importance of the target species. For this purpose, the target species were divided into three main categories. Leopard, as an endangered species, and wild sheep and wild goat, as vulnerable species, fell into the first and second categories, respectively. Brown bear, Persian squirrel and Eurasian badger fell into third category, due to their “least concern” status. Subsequently, the conservation targets of 60%, 40% and 20% were assigned to the first, second and third categories, respectively (Leroux et al., 2007; Pearce, 2008; Shafieezadeh et al., 2019). Scenario II, the “very safe scenario” constituted the highest possible target for each species before an excessive penalty was applied. To this end, the break-even point of the costs of the overall runs, which showed the highest possible target at the lowest cost, were identified for each species. Setting this scenario allowed us to ensure that priority areas were placed in the most suitable areas, with the lowest possible costs. In addition, considering the area of suitable habitats for the target species and the significance of their conservation across the study area, scenario III, as the “safe scenario”, was designed.

The SPF is a multiplier that specifies the scale of the penalty that will be assigned to the objective function, should the conservation target not be met. In this case study, the SPF was set at 1.2 to ensure that every species' targets were met.

**Table 2.** Various scenarios based on the potential suitable habitat for each species

<b>Species</b>						
<b>Scenario</b>	Persian leopard	wild sheep	wild goat	Persian squirrel	brown bear	Eurasian badger
<b>I</b>	60%	40%	40%	20%	20%	20%
<b>II</b>	67%	65%	66%	46%	53%	54%
<b>III</b>	67%	65%	55%	46%	40%	30%

### 3. Results and Discussion

Prior to presenting the results we wish to clarify that due to insufficient scientific information, certain thresholds used in the study are based on expert knowledge, which has clear limitations. This is the case for a) the habitat quality modelling of the target species, using the InVEST software (chapter 3.1), b) assigning the frangibility index in the ERI modelling (chapter 3.3) and c) selecting the best scenario for identifying the priority areas for conservation (chapter 3.6).

#### 3.1. Habitat quality modelling of target species

The spatial patterns of Habitat Quality (HQ) for the target species, namely, the Persian leopard, wild sheep, wild goat, brown bear, Persian squirrel and Eurasian badger across the study area, were shown in Fig. S1 in Appendix B in the supplementary materials. The values of HQ, which ranged between 0 and 1, were higher in places where suitable environmental characteristics for each species, including vegetation cover and availability of water (river and springs), were found. By contrast, the lower values of HQ were found around the major urban areas of Shahrekord, Farokhshahr, Borujen and Lordegan. These low values were a result of the existence of LULC types with low HQ values, comprising urban areas, road networks and industrial and intensive farmland, which had the highest levels of human activity.

Fig. S1a showed that the high values of HQ were concentrated along the east, north-west and central regions of the study area (Fig. S1a in Appendix B). Approximately 27% of the Ch and B province, including Tang-e-Sayyad National Park and its protected area, and the Sabzkouh protected area were among the most suitable habitats for the Persian leopard. This species is resident in mountainous, forest land and foothills, with suitable vegetation cover (Firouz, 2005; Ziaei, 2009; Jafari et al., 2018).

Fig. S1b showed that higher values of HQ were found along the east and north-eastern regions of the Ch and B province, and decreased towards the west and southern areas (Fig. S1b in Appendix B). The result revealed that 15% of this province, including Sheyda protected area and Tang-e-Sayyad National Park and its protected area comprised the most suitable habitats for wild sheep. Wild sheep are resident in the foothills, where essential environmental features, including suitable vegetation cover namely, *Scariola orientalis* and *Astragalus spp*, as well as availability of water (river and spring) are found, which certainly influenced the presence of this species. These results are in accordance with the ecology of this species, as cited in the relevant literature (Shackleton et al., 1997; Firouz, 2005; Ziaei, 2009; Keya et al., 2016; Jafari et al., 2018; Malakoutikhah et al., 2020; Rezvani et al., 2020).

The east, north-west and central regions, encompassing 45% of the study area were among the most suitable habitats for the wild goat. This species preferred mountainous areas with a high quality of vegetation cover (*Scariola orientalis* and *Astragalus spp*) and availability of water. These suitable environmental characteristics were found in Tang-e-Sayyad National Park and its protected area and the Sabzkouh protected area (Fig. S1c in Appendix B) (Makki et al., 2013).

Fig. S1d indicates that around 23% of the study area, particularly the west, south-west and central regions, including Helen and Sabzkouh protected areas and Shirestan wildlife refuge were among the most suitable habitats for the brown bear (Fig. S1d in Appendix B). An important environmental characteristic, including vegetation cover (oak forests), topography (mountainous areas) and availability of water (river and spring) were found in these areas. The Persian squirrel has been found in the south-west and north-western regions of the Ch and B province in Helen protected area and Shirestan wildlife refuge, which are covered by oak forests (Fig. S1f in Appendix B). Based on the results, the protected areas of Helen and Sabzkouh were considered suitable habitats for the brown bear and the Persian squirrel.

Regarding the Eurasian badger, the west, south-west and eastern regions of the Ch and B province, including Tang-e-Sayyad National Park and its protected area, as well as the Helen, Sabzkouh and Sheyda protected areas, were among the most suitable habitats (Fig. S1g in Appendix B).

It is worth mentioning that the reliability of the HQ maps was tested by comparing them with the presence data of the target species, obtained from the Department of Environment of the Ch and B.

### 3.2. Spatial road disturbance index

The total road density and road length across the study area are around 0.29 km/km<sup>2</sup> and 4800 km, respectively. In addition, the average number of vehicles per hour on the Shahrekord-Chelgerd, Naghan-Dehdez, Gandoman-Borujen and Soreshjan-Farsan main roads are 501, 320, 294, 294 and 244, respectively. Based on the results of this part of the study, the density of roads in this province is higher by comparison with other adjacent provinces, including Isfahan (0.1 km/km<sup>2</sup>), Lorestan (0.2 km/km<sup>2</sup>), Khuzestan (0.06 km/km<sup>2</sup>) and the country as a whole (0.13 km/km<sup>2</sup>) (The Ministry of Roads and Urban Development of Iran, 2018). With regard to the richness of the animal and plant species in the Ch and B province, including the Persian leopard, wild sheep and wild goat, this volume of road density was inconsequential. In particular, habitat fragmentation and barrier effects, caused by road networks, which influenced functional connectivity, were the main reasons for the decline of species throughout the Ch and B province. In addition, more than 30 animal-vehicle accidents per year were reported on Ch and B roads by the DoE, indicating the adverse impact of road networks in this province.

Fig. S2 in Appendix C presents the SPROADI map, ranging from 0 to 54.48 and focusing, in particular on the negative impact of the road networks. The results reveal that approximately 28% of the Ch and B province is negatively affected by the road networks. The most significant impact of roads was found in the north-east and central regions, in the vicinity of the Gandoman-Gosheki, Burujen-Buldaji and Shalamzar-Naghan main roads. These areas were also recorded as suitable habitats for the target species. The number of disturbances in the aforementioned areas were due to the high degree of habitat fragmentation and the high volume of traffic (Nematollahi et al., 2020).

The results of the present study were compatible with the results of the study, carried out by Jafari & Azizi, (2015) to estimate the ecological impact of road networks on habitats within the Ch and B province. The high density of the road networks and their impact in the vicinity of certain habitats is one the main risk elements of habitat degradation in the Ch and B province. Hence, this study assessed the impact of the road networks on adjacent habitats, using the buffer zone function. According to the results of this study, approximately 10% of the Ch and B province is directly affected by road networks, thereby increasing the importance of assessing the direct and indirect ecological impact of the road networks (Jafari & Azizi, 2015).

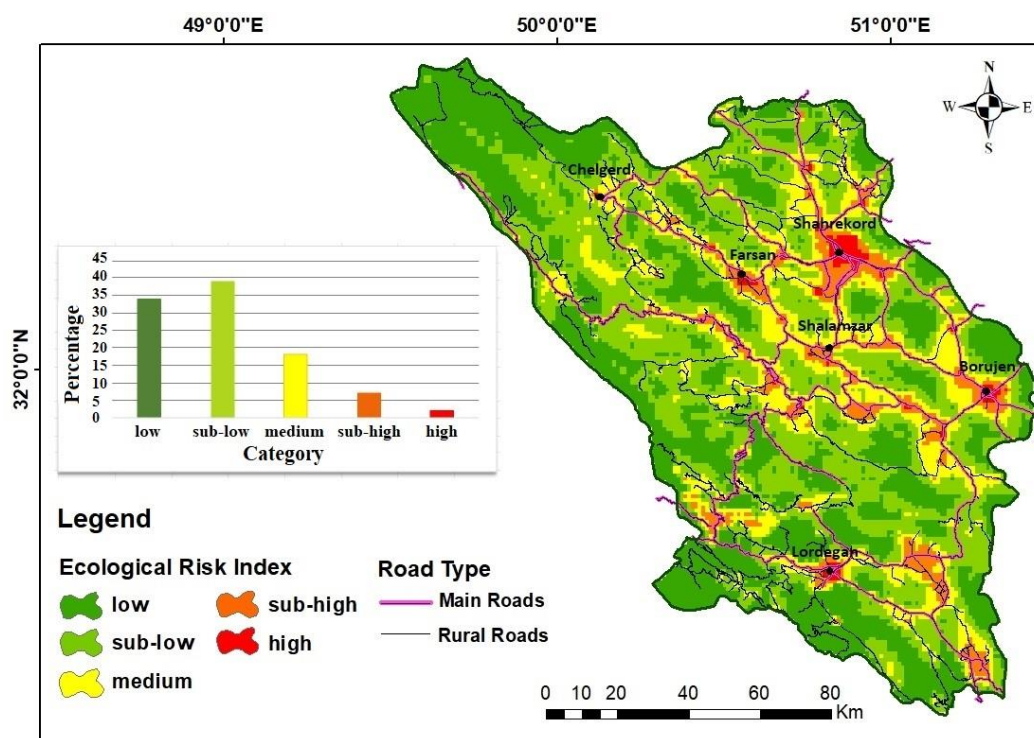
### 3.3. Landscape ERI

To analyse the ERI, after performing ordinary, kriging interpolation with the data layer of the central point, the ERI map was divided into five categories, using the natural break method with the help of ArcGIS (Fig. 3): low,

sub-low, medium, sub-high and high. The result showed that ERI was distributed irregularly across the study area. Higher ERI values were found in the central and north-eastern regions of the Ch and B province, in areas dominated by dense road networks and urban settlements, as was evident in the cities of Shahrekord, Farokhshahr, Lordegan and Borujen. This was primarily due to the rapid urban and transportation developments, which caused a higher level of landscape fragmentation and disconnection in those areas. Approximately 18%, 7% and 2% of the study area were considered medium, sub-high and high categories, respectively.

Lower values of ERI were found in the north-western, western and southern regions of the Ch and B province, which was dominated by mountainous areas encompassing forest land and grassland, and a low level of urbanization. Overlaying the ERI map with a protected areas network revealed that around 15%, 5% and 8% of the Tang-e-Sayyad National Park and its protected area, and the Sabzkouh and Helen protected areas, were considered in the high-risk category of ERI, respectively, mainly because of the roads.

Overall, the results of this section of the study indicated that the severity of ecological risk was patently correlated with the distance from compact road networks, that increased with a decreasing distance from the road networks. This result was compatible with the results of studies, carried out by Forman et al., (2003), Jaeger et al., (2011), Gong et al., (2015), Van Strien & Grêt-Regamey, (2016), Mehdipour et al., (2019) and Mann et al., (2020).



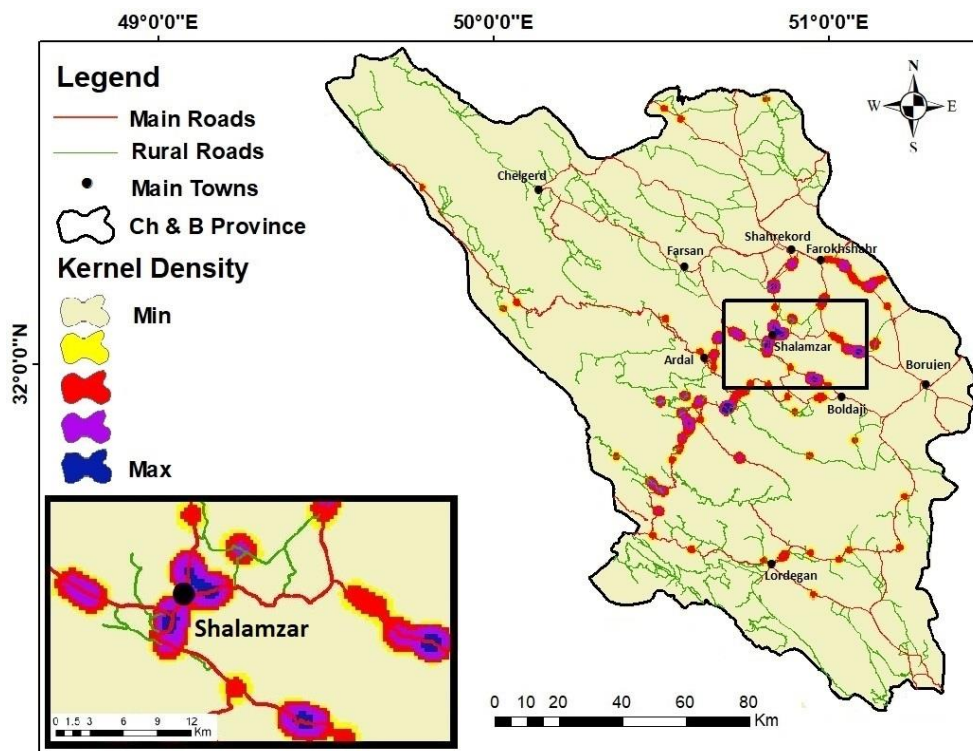
**Fig. 3.** The ecological risk index map of the Ch and B province

### 3.4. WVC hotspot

Based on the nearest neighbor distance methodology, the bandwidth of 1000 m was determined to estimate the density of WVCs. Xie & Yan, (2008) showed that a wider bandwidth seemingly provides a better sense of the “hotspot” locations at landscape scale. The estimated WVC hotspot map is shown in Fig. 4. The results showed that the key hotspots were located along the main roads near the towns of Shahrekord, Farokhshahr, Boldagi, Lordegan and Shalamzar.

Overlying this map with the protected areas network of the Ch and B province showed that certain key hotspots were found in the western and northern regions of the Helen protected area, the northern areas of the Sabzkouh protected area and around the Tang-e-Sayyad National Park and its protected area, indicating the dangers in these regions with regard to WVCs. A comparison of this map with the SPROADI index map showed that the main hotspots were located along those roads with a high level of road disturbances in the eastern and central regions of the Ch and B province.

The study, carried out by Mohammadi & Kaboli, (2016), proved that protected areas of significant biodiversity value in Iran, have been affected by transportation networks, primarily because of unsustainable road network development in Iran. This study showed that the KDE method was useful in spatially pinpointing the location of WVC hotspots, which were valuable inputs in terms of enhancing mitigation strategies (Mohammadi & Kaboli, 2016).



**Fig. 4.** The WVC hotspot map of the Ch and B province

### 3.5. The cost map: overall disturbances caused by roads

After overlaying the SPROADI, ERI and WVC layers, an “over-all cost layer” map of the total number of disturbances caused by the roads, was obtained across the study area (Fig. S3 in Appendix C). The costs ranged from 2.52 to 37.43. The result indicated that the highest levels of costs were found in the central and north-eastern regions of the Ch and B province, in places dominated by a high density of road networks and urban areas, such as the main towns of Shahrekord, Borujen, Ardal, Lordegan and Shalamzar. In other words, approximately 10% and 25% of the study area were considered as being within the high and medium disturbance categories, respectively. A study which was conducted in Romania's Southern Carpathians (Patru-Stupariu et al., 2015), a study in Colorado, USA (Marull et al., 2018) and a study in the Bojnourd metropolitan area, Iran (Darvishi et al., 2020) indicated that road network development and urbanization, constituted the main elements of landscape fragmentation, resulting in landscape degradation.

### 3.6. Identification of the priority areas

Marxan produced two maps for each scenario (six maps for three scenarios); one of them showed the best solution from all runs, the other indicated the selection frequency of each PU to be selected through all runs (Fig. 5). In this case study, the frequency ranged from 0, meaning never selected in the final solution, to 100, meaning selected in all solutions. The PUs which were frequently selected in the final solution, were clearly required for an efficient conservation system.

According to the results of Marxan, approximately 26% (scenario I), 44% (scenario II) and 36% (scenario III) of the study area, were selected as high priority areas for conservation, when all species' habitat targets were met (Fig. 5). Based on literature reviews and discussions with rangers and experts, we found that conserving 44% of the Ch and B province, considering the social and economic issues would be impossible. In other words, the target of conserving 44% of the study area is too high and does not yield any substantially new priority areas, compared to scenarios I and III. Instead, the model accepts the penalties for not meeting the requested areas, without suggesting new priority areas. The results of scenarios I and III are, therefore, more straightforward and applicable in practice. They indicated that the north-western, central and southern regions of the study area had a high ecological value on the one hand and were impacted less by disturbances caused by the road on the other hand. Hence, these areas were required to form part of an efficient conservation system in the Ch and B province.

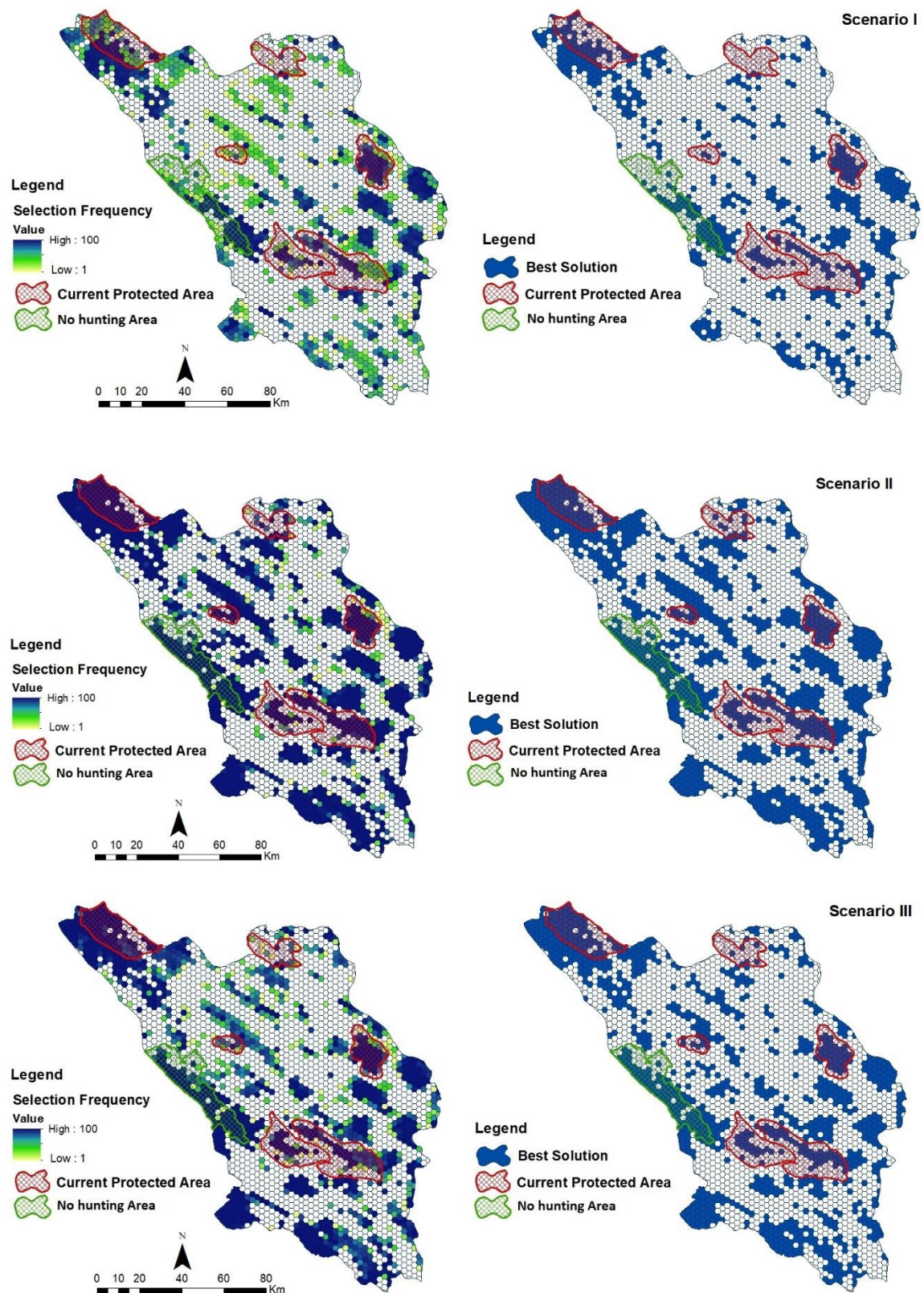
Comparing the results of scenario I and III showed that with increasing protection percentages from scenario I to III, there was an increase in the mean core area (from 3714 km<sup>2</sup> to 5251 km<sup>2</sup>) and mean patch size (from 3941 km<sup>2</sup> to 8463 km<sup>2</sup>), while the overall number of patches decreased (from 105 to 74) in the study area. Thereafter, the priority areas, selected by scenario III, were necessary for an efficient conservation system in the study area. Di Minin et al., (2013) also declared that increasing the protection level through the creation of a larger well-connected, protected areas network is crucial for mitigating anthropogenic threats to large carnivores, including the African leopard, and supporting their long-term survival.

Considering the current protected areas network, which covers approximately 11.63% of the study area, the results of scenario III recommended that the north-western regions of the Ch and B province, adjacent to the Shirestan wildlife refuge, should be added to the conservation system. In addition, the results suggested that the level of protection in the western regions of the study area, known as the Khodaafarin no hunting area<sup>1</sup>, should be increased; this region covers around 3.31% of the study area and should be protected, due to its high conservation priority.

Based on the present results, the southern regions of the study area were considered a high priority in terms of conservation. Following discussions and insights from rangers, experts and local people within these areas, it became clear that high levels of illegal poaching are causing biodiversity decline. Regarding the high protection priority of these areas on the one hand and the high level of illegal poaching on the other hand, there was a need to protect these areas. Furthermore, increasing the number of rangers by comparison with other protected areas, so as to confront hunters, was also deemed necessary.

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<sup>1</sup> No hunting areas can be considered an active natural ecosystem, if the necessary conditions are created, and can be regarded as constituting support for the protection of the country's natural resources in protected areas. In fact, hunting is temporarily banned from such areas, to assess their suitability for inclusion in the protected areas network.



**Fig. 5.** The resulting maps from three scenarios; the selection frequency of a unit (left) and best-selected regions (right)

The results of scenario III also revealed that the areas between Tang-e-Sayyad National Park and its protected area and the Sabzkouh protected area, were highly recommended for the conservation system. As previously mentioned, these areas are considered as a biosphere reserve; the central regions of the Tang-e-Sayyad National Park and its protected area, and the Sabzkouh protected area are “core zones”. The migration corridors of the Persian leopard, wild sheep and wild goat were found in the “buffer and transition zones” of the Tang-e-Sayyad and Sabzkouh Biosphere Reserve in places where high numbers of WVCs were found. Therefore, this case study suggested extending the “core zones” and increasing the level of protection in the “buffer zone”.

In addition, maintaining the north-central, suitable habitats, found in this case study, was of utmost importance, and may act as stepping-stone areas or corridors, playing an essential role in habitat connectivity. The aforementioned areas also had the potential to become another biosphere reserve, suitable for activities compatible with sound ecological practices, that can reinforce scientific research, monitoring and education. This could increase the level of economic and social status in the Ch and B province. It is worth mentioning that all the suggested solutions required more workshops and more detailed studies at a lower level.

#### **4. Conclusion**

The present study, using Marxan – a systematic, conservation planning tool – has focused on identifying the priority areas which have the highest ecological value on the one hand, and are least impacted by anthropogenic threats, particularly road networks, on the other hand. As a standard input in such optimizations, the habitat quality maps of six target species of conservation concern were used. Innovative indices for road disturbance have been used to express the overall costs of the adverse effects of roads on habitat and biodiversity. These two types of inputs complemented one other by providing valuable maps and data to identify the priority areas of high conservation value. The resulting priority maps were used to check whether the current reserves are well positioned or need refinement, and where the future extensions of the reserves would be best positioned. The approach used in the present study could be utilized on any scale and in any region to establish conservation objectives for biodiversity.

One of the prospects is to consider land cost, landownership data and other human pressures to rectify the identification of potential conservation areas, and to study how the outputs could be used to enhance restoration measures. Moreover, further detailed studies on a finer scale are required in these priority areas, which have the highest ecological values at the lowest cost and could act as stepping-stone areas or corridors.

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## Supplementary Materials

### Appendix A. The functioning of the InVEST habitat quality module, the variables and the structure and meaning of the tables for completion.

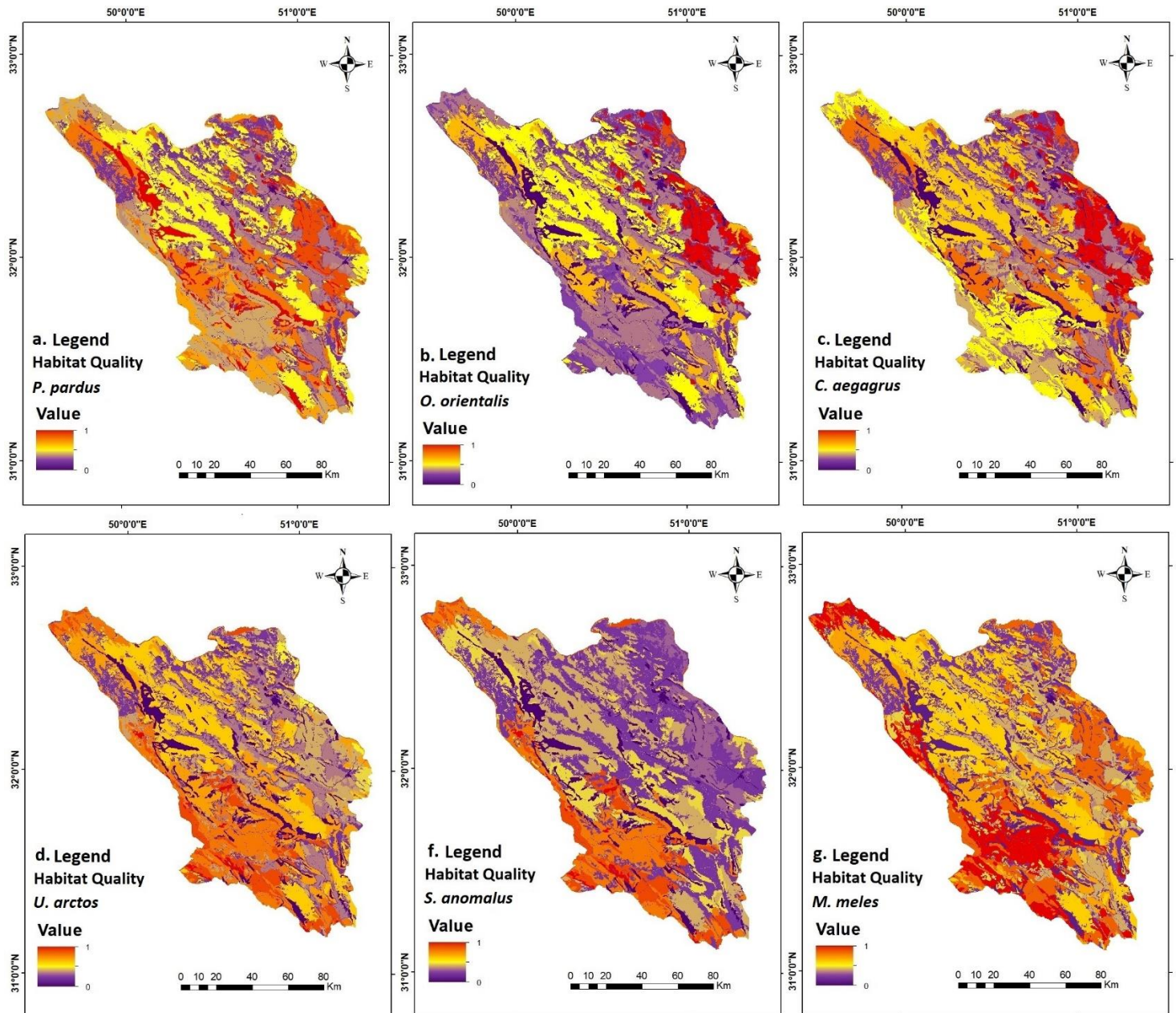
**Table S1.** The detailed questionnaires for determination of habitat suitability ( $H_j$ ) and the relative sensitivity of habitat types to threats ( $S_{jr}$ ) to map habitat quality for each target species, individually.

	Habitat Type	$H_j$ [0-1]	Relative sensitivity of habitat types to threats ( $S_{jr}$ )							
			urban	city	village	mine	first class	second class	third class	agriculture dry farming
1	Urban (Big city)									
2	City									
3	Village									
4	Mine									
5	First Class (Road)									
6	Second Class (Road)									
7	Third Class (Road)									
8	Permanent River									
9	Seasonal River									
10	Wetland									
11	Agriculture									
12	Dry Farming									
13	Scariola orientalis									
14	Astragalus app.									
15	No Range									
16	Outcrops									
17	Dense-Jungle									
18	Mod-Dense Jungle									
19	Low-Dense Jungle									

**Table S2.** Characteristics of threat sources required for the InVEST HQ model.  $W_r$  and  $D_{max}$  refer to the mean values of weights and maximum distance over which the threats affect habitat quality, and were obtained from expert knowledge and literature review (Sallustio et al., 2017; Terrado et al., 2016).

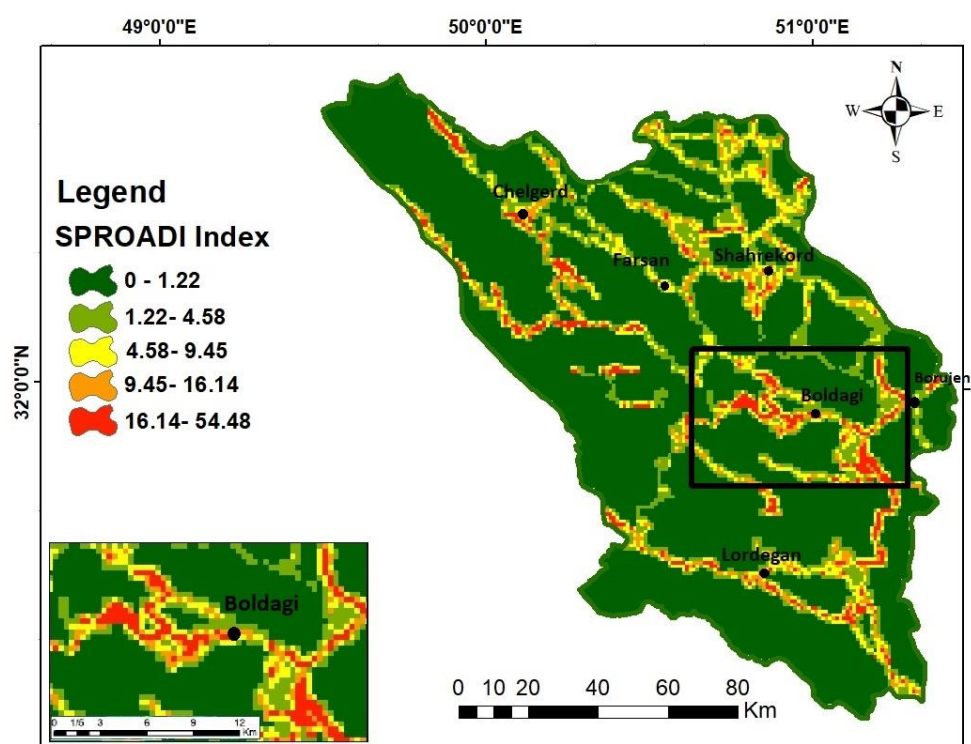
THREAT	$W_r$ [0-1]	$D_{max}$ (Km)	DECAY
Urban (Big City)	1	8	exponential
City	0.8	6.5	exponential
Village	0.6	5	exponential
Mine	0.8	6	exponential
First class	0.8	3	exponential
Second class	0.67	2	exponential
Third class	0.4	1	exponential
Agriculture	0.6	4	exponential
Dry farming	0.5	2.8	exponential

## Appendix B. Resulting map of habitat quality modelling of target species.

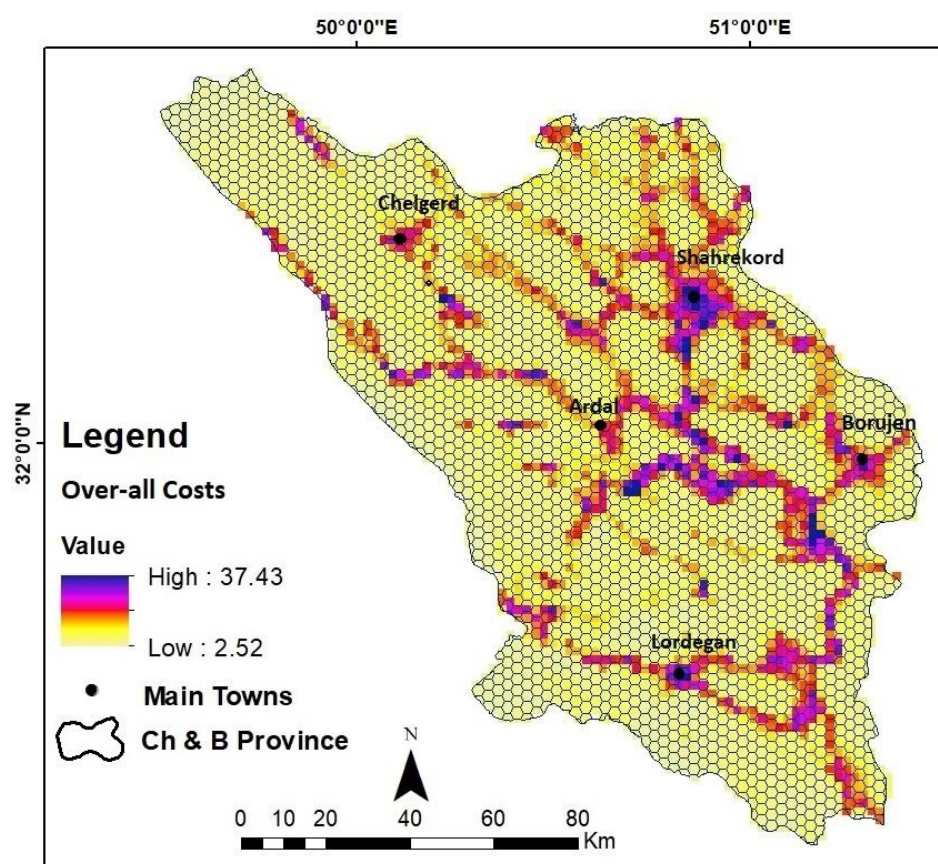


**Fig. S1.** Habitat Quality distribution of a) Persian leopard, b) brown bear, c) wild sheep, d) wild goat, f) Persian squirrel, and g) Eurasian badger at Chaharmahal and Bakhtiari

## Appendix C. Resulting maps of spatial road disturbance index and the overall cost map



**Fig. S2.** The SPROADI index map; high values in red represent high degree of road disturbance, low values in dark green represent low degree of road disturbance.



**Fig. S3.** The amount of costs for each planning units across the study area