Using a hybrid approach based on electrical circuit theory and the least cost method to determine possible corridors of Armenian Wild sheep (Ovis orientalis gmelini): A case study, west and northwest of Iran

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Abstract

Maintaining linkages between remaining natural areas is increasingly important to ameliorate the negative effects of habitat loss and fragmentation on wildlife populations. Identifying environmental corridors is critical to biodiversity conservation and landscape planning. In recent decades, many methods have been developed to increase ecological linkages and establish gene binding to prevent mismanagement of protected areas. However, the multiplicity and complexity of methods can be a barrier for conservation planners. Here, we combine a limited set of several methods to provide a connection analysis framework that provides iterative, intuitive, and environmentally related connection estimates. In this study, firstly we investigated the habitat suitability of Armenian Wild sheep as a target species by ecological niche factor analysis. Then, by using the theory of electrical circuits and analysis of the least cost route of habitat communication between habitat spots was investigated. Based on flow maps, movement patterns and functional communication were identified for the target species as well as important communication areas in the study area. The results show that based on the circuit theory approach, the flow through the pixels (nodes) is equivalent to the probability of species movement. Therefore, it can be interpreted that if the target species travel between the mentioned habitats, the sections with high flow intensity will be the most probable route for their passage. Identification of important communication areas in the region is another important result of flow maps. The protection of these important areas is very important.

Introduction

Today, the increase of the human population, especially the rapid growth of urbanization and the transformation of land cover from natural to non-pristine level has been identified as a global phenomenon (He et al. 2014; Ziv and Davidowitz, 2019). Wildlife habitat degradation directly leads to habitat fragmentation, which can be commonly observed in the suburbs of large cities (Newbold et al. 2015; Rodríguez-Rodríguez et al. 2019). In addition, habitat fragmentation, which reduces the level of the central core of conservation and increases fragmentation, can seriously impede the movement of species among habitat fragments. This factor leads to the loss of key biodiversity, area, and thus the limitation of local populations to small habitats. The result is an increase in internalization, a decrease in genetic diversity, an increase in demographic events, and thus an increased risk of extinction (Fletcher et al. 2018; Haddad et al. 2017; Haila, 2007; Randes et al. 2010). Increasing the connectivity of fragmented lands is one way to counter the effects of habitat segregation. The concept of communication routes and corridors is a practical and direct action to respond to the effects of habitat separation. Such corridors can connect fragments of disjointed habitats and effectively enhance species movement, which helps prevent regional biodiversity loss and damage to environmental processes (Sousa Miranda, et al. 2021; Correa Ayram et al. 2016; Rouget et al. 2006). In addition, environmental corridors can reduce the negative impacts of human activities on natural ecosystems and further maintain the stability and integrity of environmental processes (Ersoy et al. 2019; Pardini et al. 2005). Thus, environmental corridors are not a line but a belt with a specific spatial range (Dong et al. 2020). Conservation biology theory states that the construction of bonding structures increases life between isolated habitat spots or at least maintains levels of diffusion between spots. And therefore, it maintains gene flow and population biology (Gibson et al. 2004). Accordingly, the option of preserving corridors and artificial connections such as overpasses and underpasses to compensate for the negative and harmful effects of roads on wildlife as a suitable crossing should be given more importance (Wu et al. 2021).

Corridors have often been proposed as a strategy to connect habitat fragments and mitigate negative effects of fragmentation (Haddad et al., 2003; Sutcliffe and Thomas, 1996). Structural corridors (Baudry and Merriam, 1988) are narrow landscape components which connect two or more habitat cores (Clerici and Vogt, 2013) and enhance the “connectedness” of the landscape (Baudry and Merriam, 1988). The structural corridor concept is based on the spatial configuration of suitable habitats (physical continuity of habitat) without considering species’ behavioral responses to the landscape (Saura et al., 2011; Tischendorf and Fahrig, 2000). Functional corridors, on the other hand, describe the paths that animals would take between habitat patches whether these habitats are structurally connected to each other or not (Burel and Baudry, 2003; Farina, 2006; Taylor et al., 2006). Therefore, structural connectedness is not necessarily synonymous to functional connectivity (Tischendorf and Fahrig, 2000), and relying solely upon the concept of structural corridors (connectedness) ignores the species' reaction to the landscape structure and heterogeneous environments (connectivity) that affect the distribution of the species (Taylor et al., 2006).

The low-cost method (Adriaensen et al., 2003) and electrical circuit theory (McRae and Beier, 2007) are common methods for identifying areas of environmental corridors based on reproducible algorithms (Correa Ayram et al., 2016). And can even be used for data on poor species. In addition, these two methods offer different criteria for quantifying potential functional connectivity in selected environmental corridors (Calabrese & Fagan, 2004; Correa Ayram et al., 2016). Theoretical approaches have a high potential for practical protection (Zetterberg et al. 2010) and multi-scale communication analysis (Dilts et al., 2016; Tambosi et al. 2014); or compare connection estimates for different landscape scenarios (Clauzel et al. 2015; Mimet et al. 2016). The goal of many of these approaches is to improve the environmental relationship in the design of the protection network and increase the reproducibility of connection estimation while reducing subjectivity at all stages. However, the complexity of these analytical approaches has made their application in the design of protection networks slow and cumbersome (Kietzka et al. 2021; Bennett et al. 2006; Opdam et al. 2002; Rasco et al. 2016). In this study, we follow an approach that combines a set of different models that are well established to provide a relevant and intuitive environmental solution for corridor network design. Our goals are to provide a framework that includes (1) the power to adequately select existing methods available to application protection planners, (2) more targeted connection assessments, and (3) more environmentally relevant and informative than other traditional methods be for protection planning.

Armenian Wild sheep is an indicator species and umbrella that can put many other species such as carnivores, plant species, and other herbivores under its umbrella. On the other hand, the small and endangered populations in the western and northwestern regions of Iran were selected as the target species in this study. On the other hand, due to the morphological and demographic characteristics of this species, it is easier to observe and collect study data related to this study compared to other species. Also, the study area in this study is protected areas in the three western and northwestern provinces of Iran, which due to different development policies in each province, the habitats of this endangered species have been severely destroyed and limited. And providing a suitable approach for gene communication and linkage between these regions is strongly needed to provide practical and scientific protection and ultimately provide a conservation solution in line with current development issues. Therefore, the purpose of this study is to present a combined model of the electrical circuit theory method and the least cost method to determine possible corridors in the western and northwestern regions of Iran. In such a way as to provide an optimal solution for the practical protection of Armenian rams and, by its nature, other vulnerable species, it can also cover the shortcomings in providing optimal methods for determining environmental corridors in the research literature.

Study area

The study area (Fig 1) includes parts of three provinces of Kurdistan; Zanjan and West Azerbaijan. These areas include the main habitats of Armenian rams and ewes in three provinces and consist of the protected area of Abdul Razzaq and Bijar in Kurdistan province, Bayan wildlife refuge in West Azerbaijan province and protected area, and Angoran wildlife sanctuary in Zanjan province. In the following figure, the studied habitats on the map it has been shown.

Wild sheep occur in arid and semiarid habitats in Iran, and is a vulnerable species according to the Red List of the International Union for Conservation of Nature (IUCN) (Valdez, 2008). Wild sheep populations have been extirpated in many areas throughout their geographical range due to hunting, habitat destruction and competition with livestock (Valdez, 2008; Ziaei, 2008). There are currently protected areas in Iran, where wild sheep can be seen (Bashari and Hemami, 2013), but those areas have been selected on an ad-hoc basis (Momeni Dehaghi et al., 2013) without considering connectivity. Currently, migration of wild sheep in central Iran is faced with threats such as hunting and road construction (Ziaei, 2008). Here we compared the association between structural and functional corridors of wild sheep in the west of Iran. To address this question, we first used habitat suitability modeling to determine high-quality habitats, graph theory to model a proxy of functional corridors and image processing techniques to delineate structural corridors of wild sheep. We then compared the modeled functional corridors and structural corridors.

Method

In this study, habitat suitability assessment modeling to determine the habitats of ram and ewe species was performed by ecological nest analysis method and then using the methods of electrical circuit theory and the minimum cost method of potential emission network and possible corridors between habitats are modeled. This approach involves identifying potential and actual habitats for the species in the study area.

Preparation of habitat suitability of Armenian rams and ewes in the study area using ecological niche factor analysis method:

In this study, the method of ecological niche factor analysis and Bio mapper software was used to prepare a habitat suitability model, and also Idrisi software was used to analyze the sensitivity and also to construct information layers and enter them into Bio mapper software. The information layers required for analysis in Bio mapper software can be classified into two categories of information layers including Work maps and Ecogeographical maps. These layers were first prepared and adjusted in Idrisi software and then entered into Bio mapper software: Calculation of habitat suitability map is possible only based on the presence data of the target species and, therefore, saves time and money in providing the required information (McRae and Beier, 2007). The ecological niche factor analysis method is the central part of Bio mapper software. This method, like principal component analysis 1, summarizes environmental variables into a smaller number of non-correlated variables called factors, with the difference that factors are ecologically significant and can be considered as new variables are used in the habitat suitability model (Walpole et al. 2012; McRae and Beier, 2007; Huntera et al. 2003).

Work map. This map includes a map of the present areas of the species understudy in the region and can be a point map (species presence points) or a polygon (species range). The minimum number of species presence points for this software depends on several factors such as the variability of the study area, the degree of specialization of the species, and the degree of study accuracy. In this study, the random linear transect sampling method was performed by direct observation or identification of ram and ewe indices (dung, footprint, resting place) and was prepared in vector form. This map is first in raster format and then it became a Boolean map to be included in the ENFA analysis (Figure 2).

Eco geographical maps:

Contains information and independent habitat variables on which the presence or absence of the species depends. Raster maps of biogeographic variables affect species presence and are used as independent variables. Biogeographic variables are spatial factors of the study area and describe the quantitative features of the area (Hirzel et al. 2007) preparing independent biogeographic variables maps for this species is as follows:

1- Preparing a list of effective biogeographical variables in the presence of the target species

Raster maps of digital elevation model (using 22-meter level line map), slope and direction (based on digital elevation model), villages adjacent to the area, water resources including permanent and seasonal springs and rivers, roads Machinery, environmental checkpoints, and land cover were provided.

2- Restoring the maps in Idrisi software and paying attention to the same format of all maps.

Uniformity of maps means that their coordinate system is the same, latitude and longitude, layer type, layer format, number of rows and columns, and any parameter that exists in the information table of the desired variable. For this purpose, one layer can be specified as a template and the rest of the layers can be prepared based on it. In this study, the DEM raster map of the region was selected as a model.

Data analysis:

The steps that are done in Bio mapper software are:

1- Calling biogeographic maps and species presence map

1- Reducing layers: As mentioned, for maps to be biologically meaningful, they must be quantified. For this purpose, there are two methods of circular and direct analysis.

3. Because biogeographic maps as well as species presence maps should have a normal distribution, therefore, their status should be checked, and then the Kolmogorov-Smirnov test should be performed to ensure the normality of the data. If the data is not normal, normalization by the Box-Cox method, which can be implemented in the Bio mapper, is recommended.

4. Mask the sum of the map of independent and dependent variables to ensure that they cover the same area.

5- It is possible to compare the uniformity and usability of the maps from the Verify path. In this operation, the homogeneity of the underlying cell values, etc., is checked. Heterogeneous layers are identified in this step.

6- Investigating the correlation between biogeographic maps through correlation matrix. At this stage, correlated layers (correlation above 0.85 in this study) should be removed. Because this analysis requires variables that are independent and non-correlated, in the ecological nest factor analysis, if two variables are correlated, both will appear with a coefficient in the model. It is up to the ecologist to decide whether to keep both layers or remove one of them. Variables that do not explain a significant amount of change are removed from the final model.

7- Performing factor analysis of ecological niche.

8- Calculating the factors required to prepare a habitat suitability map.

9- Calculation of habitat suitability map.

Results

Implementation of ENFA Bio mapper

ENFA analysis is performed based on raster information layers in this software. Hence, the first step is to enter the data into the software. Maps are classified into two categories: maps of species presence points and maps of independent environmental variables. For this step, the correlation matrix of EGV maps was calculated. The correlation between the variables was less than the critical rate for deleting one of the variables. Therefore, all remaining variables were used for ENFA analysis.

Table 1. Investigation of the degree of correlation of independent environmental layers

Correlation matrix:

	aspect	dem	land cover	river	road	slop	village
aspect	1	0.759	0.635	0.313	0.306-	0.597	0.371-
dem	0.759	1	0.831	0.399	0.39-	0.722	0.482-
Land cover	0.635	0.831	1	0.29	0.318-	0.659	0.506-
river	0.313	0.399	0.29	1	0.191-	0.28	0.163-
road	0.306-	0.39-	0.318-	0.191-	1	0.169-	0.467
slop	0.597	0.722	0.659	0.28	0.169-	1	0.3-
village	0.371-	0.482-	0.506-	0.163-	0.467	0.3-	1

After determining the degree of correlation, factor analysis of the ecological niche is performed. This analysis is similar to principal component analysis. The two important outputs of factor analysis of ecological nests are eigenvalues and score matrices, which contain the two main components of marginality and specialization, and must be carefully examined to understand the current situation ecologically.

Ecological Niche Factor Analysis (ENFA):

ENFA analysis forms the core of Bio mapper software. The ENFA analysis, similar to the Principal Component Analysis, calculates factors that explain much of the impact of species-independent environmental variables. Similar to principal component analysis, the calculated factors are not correlated with each other but are ecologically significant. The first column of the score matrix or eigenvector always represents 100% of the marginalization factor and 10 to 70% of the specialization factor, while the other columns, or in other words the number of independent environmental variables minus one, only represent the factor of specialization. The rows show the share of independent variables in each factor. In fact, in this matrix, the factors that explain sufficient information as well as the variables that show the highest coefficient (absolute value) will be very important in expressing the species distribution. Factors with a value of almost zero can be eliminated (Tables 3).

Table 2- Score matrix

Score matrix

	1	2	3	4	5	6	7
aspect	0.816-	0.172-	0.077	0.227-	0.47	0.14	0.085
dem	0.935-	0.122-	0.051	0.052-	0.008	0.133-	0.297-
Land cover	0.873-	0.092-	0.18	0.11	0.091-	0.385-	0.169
river	0.468-	0.181-	0.851-	0.149	0.011-	0.011	0.029
road	0.507	0.716-	0.169	0.423	0.149	0.003-	0.03-
slop	0.773-	0.375-	0.178	0.044-	0.361-	0.309	0.047
village	0.628	0.551-	0.125-	0.504-	0.078-	0.16-	0.008

The first factor is marginalism and expresses the difference between the average habitat preference of a species or species distribution and the average habitat conditions or general distribution. In other words, this factor indicates the distance between the desired conditions of the target species and the prevailing conditions in the habitat. The value of marginalization is often between zero and one. Values close to zero indicate that the species tend to live in the mean conditions of the study area and there is no difference between the mean of the existing habitat and the species habitat. Values close to one indicate that the species lives in very special habitat. Marginality indicates the position of ecological niches in the environment. The second factor of ecological nests is specialization, which indicates the extent of ecological nests. Specialism is the ratio of variability or standard deviation of the general distribution to the variability or deviation of the species distribution. In other words, this factor is a measure of the range of environmental conditions that the species tolerates. In this case, values close to zero indicate that the target species can survive in a wide range of environmental conditions. High values of this factor indicate that the species is very specialized and lives in a narrow range of environmental conditions and, therefore, has a small ecological nest. The tolerance factor is the opposite of specialization and its values close to zero indicate the low tolerance of the species and its specialization. Conversely, On the contrary, the high values, while expressing the high tolerance of the species, indicate that the species does not need very special and special conditions in the habitat for life.

tolerantly	specialization,	Marginality,
489/0	366/12	664/0

Table 3. Table of scores and correlations between ecological niche factors analysis and independent environmental variables.

Score table

Ecogeographic maps	Factor 1 (54%)	Factor 2 (15%)	Factor 3 (12%)	Factor 4 (7%)	Factor 5 (6%)	Factor 6 (4%)	Factor 7 (2%)
aspect-box	——	**	*	**	*****	*	*
dem-box	———	*	*	*	0	*	***
land-box_cover	———	*	**	*	*	****	**
river-box	—	**	*********	*	0	0	0
road-box	+++++	*******	**	****	*	0	0
slop-box	——	****	**	0	****	***	0
VILLAGE-box_FIN	++++++	******	*	*****	*	**	0

The first column represents 100% marginalization. The numbers in parentheses indicate the percentage of agent specialization. Signs (+) for the marginalization factor indicate that rams and ewes are present in habitats with values higher than the average habitat conditions, and signs (-) are the opposite. The number of symptoms indicates the degree of correlation. In the case of specialization, the sign (*) indicates the presence of rams and ewes in a narrow range of conditions. The number of these symptoms is a sign of a limited range of presence. The numbers zero indicate specialization as well as very low correlation.

Habitat suitability map:

A habitat suitability map is a map whose value of each cell is equal to the percentage of the desirability of that part of the habitat for the species. After performing ENFA analysis and obtaining the relevant outputs, the habitat suitability map can be calculated. The first step in calculating the habitat utility map is to calculate the Factor map. The results of this analysis are required to calculate the habitat utility map. The important point in this analysis is to determine the number of ENFA maps included in the Habitat suitability analysis. In Factor map analysis, the user determines how many ENFA maps are generated during this analysis. Of course, the Biomapper itself suggests the number of ENFA maps based on the Mc-Arthur broken wood criterion, but the user can determine this number himself based on the cumulative amount of variance justified by the factors.

Least cost path and circuit modeling approaches:

Two straightforward premises underlie the least cost path (LCP) to pass between two points involves encounters with topographic, natural, and/or cultural features that impede movement the optimal path of travel can be calculated by finding the one that passes between points with the minimum accumulation of these impediments or ‘costs’ (Atkinson et al. 2005; Berry, 2004; Collischonn and Pilar, 2001; Douglas, 1994; Lee and Stucky, 1998; van Leusen, 2002). LCP modeling identifies a single optimum solution for individuals of a species group to travel across a landscape. In many ways, the fact that LCP modeling produces one specified travel route has made this approach attractive to researchers but this modeling is not free from limitations.

LCP modeling assumes a traveler has complete knowledge of the landscape they are traversing (McRae et al. 2008) and operates under the assumption that they will be both able and willing to select the lowest single path cost based on this knowledge. However, individuals can be isolated in landscapes, unaware of potential matrix heterogeneity they will experience as they disperse across a landscape, making them unable to select a single optimum route. Even when individuals have landscape knowledge, various factors can lead to divergences from optimum path selection. For instance, optimum paths can become blocked or closed to dispersers. Moreover, individual travel preferences can change; across species “individuals rarely use a single optimum route” and thus LCP “fails to incorporate variation in individual behavior” (Pinto and Keitt, 2009).

Circuit modeling attempts to move away from the limits of LCP modeling’s reflection of the movement cost accrued by a single individual by using a concept of resistance distance that incorporates both the minimum movement distance (or cost) and the availability of alternative pathways. Unlike least-cost path modeling, as additional links are added, individuals do not necessarily travel shorter paths but have more pathways available to them (McRae et al. 2008).

Three interconnected layers of theory underlie circuit modeling: graph theory, network theory, and circuit theory (and associated with this is random walk theory). In short, graph theory is the branch of mathematics concerned with connections among discrete objects; network theory applies graph theory with a focus on properties of real-world networks, their structural dynamics, and the relationship between their structure and function; and circuit theory applies network theory to quantify connectivity in circuited systems that respond positively to the presence of alternative pathways (Rayfield et al. 2011). Random walk theory facilitates circuit theory’s application to species movement in a landscape by assuming random dispersal of species, the fates of random walkers on circuits can be predicted by resistance, conductance, effective resistance, effective conductance, current, and voltage (see McRae et al. 2008; Shah and McRae, 2008 for a more detailed description of measures).

Applying circuit theory to find optimal paths:

Circuit theory uses theory-based theory to model the communication of wildlife populations in the appearance of heterogeneous lands. This software is the most common application that models the movement and flow of genes for plants and animals, as well as identifies important areas for conservation and connection between habitats. Circuit theory uses land use data to predict and identify habitat relationships. Electrical circuits are networks consisting of nodes that are connected by electrical components that conduct current. According to Ohm's law, when a voltage (V) is established between two nodes, the total current flow depends on the amount of voltage and the resistance of the resistors

(Mertzanis et al. 2006). In this theory, electrical nodes are considered as habitat spots, current movement as the movement of individuals, and resistors between nodes are considered as habitat paths or corridors. Increasing the number of parallel resistors increases the current flowing through the nodes. Increasing the number or extent of habitat spots connecting populations and habitats also increases the likelihood of movement and communication between them. Landscape circuit theory considers the surface as a conductive surface in which each pixel is converted into an electrical node and an electrical circuit is formed by connecting adjacent nodes (Roever et al. 2013). The results of this theory are current and voltage maps. The intensity of the electric current indicates the possibility of movement of people in the landscape. In addition, by using the flow map, it is possible to identify important corridors and communication areas in the landscape. Voltage, which indicates the amount of electric current flux difference between two nodes in a circuit, can also be used to predict the probability of an individual arriving from a point in the circuit to a specific destination, or in other words, to predict the success rate of individuals. (Srisang et al. 2007). The superiority of this model over other common analytical models that study habitat relationships is in identifying multiple pathways for species distribution (Minor and Urban, 2007). The advantage of this method is that if one or more of the diffusion and migration routes are lost at some point, the importance of the other remaining predicted routes increases. More importantly, the communication models resulting from this theory are very close to how the species move in the landscape. The idea of using habitat suitability models to calculate resistance is that in the landscape, pixels with desirable habitat characteristics, such as low human population density and the absence of roads, have little resistance to species passage, while Pixels with poor habitat characteristics such as agricultural land, high human population density, and roads show high resistance to species movement (Minor and Urban, 2007). This means that there is an inverse relationship between resistance and habitat suitability. Therefore, the relevant layer can be used to prepare the resistance layer (Hirzel et al. 2007). The inverse resistance layer is the habitat utility layer. Where the value of the pixels is high, it means that there are many obstacles to the movement of the species and the species is less inclined to move in those directions.

Map of main nodes

Habitat maps show the resistance of each pixel of the land landscape to the conductivity of the flow conductor (SalmanMahiny and Kamyab, 2011). This map shows spots or polygons (usually the main habitats) that indicate the degree of habitat connection they are modeled (Roever et al. 2013). Here, about fifty major nodes are shown as high-habitat patches and as a map of the main nodes.

Since the electrical circuit program uses data in ASCII format, after preparing the layers in the Idrisi environment, their format became the desired format.

Execution of electrical circuits program

By converting habitat raster pixels to nodes and connecting each of them to the nearest adjacent nodes, the program forms networks and calculates the intensity of the flow through the nodes (communication or the possibility of propagation of individuals). Slowly the electrical current between the nodes is calculated based on the average resistance or the average amount of conductivity between the nodes. Because the selected raster map of the habitats showed the resistance of the study area, the relationship was calculated based on the mean resistance. Circuit theory uses one of the following four methods to calculate the relationship between nodes.

1- Pairwise: In this method, the relationship between the two nodes (pixels) is calculated. In this method, one node is optionally connected to the output (Ground) and the other node to a current source of one ampere (Source), and the current passing through the two nodes is calculated and this process is repeated between all pairs of nodes.

2-: One - to - all in this method, one node is connected to the current source of one ampere and the other nodes are connected to the ground and the process is repeated for each node.

-: All-to-one in this model, one node is connected to the ground and the other nodes are connected to a current source of one ampere. This method is a good alternative to the first method. Especially when the goal is to map important communication areas between multiple habitats.

4-Advanced mode: In this method, the user has the option to specify any number of input (Source) and output (Ground) for the electric current in the landscape (Roever et al. 2013). In this study, the third model was used to calculate the electric current. Because it shows important areas for habitat communication better than the other three models, it also runs faster and requires less memory.

Preparation of electric current map (corridors between two habitats)

Here, the One - to - all method is used to determine the optimal network model of corridors and the results of the implementation of circuit theory in the form of a flow intensity map for rams and ewes are shown in Figure 8. In this model, the value of each pixel indicates the intensity of the current passing through that pixel (node) or in other words the probability of the species moving from one habitat spot to other spots. Warmer (brown) colors indicate higher flow intensities than diffusers, which can be seen in different parts of the study area. As we move towards lighter browns, the flow rate decreases, and consequently the probability of propagation decrease. In bold areas, the probability of species movement is very high, but the small width of some areas makes communication very vulnerable.

Identifying the areas where the movement of the flow, or in other words the movement of the species through the narrow zone, is one of the most important results of the flow maps for the target species. These important communication areas, called pinch points, are the most sensitive and vulnerable parts of the communication network because the elimination or reduction of habitats in these areas can disrupt or cut off communication in the whole area.

Habitat corridor modeling

Least-cost modeling is a method used for measuring the effective distance, rather than the Euclidian distance, between habitat patches. This method has been used in planning to assess the connectivity of existing or proposed reserves. GIS technology is an important tool for conducting least-cost analyses. Typically, a resistance surface in raster format is the input to the least-cost modeling. This resistance surface is derived from one or more spatially explicit variables such as animal-habitat relationships distance to development or other avoided areas, topography, physical barriers such as fences, roads, or streams. GIS habitat layers in polygon or grid format are weighted according to the expected resistance encountered by an organism when moving across the surface and linear features are then merged with the weighted resistance surface. Care must be taken when adding narrow features to the resistance surface to ensure that the narrow features are completely connected. ‘Cracks’ in narrow linear features may allow the least-cost path to incorrectly pass through an area with high resistance.

We used CorridorDesigner software in ArcGIS 10.2 to model habitat corridors. CorridorDesigner identifies least-cost corridors between termini (start–end locations). We identified a terminus in each core area as the set of all potential population patches within the core area.

Discussion And Conclusion

One of the main goals of this study was to analyze the overlap of structural and functional corridors of wild sheep, a threatened species in semi-arid area in the west of Iran. To address this goal, we used mathematical morphology and circuit theory to map structural and functional corridors of wild sheep respectively. In accordance with Van Looy et al. (2014) our results revealed a mismatch between structural and functional corridors, suggesting that Conservation planning cannot rely on structural corridors alone. Protecting structural corridors may therefore have limited efficacy in this region. The exact proportion of animal movement occurring in structural corridors likely depends on the configuration of protected areas and structural corridors. Nevertheless, these results are in agreement with observations from local communities and conservation officers.

We gained incomplete information from interviews with locals which was limited to few villages. In the future, systematic interview with informed locals is recommended to gather more extensive data on brown bear presence in the study area. Iranian protected areas are close to the VI category of the IUCN, whereas wildlife refuges and national parks resemble the IV and II categories of the IUCN, respectively (Lausche and Burhenne-Guilmin2011). Based on the modeled connectivity, connectivity currently occurs among some habitat patches of the wild sheep in the study area. Without doubt, local education on values of the wild sheep in the region could also be effective along with appropriate law enforcement to reduce sheep–human conflicts and consequently enhance wild sheep conservation in both habitat patches and areas of connectivity (Baruch-Mordo et al. 2011).

Maintaining and restoring communication in different parts of the country's landscape requires communication models and indicators that are reliable and efficient. One of these models is the communication model which is based on the theory of electrical circuit and has been used to predict the movement pattern in the landscape, identify important habitat spots and corridors to plan for protection (McRae, 2006). In this study, this modeling approach was used to investigate habitat relationships and identify migration corridors for the vulnerable species of Armenian rams and ewes in the study area in three provinces of Kurdistan, Zanjan, and Azerbaijan. Because according to the circuit theory approach, the flow through the pixels (nodes) is equivalent to the probability of species movement, it can be interpreted that in the case of ram and ewe traffic between the mentioned habitats, the sections with high flow intensity will be the most probable route for their passage. Identification of important communication areas in the region is another important result of flow maps. The protection of these important areas is very important.

Although accuracy assessment of our results is mainly based on conservation officers' observations, we solicited information from only the experienced ones in our study with a good knowledge of the study area and species. Of course to obtain more robust results in future research, application of tracking methods and gene flow analysis are suggested. On the other hand, to produce landscape resistance against the movement of wild sheep, we used inverse of habitat suitability as a common method. Comparison of our results with resistance layers derived from land-cover, topography, and level of human disturbance are also suggested for future studies.

Declarations

Conflicts of interest

The authors declare no conflict of interest.

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Authors' contributions

HR: conceptualizing, reviewing, and writing. FH: writing, has reviewed the paper and helped to respond to the paper's questions. KA: has reviewed the paper, edited grammar, and helped to respond to the paper's questions. MM: has collected environmental data and reviewed it. All authors read and approved the final manuscript.

References

1. Adriaensen, F., J.P. Chardon, G. De Blust, E. Swinnen, S. Villalba, H. Gulinck, and E. Matthysen. (2003). The application of 'least-cost' modelling as a functional landscape model. Landscape and Urban Planning 64:233–247. http://dx.doi.org/10.1016/S0169-2046(02)00242-6.
2. Atkinson, D., Deadman, P., Dudycha, D., Traynor, S., 2005. Multi-criteria evaluation and least cost path analysis for an arctic all weather road. Applied Geography 25, 287e307.

3. Bashari, H., Hemami, M.R., 2013. A predictive diagnostic model for wild sheep (Ovis orientalis) habitat suitability in Iran. J. Nat. Conserv. 21, 319–325.
4. Baruch-Mordo S, Breck SW, Wilson KR, Broderick J (2011) The carrot or the stick? Evaluation of education and enforcement as management tools for human-wildlife conflicts. PLoS One 6(1):e15681
5. Beier, P., Noss, R .F. (1998). Do habitat corridors provide connecti vity? Conservation Biology.12(6). 1241–1252. http://dx.doi.org/10.1111/j.1523-1739.1998.98036.x.
6. Beier, P., D.R. Majka, and W.D. Spencer. (2008). Forks in the road: Choices in procedures for designing wildland linkages. Conservation Biology 22:836–851. https://doi.org/10.1111/j.1523-1739.2008.00942.x.
7. Bennett, A. F., Crooks, K. R., & Sanjayan, M. (2006). The future of connectivity conservation. In K. R. Crooks, & M. Sanjayan (Eds.). Connectivity conservation (pp. 676– 694). Cambridge, UK: Cambridge University Press.
8. Berry, J. (2004). Optimal Path Analysis and Corridor Routing: Infusing Stakeholder Perspective in Calibration and Weighting of Model Criteria. http://www.innovativegis.com/basis/present/GeoTec04/GIS04_Routing.htm.
9. Burel, F., Baudry, J., 2003. Landscape Ecology : Concepts, Methods, and Applications. Science Publishers, Enfield, N.H.
10. Baudry, J., Merriam, H.G., 1988. Connectivity and connectedness: functional versus structural patterns in landcapes. In: Schreiber, K.F. (Ed.), Connectivity in Landscape Ecology. Proceedings of the 2nd International Seminar. International Association for Landscape Ecology.
11. Calabrese, J. M., & Fagan, W. F. (2004). A comparison-shopper's guide to connectivity metrics. Frontiers in Ecology and the Environment, 2(10), 529–536. https://doi.org/10.1890/1540-9295(2004)002[0529:ACGTCM]2.0.CO;2.
12. Clauzel, C., Xiqing, D., Gongsheng, W., Giraudoux, P., & Li, L. (2015). Assessing the impact of road developments on connectivity across multiple scales: Application to Yunnan snub-nosed monkey conservation. Biological Conservation, 192, 207–217. http://dx.doi.org/10.1016/j.biocon.2015.09.029.
13. Collischonn, W., Pilar, J.V. (2001). A direction dependent least-cost path algorithm for roads and canals. International Journal of Geographical Information Science 14, 397e406. https://doi.org/10.1080/13658810050024304.
14. Correa Ayram, C. A., Mendoza, M. E., Etter, A., & Salicrup, D. R. P. (2016). Habitat connectivity in biodiversity conservation: A review of recent studies and applications. Progress in Physical Geography, 40(1), 7–37. https://doi.org/10.1177/0309133315598713.
15. Dilts, T. E., Weisberg, P. J., Leitner, P., Matocq, M. D., Inman, R. D., Nussear, K. E., & Esque, T. C. (2016). Multiscale connectivity and graph theory highlight critical areas for conservation under climate change. Ecological Applications, 26(4), 1223–1237. http://dx.doi.org/10.1890/15-0925.

16. Douglas, D.H. (1994). Least-cost path in GIS using an accumulated cost surface and slopelines. Cartographica 31, 37e51. https://doi.org/10.3138/D327-0323-2JUT-016M.
17. Dong, J., Peng, J., Liu, Y., Qiu, S., Han, Y. (2020). Integrating spatial continuous wavelet transform and kernel density estimation to identify ecological corridors in megacities. Landscape and Urban Planning. 199 (2020) 103815. https://doi.org/10.1016/j.landurbplan.2020.103815.
18. Estrada, E., and O. Bodin. (2008). Using network centrality measures to manage landscape connectivity. Ecological Applications 18:1810–1825. https://doi.org/10.1890/07-1419.1.
19. Ersoy, E., Jorgensen, A., & Warren, P. H. (2019). Identifying multispecies connectivity corridors and the spatial pattern of the landscape. Urban Forestry and Urban Greening, 40, 308–322. https://doi.org/10.1016/j.ufug.2018.08.001.
20. Fletcher, R. J., Didham, R. K., Banks-Leite, C., Barlow, J., Ewers, R. M., Rosindell, J., .Haddad, N. M. (2018). Is habitat fragmentation good for biodiversity? Biological Conservation, 226, 9–15. https://doi.org/10.1016/j.biocon.2018.07.022.
21. Farina, A., 2006. Principles and Methods in Landscape Ecology-towards a Science of the Landscape, 2th ed. Springer, Netherlands.
22. Gibson, L.A., Wilson, B. A., Cahill, D. M. and Hill, J. (2003). Modelling habitat suitability of the swamp antechinus (Antechinus minimus maritimus) in the coastal heathlands of southern Victoria, Australia. Biological Conservation 117(2):143–150. http://dx.doi.org/10.1016/S0006-3207(03)00288-X.
23. Clerici, N., Vogt, P., 2013. Ranking European regions as providers of structural riparian corridors for conservation and management purposes. Int. J. Appl. Earth Obs. Geoinf. 21, 477–483.
24. Haddad, N. M., Gonzalez, A., Brudvig, L. A., Burt, M. A., Levey, D. J., & Damschen, E. I. (2017). Experimental evidence does not support the Habitat Amount Hypothesis. Ecography, 40(1), 48–55. https://doi.org/10.1111/ecog.02535.
25. Haddad, N.M., Bowne, D.R., Cunningham, A., Danielson, B.J., Levey, D.J., Sargent, S., Spira, T., 2003. Corridor use by diverse taxa. Ecology 84, 609–615.
26. Haila, Y. (2007). A conceptual genealogy of fragmentation research: From island biogeography to landscape ecology. Ecological Applications, 12(2), 321. https://doi.org/ 10.2307/3060944.
27. He, C., Liu, Z., Tian, J., & Ma, Q. (2014). Urban expansion dynamics and natural habitat loss in China: A multiscale landscape perspective. Global Change Biology, 20(9), 2886–2902. https://doi.org/10.1111/gcb.12553.
28. Hilty, J.A., W.Z. Lidicker, Jr., and A.M. Merenlender. (2006). Corridor ecology. The science and practice of linking landscapes for biodiversity conservation. Island Press, Washington, DC, USA.
29. Hirzel, A. H., Hausser, J., perrin, N. 2007. Biomapper 4.0, Laboratory for Conservation Biology, Department of Ecology and Evolution, University of Lausanne, Switzerland. URL, Viewed 10 November 2010. <http://www2.unil.ch/biomapper>.
30. Huntera, L., G. Balme, C. Walker, K. Pretorius, And K. Rosenberg. (2003). The landscape ecology of leopards (Panthera pardus) in northern KwaZula-natal, south Africa: A preliminary project report.

Ecological journal.
31. Kietzka, G, J., Pryke, J, S., Gaigher, R., Samways, M, J. (2021). Webs of well-designed conservation corridors maintain river ecosystem integrity and biodiversity in plantation mosaics. Biological Conservation. 254. 108965. https://doi.org/10.1016/j.biocon.2021.108965.
32. Lausche BJ, Burhenne-Guilmin F (2011) Guidelines for protected areas legislation. IUCN
33. Lee, J., Stucky, D. (1998). On applying viewshed analysis for determining least-cost paths on digital elevation models. International Journal of Geographical Information Science 12, 891–905.
34. McRae, B. H. (2006). Isolation by resistance. Journal of Evolution 60: 1551–1561.
35. McRae, B. H. and P. Beier. (2007). Circuit theory predicts gene flow in plant and animal populations. Journal of Proceedings of the National Academy of Sciences of the United States of America 104: 19885–19890. https://doi.org/10.1073/pnas.0706568104.
36. McRae, B. H, B.Dickson, T. H. Keitt, and V. Shah. (2008). Using circuit theory to model connectivity in ecology, evolution and conservation. Journal of Ecology 89(10): 2712–2724. http://dx.doi.org/10.1890/07-1861.1.
37. Mertzanis, G., Korakis, G., Kallimanis, A., Sgardelis, St., Aravidis, I. (2006). Bear habitat suitability in relation to habitat types of European interest in NE pindos mountain range, Greece. Pp: 321–326.
38. Mimet, A., Clauzel, C., & Foltête, J.-C. (2016). Locating wildlife crossings for multispecies connectivity across linear infrastructures. Landscape Ecology, 31(9), 1955–1973. http://dx.doi.org/10.1007/s10980-016-0373-y.
39. Minor, E. S., D. L. Urban. (2007). Graph theory as a proxy for spatially explicit population models in conservation planning. *Journal of Ecological Applications* 17: 1771–1782. https://www.jstor.org/stable/40062073.
40. Momeni Dehaghi, I., Salman Mahiny, A., Alizadeh Shabani, A., Karami, M., 2013. Efficiency of current reserve network in Golestan province (Iran) for the protection of hoofed ungulates. Biodiversity 14, 162–168.
41. Newbold, T., Hudson, L. N., Hill, S. L. L., Contu, S., Lysenko, I., Senior, R. A., Purvis, A. (2015). Global effects of land use on local terrestrial biodiversity. Nature, 520(7545), 45–50. https://doi.org/10.1038/nature14324.
42. Noss, R.F., H.B. Quigley, M.G. Hornocker, T. Merrill, and P.C. Paquet. (1996). Conservation biology and carnivore biology in the rocky mountain. Conservation Biology 10:949–963. https://www.jstor.org/stable/2387132.
43. Opdam, P., Foppen, R., & Vos, C. (2002). Bridging the gap between ecology and spatial planning in landscape ecology. Landscape Ecology, 16, 767–779. https://doi.org/10.1023/A:1014475908949.
44. Pardini, R., De Souza, S. M., Braga-Neto, R., & Metzger, J. P. (2005). The role of forest structure, fragment size and corridors in maintaining small mammal abundance and diversity in an Atlantic forest landscape. Biological Conservation, 124(2), 253–266. https://doi.org/10.1016/j.biocon.2005.01.033.

45. Pinto, N., Keitt, T. (2009). Beyond the least-cost path: evaluating corridor redundancy using a graph-theoretic approach. Landscape Ecology 24, 253e266. http://dx.doi.org/10.1007/s10980-008-9303-y.
46. Rands, M. R. W., Adams, W. M., Bennun, L., Butchart, S. H. M., Clements, A., Coomes, D. Vira, B. (2010). Biodiversity conservation: Challenges beyond 2010. Science, 329(5997), 1298–1303. https://doi.org/10.1126/science.1189138.
47. Rayfield, B., Fortin, M., Fall, A. (2011). Connectivity for Conservation: a Framework to Classify Network Measures. Ecology, prepublished. 92(4):847 – 58. https://doi.org/10.1890/09-2190.1.
48. Roever, C. L., A. R. J. Van., K. Leggett. (2013). Functional connectivity within conservation networks: Delineating corridors for African elephants. Journal of Biological Conservation 157: 128–135.
49. Resasco, J., Bruna, E., Haddad, N., Banks-Leite, C., & Margules, C. (2016). The contribution of theory and experiments to conservation in fragmented landscapes. Ecography, 40, 109–118. http://dx.doi.org/10.1111/ecog.02546.
50. Rodríguez-Rodríguez, D., Sebastiao, J., Salvo Tierra, Á. E., & Martínez-Vega, J. (2019). Effect of protected areas in reducing land development across geographic and climate conditions of a rapidly developing country, Spain. Land Degradation and Development, 30(8), 991–1005. https://doi.org/10.1002/ldr.3286.
51. Rouget, M., Cowling, R. M., Lombard, A. T., Knight, A. T., & Kerley, G. I. H. (2006). Designing large-scale conservation corridors for pattern and process. Conservation Biology, 20(2), 549–561. https://doi.org/10.1111/j.1523-1739.2006.00297.x.
52. SalmanMahiny, A. R. Kamyab, H. R. (2011). Remote sensing and applied geographic information systems with Idrissi software (translation). By Eastman, vol. Ronald. Mehr Mehdis Publications .596 p. (In Persian).
53. Saura, S., Vogt, P., Velázquez, J., Hernando, A., Tejera, R., 2011. Key structural forest connectors can Be identified by combining landscape spatial pattern and network analyses. For. Ecol. Manag. 262, 150–160.
54. Shah, V.B., McRae, B.H. (2008). Circuitscape: a tool for landscape ecology. In: Varoquaux, G., Vaught, T., Millman, J. (Eds.), Proceedings of the 7th Python in Science Conference (SciPy 2008), pp. 62–66.
55. Sousa Miranda, L,d., Awade, M., Jaffé, R., França Costa, W., Carreira Trevelin, L., Cabral Borges, R., Melo de Brito, R., Reverberi Tambosi, L., Cristina Giannini, T. (2021). Combining connectivity and species distribution modeling to define conservation and restoration priorities for multiple species: A case study in the eastern Amazon. Biological Conservation. 257. 109148. https://doi.org/10.1016/j.biocon.2021.109148.
56. Srisang, W., Jaroensutasinee, k., and Jaroensutasinee, M. (2007). Assessing habitat suitability models with a virtual species aat Khao Nan national park, Thailand. Proceeding of world academy of science. Engineering and technology. 21: 1307–6884.
57. Sutcliffe, O.L., Thomas, C.D., 1996. Open corridors appear to facilitate dispersal by ringlet butterflies (Aphantopus hyperantus) between woodland clearings. Conservation Biology 10, 1359–1365.

58. Tambosi, L. R., Martensen, A. C., Ribeiro, M. C., & Metzger, J. P. (2014). A framework to optimize biodiversity restoration efforts based on habitat amount and landscape connectivity. Restoration Ecology, 22(2), 169–177. http://dx.doi.org/10.1111/rec.12049.
59. Taylor, P.D., Fahrig, L., With, K., 2006. Landscape connectivity: a return to the basics. In: Crooks, K., Sanjayan, M. (Eds.), Connectivity Conservation. Cambridge University Press, Cambridge, UK, pp. 29–43.
60. Tischendorf, L., Fahrig, L., 2000. On the usage and measurement of landscape connectivity. Oikos 90, 7–19
61. Valdez, R., 2008. In: Ovis orientalis. The IUCN Red List of Threatened Species,. http:// .
62. Van Leusen, M. (2002). Pattern to Process: Methodological Investigations into the Formation and Interpretation of Spatial Patterns in Archaeological Landscapes, PhD Dissertation, Groningen University.
63. Van Looy, K., Piffady, J., Cavillon, C., Tormos, T., Landry, P., Souchon, Y., 2014. Integrated modelling of functional and structural connectivity of river corridors for European otter recovery. Ecol. Model. 273, 228–235.
64. Walpole, A. A., J. Bowman, D. L. Murray and P. J. Wilson. (2012). Functional connectivity of lynx at their southern range periphery in Ontario, Canada. Landscape Ecology 27: 761–773. http://dx.doi.org/10.1007/s10980-012-9728-1.
65. Wu, J., Delang, C. O., Li, Y., Ye, Q., Zhou, J., Liu, H., He, H., He, W. (2021). Application of a combined model simulation to determine ecological corridors for western black-crested gibbons in the Hengduan Mountains, China. Ecological Indicators. 128. 107826. https://doi.org/10.1016/j.ecolind.2021.107826.
66. Ziaei, H., 2008. A Field Guide to the Mammals of Iran, second ed. Iran Wildlife Center.
67. Zetterberg, A., Mortberg, U. M., Balfors, B., & Mörtberg, U. M. (2010). Making graph theory operational for landscape ecological assessments, planning, and design. Landscape and Urban Planning, 95(4), 181–191. http://dx.doi.org/10.1016/j.landurbplan.2010.01.002.
68. Ziv, Y., & Davidowitz, G. (2019). When landscape ecology meets physiology: Effects of habitat fragmentation on resource allocation trade-offs. Frontiers in Ecology and Evolution, 7, 1–8. https://doi.org/10.3389/fevo.2019.00137.

Figures

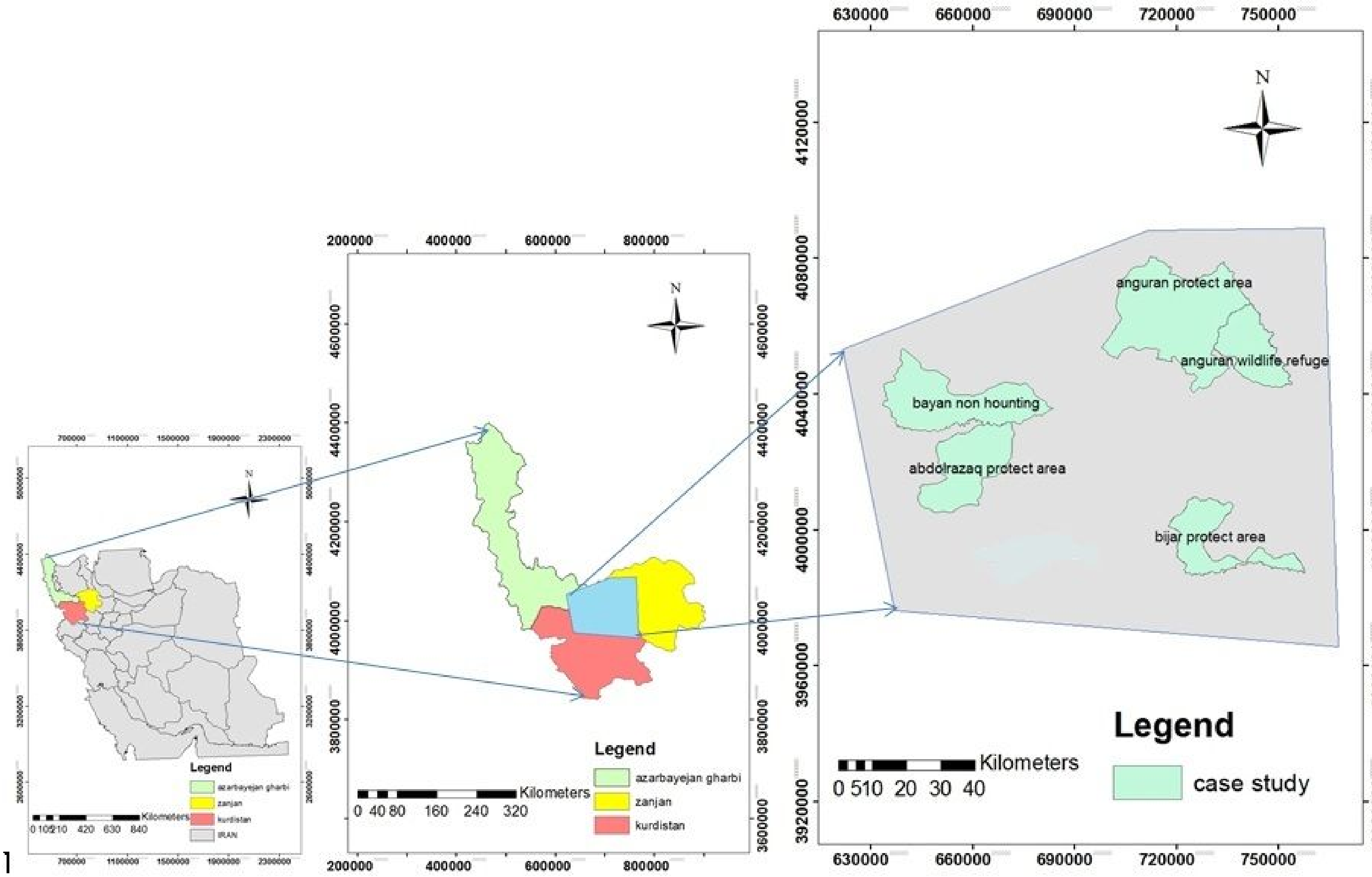

Figure 1

Geographical location of the study area

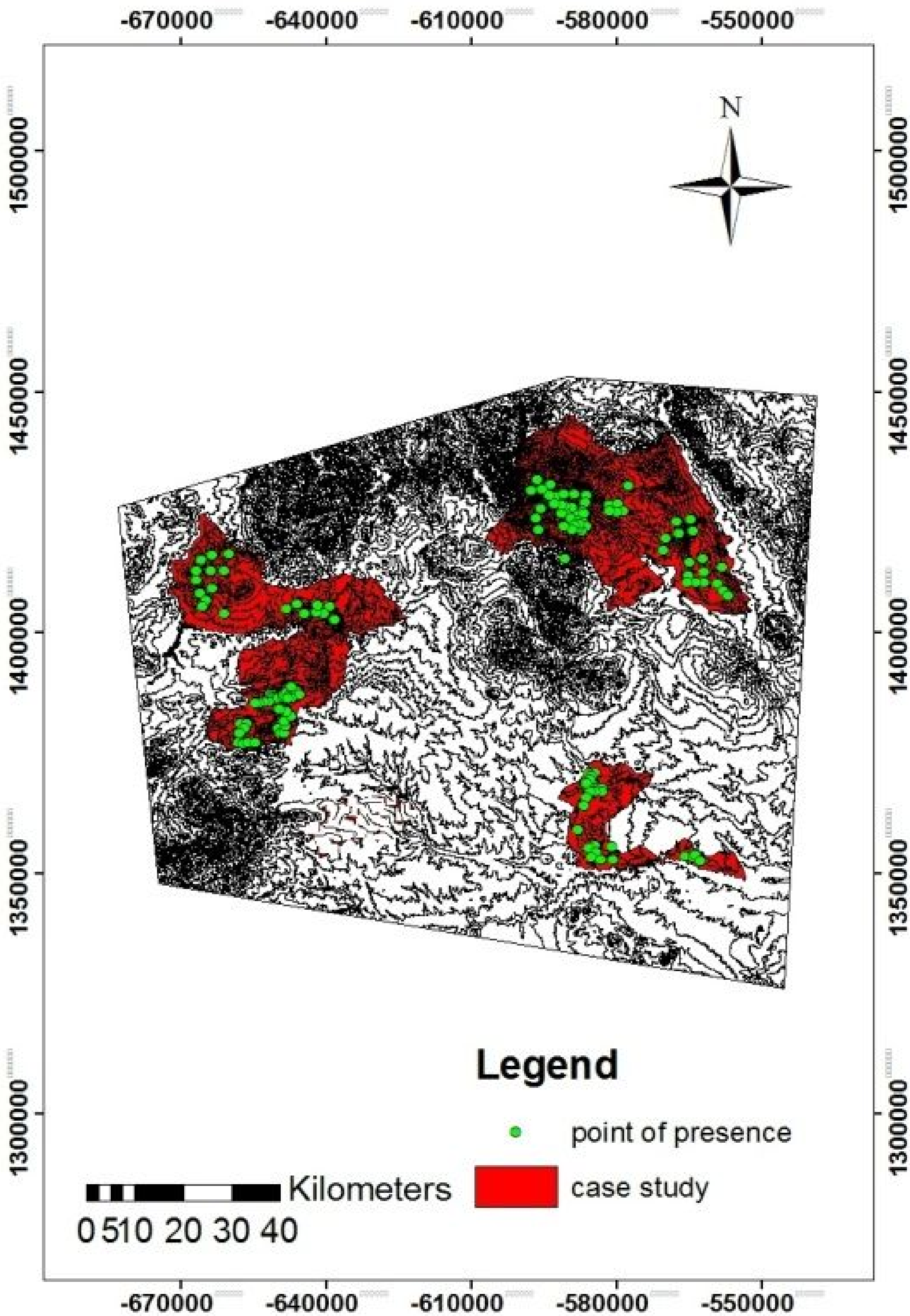

Figure 2

Presence points of Armenian rams and ewes in the study area

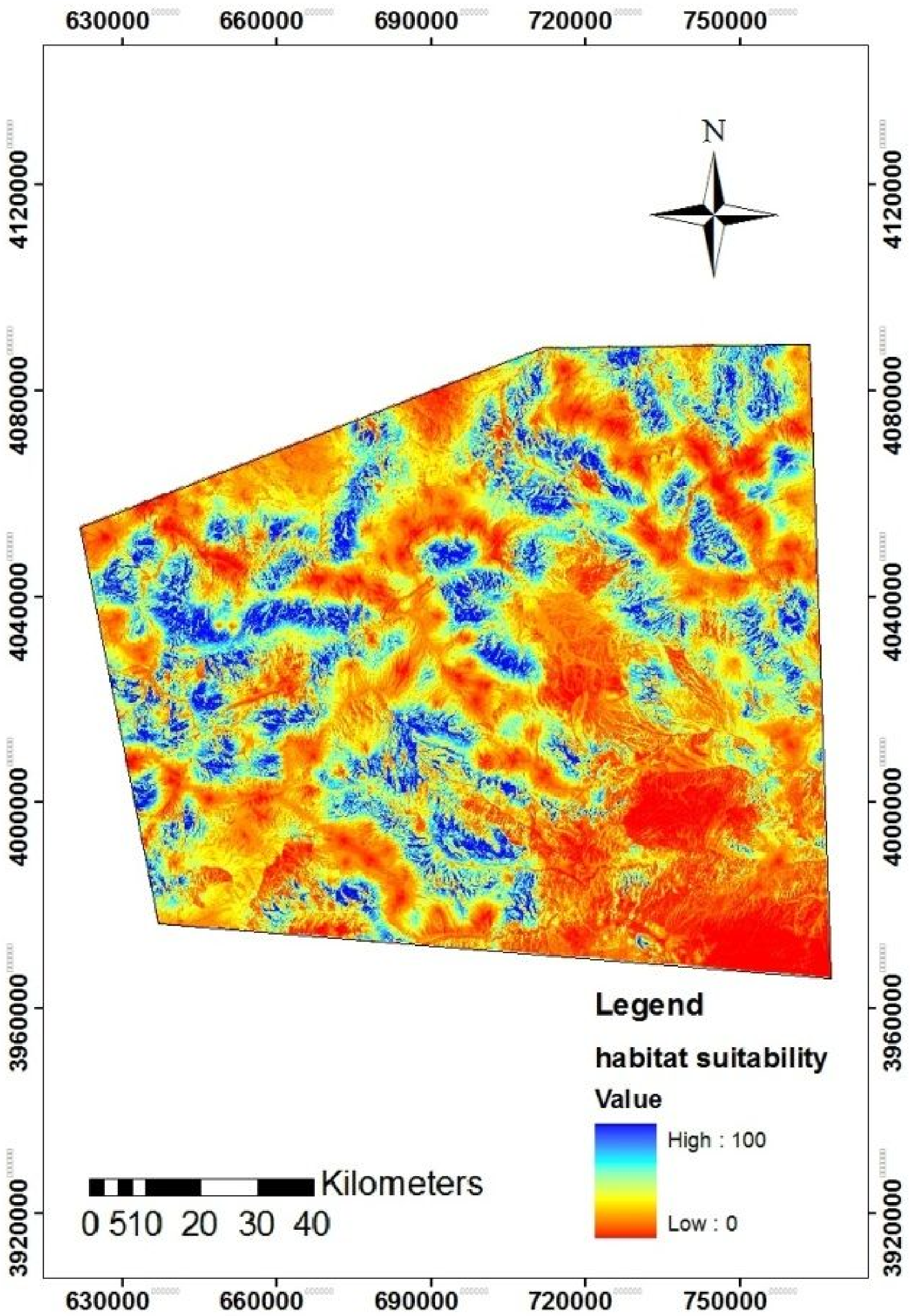

Figure 3

Habitat suitability in the study area

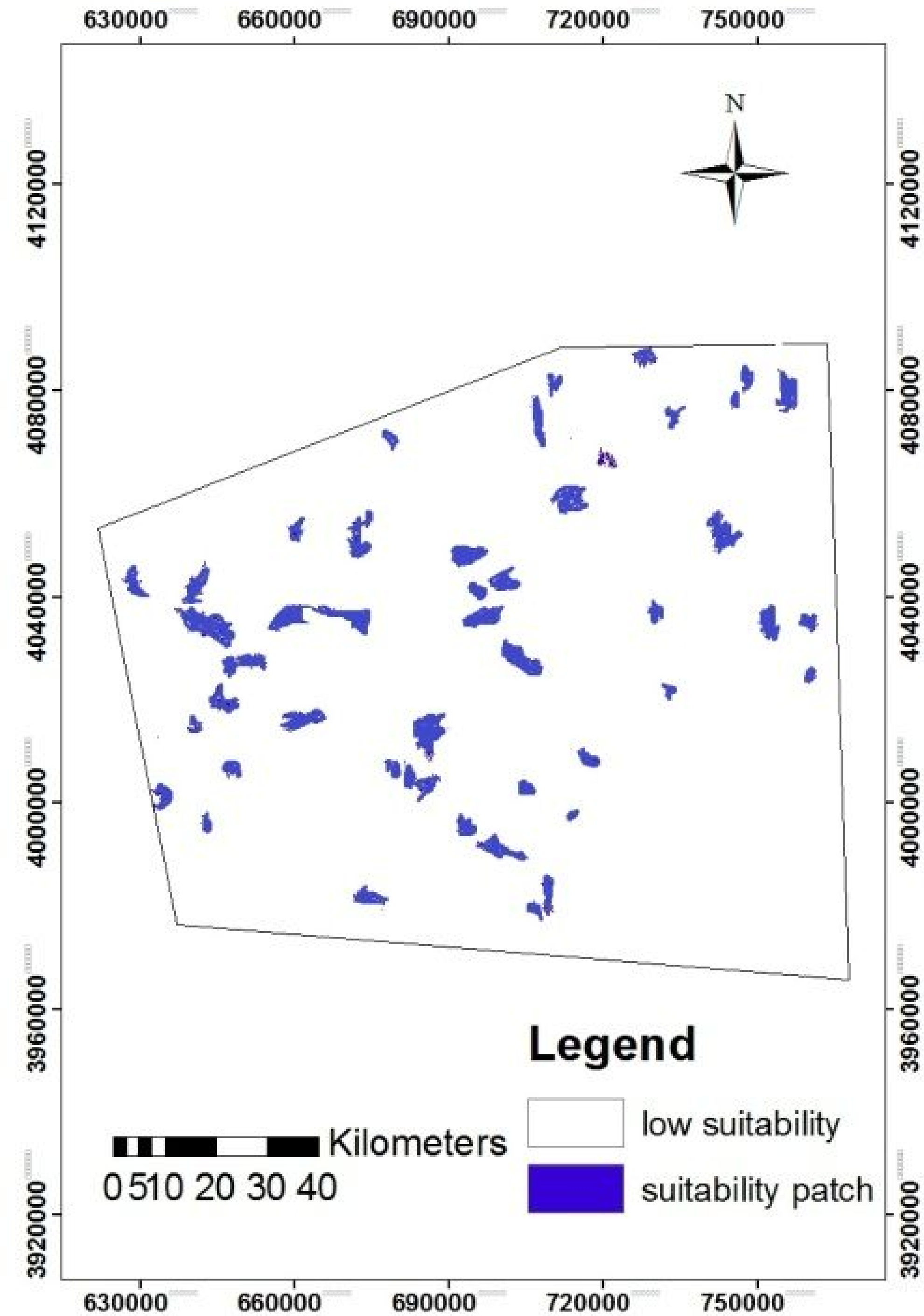

Figure 4

Habitat spots that is highly desirable for rams and ewes

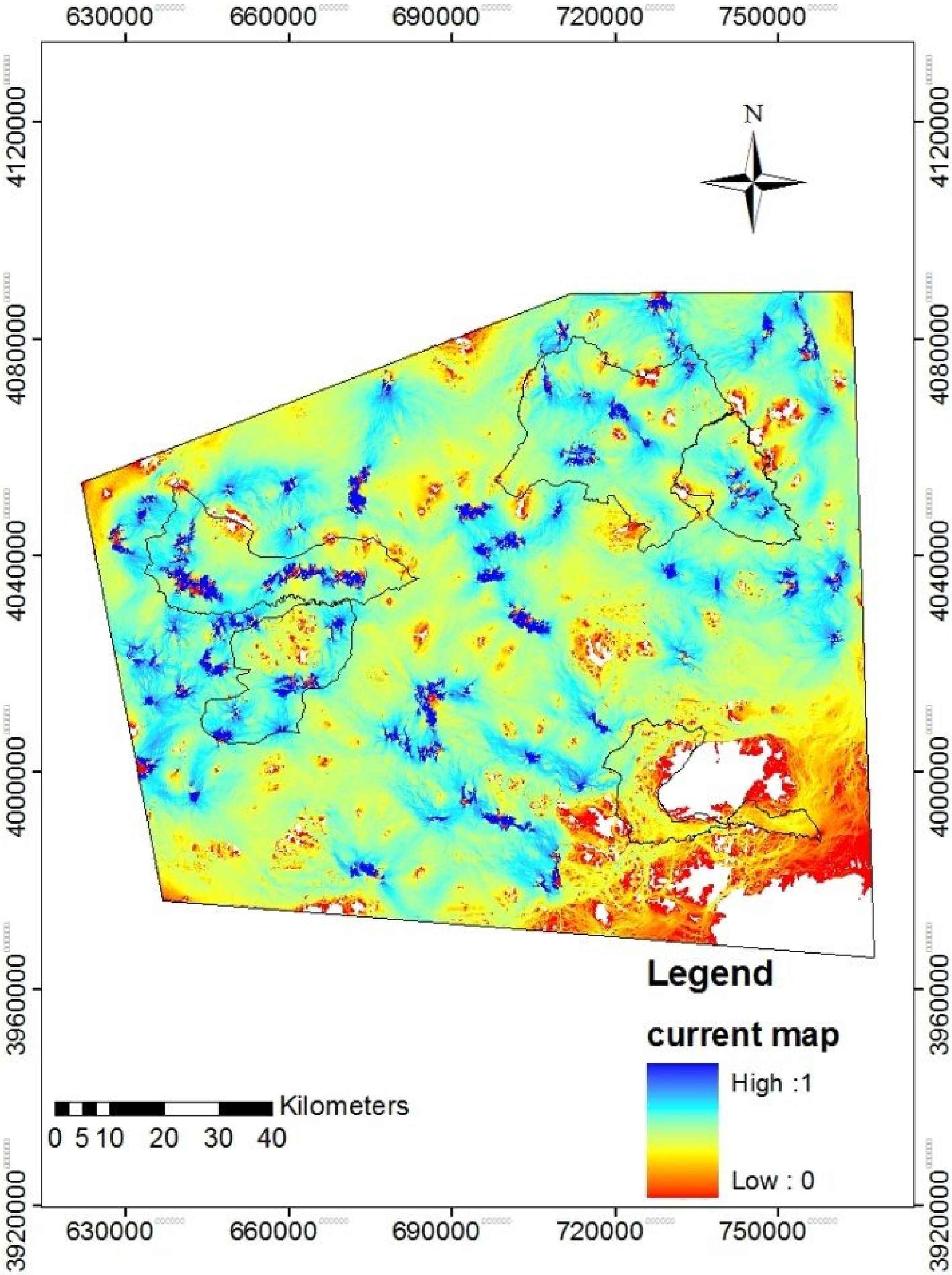

Figure 5

Flow map between studied habitats

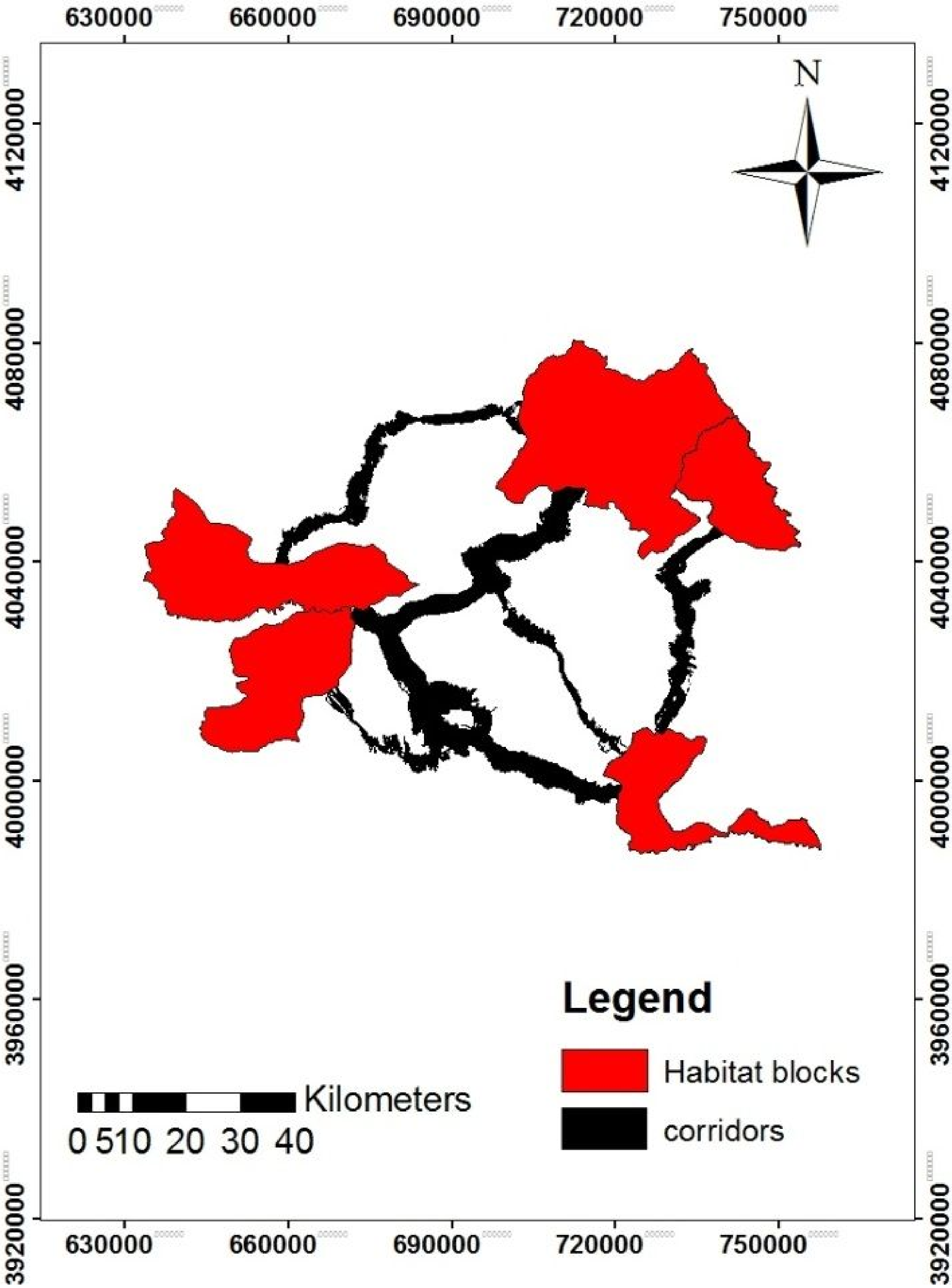

Figure 6

Least cost corridor map between studied habitats