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Habitat Quality Assessment, Optimization of Habitat Structure through Ecological Network Analysis and Graph Theory and Estimating Spatiotemprol Changes

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Landscape ecology

Abstract

Context. Recently, the land use changes in Northern provinces of Iran have led to great damages to ecological systems and services provided by these areas. These changes effect on interconnectedness of green patches and habitats which enables animal movement and gene transfer.

Objectives. This study aimed to provide a model for planning to increase habitat quality and to improve the structure and function and conservation of biodiversity by applying the principles of landscape ecology, graph theory, and ecological network.

Methods. This study was performed on Phasianus colchicus in the part of north of Iran, where is the main habitat of this species. For this purpose, after extracting the ecological network of the highest quality habitats and the most important cores, corridors were determined to increase their function and structure. Finally, the habitats changes and corridors were anticipated in the future.

Results. The results show that the foothill regions of studied where link Hyrcanian forests, farmlands, and tea farmlands are among the highest priorities for pheasant habitat in this region. However, the small number of bridges as corridors connecting habitats in this ecological network, the large number of main components and the extremely high percentage of isolated patches indicates the high disintegration of these habitats and therefore the poor condition of the habitat of this species.

Conclusions. The methodology of this study can be used in different scale to identify potential corridors and manage them by taking long-term view and considering the continuation of the past trend.

Key words: ecological network, graph theory, habitat, corridor, Phasianus colchicus

1. Introduction

Biodiversity conservation, as a crucial ecosystem service, is strongly related to other ecosystem services (Wilson 1988). It can directly influence the provision of many other ecosystem services which are sensitive to specific species communities (Alves and Rosa 2007; Isbell et al. 2013) and also indirectly affect some ecosystem services related to biological processes (Roe et al., 2019; Sanderfoot and Holloway 2017) by influencing inner ecosystem processes, such as mediating the activities of species as mediators (Mohallem et al. 2005). Biodiversity is affected by several factors such as invasive species, climate change, pollution, overexploitation, natural disease spread, nutrient salinity loads, and contamination, among which habitat changes are considered the greatest threats to biodiversity (Lee and Jeon 2020; Singh et al. 2021).

Habitat quality refers to the ability of ecosystems to provide appropriate and suitable living conditions for the survival, reproduction, and population persistence to sustain a species (McKinney 2002; Sharp et al. 2016).,Therefore Habitat quality, as a proxy of biodiversity, can characterize regional biodiversity levels and overall ecological quality based on the spatial distance between habitat and threats to certain extent (Hall et al. 1997; Zhang et al. 2020; Wu et al. 2021; Sharp et al. 2018; Terrado et al. 2016; Peng et al. 2018). With the increased need for scientific research and developing advanced technologies, some proxy indicators and models, which mainly depend on more available data (Bright 1993), such as remote-sensing images (Symes et al. 2018), have been developed in recent years (Carrete et al. 2019). Compared with some quantitative measurement based on species distribution data and direct records, these methods make measuring biodiversity more efficient and feasible (Hammerschlag & Gallagher 2017) since it can save time and energy for researchers (Bodeker et al. 2014). The habitat quality index (HQI), which demonstrates the potential of habitat to provide a sustainable living environment for organisms (Chapin and Diaz 2020), is one such indicator.

1.1. Ecosystem services and InVEST

The structure and function of an ecosystem products goods and services that are valuable and well known as ecosystem services (Heal et al. 2005). InVEST, which provides evaluation methods for more than twenty-five ecosystem services (Linders et al., 2019; Kilpatrick et al., 2017), is one of the most widely used software for evaluation and spatialization of ES (Singh et al. 2021), that can assess various ecosystem service, provide comprehensive analysis for planning ecological restoration, pay ecosystem services (PES), and assess developmental effects and space permit (Liu and Zhao 2018). Liu and Zhao (2018), Lüke and Hack (2018), Sadat et al (2019), Li et al (2020), Wang et al (2020), Shi et al (2020), Thellmann (2021) and Guo et al (2021) applied the InVEST model to simulate the ecosystem services. InVEST model of habitat quality index (Sharp et al. 2018) with the most detailed routine for evaluation of biodiversity (Cotter et al. 2017), combines information on land use and land cover change (LUCC), accessibility to sources of threats, threats to biodiversity, the sensitivity of habitat to threats, and a half-saturation constant to generate HQ maps. Therefore, it has been widely and successfully employed for the maintenance of biodiversity based on the relative reach and degradation of different habitat types, resources and environment management and land-use planning (Sharp et al. 2018). Such as Lin et al (2017), Haiping et al (2018), Gong et al (2019), Jie et al (2019), Choudhary et al (2020), Kija et al (2020), Berta Aneseyee et al (2020), Lee and Jeon (2020), Song et al (2021), Yang (2021), Wu et al (2021).

1.2. Ecological network and habitat quality

Ecological connectivity is a structural characteristics of land landscape which is commonly defined as the degree in which the land landscape can facilitate the movement of animals among their habitats and become a vital factor for genetic survival of species (Liu et al. 2018). Essentially, a proper landscape design requires a biological network and system (Zhao et al. 2019). Ecological networks are often characterized as a collection of habitat cores linked by buffer zones, corridors, and stepping stones that enable animals to move among them (Bennett et al. 2006). Ecological network analysis is a technique for analyzing the interactions and linkages between ecosystem components through corridors and finding the ecosystem's underlying features. This method emphasizes the ecosystem's structural characteristics and functional interactions (Dos et al. 2020; Zhao et al. 2019). As a result, ecological networks are used and discussed with the goal of proper land use planning, and because the creation of these networks has the capability to connect and integrate fragmented habitats, it is a significant tool for conserving habitats and species, as well as improving the ecological structure and function (Yang et al. 2017; Opdam et al. 2006; Worboys et al. 2010).

In recent years, the morphological spatial pattern analysis method, which focuses primarily on structural connection, has become more popular in environmental network analysis (An et al. 2020). This method is a way of processing. Vogt and Soille developed this image in 2009. Based on the four main operations of mathematical morphology, namely "corrosion," "expansion," "opening," and "closure," this approach can measure, detect, and discriminate the spatial pattern of raster pictures. MSPA is mostly used for structural link analysis, but it may also be used to separate landscapes from structures (Soille and Vogt 2009). As a result, this model is utilized to identify critical habitat plots and corridors that contribute to landscape connectivity at the pixel level (Ye et al. 2020).

The utilization of land characteristics is one of the most prevalent approaches for surveying and measuring ecological cohesiveness. Landscape measures are valuable tools for describing spatial patterns and assessing the order of landscape components in time and space (Zhou and Li 2015; Frazier et al. 2019). The majority of ecological measures do not view the region within the spots as a continuous place, according to critics of researchers that use those. In other words, the higher the number of spots, the higher the degree of continuity evaluated by these measurements (Shafinejad et al. 2015). Despite the fact that graph theory has a long history of environmental protection, recent environmental researchers have discovered that it is a more effective way of measuring ecological continuity and evaluating functional connectivity and continuity, and that it can play a key role in the landscape. It can determine their contribution to the overall Landscape link and quantify it (Liu et al. 2018; Zhang et al. 2019; Baranyi et al., 2011;

Pirnat et al. 2016). Zhang et al. (2019), Liu et al. (2018), Xiao et al. (2020), Cui et al. (2018), Ye et al. (2020), Dai et al. (2021), Foltête et al. (2014) and Shafinejad et al. (2015) proved the potential of graph theory to measure land image metrics for analyzing its continuity.

1.3. Corridors and habitat quality

The core of ecological corridors, which is connected organisms with landscape (Saura et al. 2011), provide some ecological services such as saving water, purifying pollutants, and reducing the heat island effect (Zang et al. 2002). Ecological corridors facilitate the migration of animals and plants between habitat patches, thus enhancing connectivity between isolated populations. It is suggested to use corridors to connect isolated habitat patches to mitigate the negative impact of habitat fragmentation (Ye et al. 2020). In recent years, some researches has been conducted to determine the ecological network extract potential corridors in some habitats and to in them. Including Ye et al (2020), Xiao et al (2020), Ye et al (2020), Guo et al (2018), Shi and Qin (2018), Shi et al (2020), Wei et al (2018)

Gilan Province, situated in northern Iran, is one of the country's fastest-growing provinces in terms of land usage (conversion of forest to agricultural land) (Nohegar et al. 2015). The distribution of certain terrestrial species has shifted in recent years as a consequence of land use change, urbanization, and land degradation (Ashoori 2009). Phasianus colchicus is one of the province's most threatened terrestrial birds, with its name designated as the least endangered species on the Red List of the International Union for Conservation of Nature. Pasture areas, tea farmlands, agricultural lands, orchards, and broadleaf woods with an area of at least 640 hectares are ideal habitat for pheasant species. Approximately 5 to 10% of this area, or 30 to 60 hectares, should be covered with grasslands and bushes (Ashoori et al. 2018; urban habitat basic 2021). This bird may lay eggs and build a nest among pastures and bushes. However, a tree cover density of 5 to 25% is preferred for such. Due to the fact that these woodlands are mostly covered with bushes. Because the pheasant's protective strategy against predators is to conceal, this species avoids canopy forests by more than 25% because it may be impossible for the species to hide owing to plant scarcity (Robertson 1997; Li et al. 2009). Furthermore, since it favors flying species to avoid being hunted in an emergency, decreased tree density may aid the bird's flight (Li et al 2009). Finally, typical pheasants need forests and agricultural fields because agricultural lands give food and forests provide habitat for species.

Several research are done about demography and habitat selection by pheasants in the world. Male pheasants prevail in natural or manmade plant strips (wood borders, fences, hedges, and rows of trees) and in places characterized by significant habitat variety, according to research by Meriggi et al. (1996) and Nelli et al. (2012) in Italy. Pheasants also prefer smaller areas of habitat with more regular boundaries. Furthermore, according to Li et al. (2009), terrain, vegetation, and distance from water sources, and human presence are all critical factors in Phasianus colchicus foraging habitat selection in Huanglong. In Iran, Ashoori et al. (2018) identified locations in Gilan province with promise as a habitat for this bird based on physical, human, land cover, and climatic characteristics. Following a comprehensive assessment of this species' current habitat, the most important extraction, connection of land, habitats, and main and important corridors according to habitat type and distribution distance of Phasianus colchicus species is performed in the first step, and the future status of these habitats and corridors is predicted in the second step. The key issue here is that there isn't a thorough approach for studying this species. This implies that non-use of species, disregarding the resistance of various land uses, and failure to utilize a proper approach to assess the priority of habitats and ecological networks may be shown in many research.

2. Material and method

2.1. Study area

The study area in this research is combining Lahijan Chaksar and Astaneh-Kuchesfahan watersheds in the east and capital of Gilan province, respectively (Fig. 1). Astana-Kochsfahan basin with an area of 1100 square kilometers is formed on the Caspian Cone and the Sefidrud River deltas. The surface boundaries of this basin are the Caspian Sea and the Sepidroud River deltas in the north, Hyrcanian forests in the south, Lahijan-Chakaksar watershed in the east and Fumanat plain in the west. The longitude of this basin fluctuates from 49^0 12' to 50^0 5' eastern latitude and 37^0 07' to 37^0 25' north length. This area involves sections of Astana, Rasht, Siahkal, Rudbar and Lahijan counties. Lahijan Chaksar watershed with an area of 30 square kilometers is located from 50^0 21' to 50^0 26' eastern latitude and 37^0 02' to 37^0 06' north length. The borders of this area from the north to Caspian Sea, to the east and west, to the dry rivers of Rud and Polroud, and from the south involve section of Hyrcanian forests. This area involves sections of Lahijan, Langarud, Amlash, Rudsar, Siahkal and few sections of Rudbar.

2.2. Data analysis

This study is classified as an applied research, because of its nature and its contribution to improve the decision-making atmosphere. In this study, INVEST and Conefore softwars, CA Markov models and MSPA method as well as different satellite images are applied to evaluate the Phasianus colchicus habitat quality and influence of future land cover changes on these habitat ecological network.

2.2.1. Classification of satellite images

Challenges ahead in satellite images classification ensure image super-quality, which is highly prevalent in certain locations such as the Northern provinces, develop an ideal technique to correct atmospheric and geometric images, and lastly process and categorize them in an optimal manner (Sadat al 2021). The research employed Google Earth Engine to categorize satellite images in order to overcome these issues. The system is a web-based platform that was initially introduced in 2008. For processing extremely big data sets, this system enables convenient access to high-performance computer resources without the need for substantial software expertise (Xiong et al 2017). Users of Earth Engine may access and evaluate data included in operators' general and personal instructions. These operators are implemented in a massive parallel processing system that separates, distributes, and performs high-performance parsing automatically (Gorelick et al. 2017). This system's general data instruction is a collection of frequently used geographical databases that spans many petabytes. The majority of these recommendations are made up of ground-based remote sensing images, including the full Landsat library as well as the whole archive of Sentinel-1 and Sentinel-2 data (Fuentes et al., 2018; Shelestov et al. 2017). Climate projections, land cover data, and a variety of environmental, geophysical, and socioeconomic data sets are also included (Gorelick et al. 2017). The Google Earth Engine receives pre-processed images for quick and simple access (Kumar and Mutango 2018; Venter et al. 2020).

Based on the mentioned cases for land cover classification in present research, from the total of Landsat 8 images in the period 01/01/2020 to 01/01/2021 and the total of Landsat 5 images in the period 01/01/2000 to 01/01/ 2001 and 01/01/2010 to 01/01/2011, which had a cloud cover below 5%, were applied. Land cover was classified into eight categories using the products and instructions of the vegetation index 9 related to the four seasons in the mentioned time periods, urban lands, canopy cover to identify forest areas with trees above 30 meters, and finally educational data removed from the ground and entered into the system by the user. Forest, open space, rangeland, farmland, tea farmland, open space, water body, and built up area including were all used.

2.2.2. Monitor and predict of land cover

In this step, Markov chain analysis was used as a basis for mapping the future changes to analyze land cover changes from one period to another. This model is a random model where the state of one future system (t2) can be predicted according to its previous state (t1) and the potential for transmission. Markov model in homogenous mode is displayed to compute land use changes such as Eq. 1

$$L_{(t+1)} = P_{ij} \times L_{(t)}$$

$$\sum_{j=1}^{m} P_{ij} = 1.\ i.j = (1.2\ldots\ldots m) \qquad \text{(Eq. 1)}$$

$$(0 \le P_{ij} \le 1)$$

T + 1, respectively, and Pij are matrix of probable transition in one case. In other words, the Markov chain is like Eq. 2 It is created from the land use distribution at the beginning (Mt) and the end of a separated period of time Mt + 1) as well as from a transition matrix (MLc) that illustrates the changes that occurred in the intended time period.

$$M_{le} \times M_{t} = M_{t+1} \qquad \text{(Eq. 2)}$$

Outputs of this analysis include transition probability matrix (TPM), transitioned area matrix (TAM), and conditional probability images (CPI) (Salman Mahini and Kamyab, 2009). In this study, the automated cells model was used in combination with the Markov chain model for locating the changes. The automated cells-Markov model is a combination of automated cells, Markov chain and Multi Objective Land Allocation which is used to predict future changes in land cover and land use.

The Markov chain does not add any information about the random spatial distribution within each land use category. There is no spatial component in the output of modeling, moreover, its failure to provide information about spatial distribution in the Probability Markov model, another issue arise which is the study of the homogeneous transition probability for the categories use in this model, whereas the probability of transition is not constant in each class .

Therefore, cellular automation can be used as a supplement to this model, especially when different processes are analyzed at different spatial and temporal scales and this model is characterized by high flexibility and simulation potential(Peter et al. 2004; Deep and Saklani 2014; Arsanjani 2013).

Using the automated cells-Markov model to predict the land cover map of 2040 requires initial examination of the model capability to predict changes in the region. For this purpose, land cover maps from 2000 to 2010 were analyzed in Software IDRISI Selva using Markov module. Thereby, the transition probability matrix of this 10-years period was calculated and used for predicting the changes in land cover in the studied area nine years later (2020). At this stage, the relative error of maps used in the analysis was also calculated as the kappa coefficient equal to 0.85. Then, the map of 2020 was used as a base map to simulate future changes. The land cover changes for 2040 were predicted using automated cells Model and the image of 2020. In This prediction, the relative error of maps used in the Markov analysis was 15%, the repetitions number of automated cells was considered 10 times and the adjacent filter with a 5*5 window was used.

2.2.3. Habitat quality assessment

As noted above, The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model of habitat quality (Sharp et al. 2018) was used for modeling the Phasianus colchicus habitat quality in 2020. In this model the quality of habitat in parcel x that is in LULC j be given by Qxj where,

$$Q_{xj} = H_j \left(1 - \left(\frac{D_{xj}^z}{D_{xj}^z + k^z}\right)\right) \quad \text{(Eq. 3)}$$

Here, Qxj is the habitat quality of grid x in habitat type j, and habitat suitability Hj represents the degree of suitability as a habitat for different types of habitats. The value of habitat suitability ranges between 0 and 1. The larger the value, the higher the suitability is. Dxj refers to the degree of reduction in the quality of the habitat in grid x and habitat type j; k is a half-saturation constant, which is half of the maximum reduction degree, and z is a normalized constant. Habitat degradation needs to be calculated first, as shown in Equation (4):

$$D_{xj} = \sum_{r=1}^{R} \sum_{y=1}^{Y_r} \left(\frac{w_r}{\sum_{r=1}^{R} w_r}\right) r_y i_{rxy} \beta_x S_{jr} \quad \text{(Eq. 4)}$$

Where D_{xj} is the habitat degradation or total threat level of LULC type j in a grid cell x; *R* is the number of threat factors; *r* presents the threat layer; *y* indicates all grid cells on a raster map of *r*; *Yr* indicates the set of grid cells on a raster map of *r* ; *w r* indicates the weight of each threat factor (value from 0 to 1); *ry* indicates the effect of threat *r* that originates in grid cell *y* ; *irxy* indicates the distance between habitat and the threat source and the impact of the threat across space; β_χ is the factor that may mitigate the impact of threats on habitat through various protection policies *S jr* indicates the sensitivity of LULC type *j* to threat factor *r* , where values closer to 1 indicate greater sensitivity.

The model uses seven types of input data include Current LULC map, Threat data, Sources of threats, Habitat types and sensitivity of habitat types to each threat**.** With reference to related research (Ashorri et al. 2018; Mirzaei et al. 2015; Peng et al. 2021; Li et al. 2009; Chhetri et al. 2021) the threats to habitats, maximum impact distance, and weights for each factor were derived (Table 1). The main threats to the Jeju roe deer were urban land, farmland, and bare land, which can be termed human activity areas. The roads were designated as a separate threat category, especially because roads were the biggest threat due to accidents with vehicles. The averages of the values presented in existing references were used as the weights.

Table 1 Threat factors and their maximum distance of influence, weight, and type of decay over space

Threat Factors	Maximum Distance of Influence (km)	WEIGHT	Type of Decay over Space

Slope	0.1	0.05	Linear
Dem	0.1	0.1	Linear
Climate	0.3	0.1	exponential
Path forest	0.05	0.35	exponential
Canopy cover	0.1	0.4	exponential

Also the sensitivity of habitats to threat factors were derived from previous studies (Schmitz and Clark 1999; Jiliang et al. 2006; Li et al. 2009; Ashorri et al. 2018; Karami et al. 2008; Leif 2005). The sensitivity of land use type to threats factors is shown in Table 2.

Table 2 The sensitivity of land-use type to habitat threat factors

LULC	HABITAT	SLOPE	DEM	CLIMATE	PATHFOREST	CANOPY COVER
Forest	0.4	0.1	0.5	0.4	0.5	0.8
Open space	0	0	0	0	0	0
Rangeland	0.6	0.3	0.5	0.6	0.5	0.3
Farmland	0.6	0.3	0.5	0.6	0.7	0.1
Tea farmland	0.8	0.3	0.1	0.1	0.1	0.1
Garden	0.3	0.1	0.5	0.5	0.4	0.2
Built up area	0	0	0	0	0	0

2.2.4. Landscape Pattern Analysis Based on the MSPA Method

The MSPA classification routine starts by identifying core areas, based on user-defined rules for defining connectivity and edge width. Different from the traditional method in which the nature reserves or forest parks were selected directly as the patches or corridors, MSPA is used to identify the important habitat patches and corridors which play an important role in landscape connectivity at the pixel level (Vogt 2018). After the classification of habitat quality map, the most important habitats are extracted to be the foreground, and others as the background, background, a series of image processing methods are used to divide the foreground into seven non-overlapping categories (Table 3).

Table 3 Definition of landscape type based on the morphological spatial pattern analysis (MSPA)

Class	Description
Foreground	Area under forest pixels
Background	Area under non-forest pixels
Core	Foreground pixels surrounded by foreground pixels are greater than the specified edge width distance from the background. The larger habitat patches in the foreground pixels can provide a larger habitat for the species and are the ecological source of the ecological network.
Islet	Foreground pixels that do not contain the core. Isolated, broken small patches that are not connected.
Perforation	Pixels that form the transition zone between foreground and background for interior regions of the foreground. The pixels forming the inner edge would be classified as perforations.
Edge	Pixels that form the transition zone between foreground and background for interior regions of the foreground. The pixels forming the outer edge would be classified as edge.
Bridge	Foreground pixels that connect two or more disjunct areas of the core. It represents the corridor connected by patches in the ecological network
Loop	Foreground pixels that connect the same core area. Loop is a shortcut for species migration in the same core area

Branch	Foreground pixels that extend from an area of the core, but do not connect to another area of the core. Only one end of it is connected to the edge, bridge, loop or perforation

Unlike traditional methods that focus on the area or importance of a single patch without taking the integrated landscape connectivity into account, this method provides the four- or eight-neighbor rule since the connectivity analysis is conducted on a raster grid. It allows automatic classification based on geometric concepts at a pixel level (Guo et al., 2018).Then the core area, which is regarded as the most important area for landscape connectivity, under the eight-neighbor rule and the edge width as 30 meter (which can meet the needs of pheasants in the area) extracted for next step. Also according to the initial images, the cell size was considered 30×30 meters, which can preserve the main elements of the landscape of the study area.

2.2.5. Evaluation of Landscape Connectivity in the Study Area

Graph theory may be used to determine the landscape's connectivity and the function of each point inside it. Conefor2.6 software was used to prepare the core communication network after constructing the ecological network and identifying the habitat cores. In this method, habitat core networks were built with a neighborhood link between them, which is what each of these connections is referred to as a connection. The joints were weighted and measured based on the distance between the core locations and the distance from the edge to edge of each spot relative to each other. The information was then loaded into the program as primary data in the form of two text files based on the features of each place, the distances between them, and the potential or impossibility of linking them.

According to Leif's research on 95 male pheasants from 1997 to 2001, pheasants dispersed and moved an average of 3.2±0.3 km. Therefore, in this study, the threshold of the connection distance of the core has been set at 3.2 km, which can guarantee the successful migration of this species (Lief 2005).

Conefor is a graph theory-based software tool that helps experts understand the relevance of habitats and connections in maintaining or improving the landscape, as well as evaluating the impacts of habitat and land use change on patchwork. As a result, by identifying and prioritizing critical locations for ecological connectedness, it is seen as a tool to aid decision-making in environmental preservation and land use planning. Because of its innovative performance continuity measurements, this program outperforms competing software and indicators (Saura et al., 2011).

The metrics used to quantify the landscape connectivity are probability of Connectivity (PC) Equation (2)),, and the delta of PC (dPC, Equation (3)) which are based on a probabilistic connection model, and Integral Index of Connectivity (IIC) and Delta of Integral index of connectivity (dIIC), which are based on a binary connection model. These metrics, which can reflect well the degree of connection between core patches in the regional level were calculated based on a graph-theoretic approach by Conefor Sensinode 2.6 software (Cook 2002; Ye et al. 2020; Xiao et al. 2020; Saura and Pascual-Hortal 2007; Dai et al. 2021; Cui et al 2018).
It's worth noting that the first two measures are used to investigate species movement, while the second two measures are used to investigate network structure (Qi et al. 2017; Bodin and Saura 2010).

The landscape connectivity indices were calculated as follows:

The probability of connectivity (PC) can not only quantitatively describe the landscape connectivity, but it can also identify patches with important connectivity. PC is calculated by the following formula (0 < PC < 1) (Eq. 5):

$$PC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} p_{ij} a_i a_j}{A_L^2} \qquad \text{(Eq. 5)}$$

Where n is the total number of habitat nodes in the landscape, ai and aj are the area of nodes i and j, AL is the total landscape area, and pij is the maximal probability of the potential paths between patches i and j (Shi et al., 2020).
The delta of PC (dPC) can calculate the contribution of each patch to the overall connectivity of the ecological network. It can identify patches that are crucial to PC. dPC is calculated according to the following formula (Eq. 6):

$$dPC\ (\%) = \frac{PC - PC'}{PC} \times 100\% \qquad \text{(Eq. 6)}$$

Where PC is the overall landscape connectivity and PC’ is the overall landscape connectivity after removing a patch from the original landscape. The change of the overall landscape connectivity is regarded as the importance value of the removed patch.

The Integral index of connectivity (IIC) is recommended as the best binary index for the type of connectivity analysis (Eq. 7) (Pascual-Hortal and Saura 2006).

$$IIC = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} a_i a_j}{A_L^2} \qquad \text{(Eq. 7)}$$

Where *n* is the total number of nodes in the landscape, *ai* and *aj* are the attributes of nodes *i* and *j*, *nlij* is the number of links in the shortest path (topological distance) between patches *i* and *j*, and *AL* is the maximum landscape attribute.

The importance of an existing node for maintaining landscape connectivity (dI) is calculated according to a certain index (I) as a percentage (Eq. 8).

$$dIIC = 100.\frac{(IIC - IIC_{remove})}{IIC} \qquad \text{(Eq. 8)}$$

Where IIC is the overall index value when all of the initially existing nodes are present in the landscape and IIC remove is the overall index value after the removal of that single node from the landscape (Shi et al 2020).
Following the collection of measurements for each cores, the top 8 patches with a dPC value greater than 4 were chosen as the most significant habitats in this research and as a base for future investigation.

2.2.6. Ecological Corridor Construction Based on the Least-Cost Path
For this objective, in this research, the analysis of the minimum cost path that is a computer-based method to find and visualize the optimal paths was applied.

The least-cost path analysis was most applied to design communication corridors among protected areas. The basis of this method is to determine the route that a species travels from one area to another at the lowest possible cost (Abdollahi and Ildermi 2017).Based on the cumulative cost of mobility, this technique analyses the probable travel patterns of animals (Etherington, 2016). A small comparison of alternative animal movement pathways, the ability to incorporate simple or complicated models of habitat influences on animal movement, and the restriction of structural communication models by modeling the communication of animals in the landscape are all benefits of this technique (Taylor et al. 2006).

Network development is often optimized using least cost-path analysis. This method assumes that species incur a cost when crossing an area, which is also known as resistance, and is the amount of resistance used to calculate the connection between two habitats per unit of land cover (Bunn et al. 2000), which can indicate the energy expended while crossing the area, the risk of death, or the impact on the species' future ability to reproduce (Abdollahi and Ildermi 2017). In this research, the optimum path with the lowest cost for the species is selected using this algorithm from among the various corridors linking the two habitats. Table 4 indicates the assigned resistance values (Kong et al. 2010; Guo et al. 2018).

Table 4 Land cover resistance value

Land cover class	Resistance Value
Forest	10
Open space	30
Rangeland	10
Farmland	5
Tea farmland	1
Built up area	1000

At last, the condition of the ecological network is extracted and suggested corridors are forecasted in the future by overlaying the land cover map for 2040 with the map of the most significant Phasianus colchicus habitats and ecological corridors constructed for this species.

3. Results

3.1. Classification of satellite images and monitoring LC dynamics

According to the LC maps, figure 1 shows the spatial–temporal changes in land cover over the past 20 years (2000-2020). The LC pattern in the study area has changed dramatically in this period of time. The forest cover declined significantly by 20171 ha, while built-up land and open spaces expanded significantly from 2000 to 2020 by +10508.7 and -131992.21 ha, respectively (Table 5).

However, the habitat of this species is immediately impacted by the conversion of farmland, rangeland, forest, and tea farmland to cities and other built-up regions and open spaces. Furthermore, increasing pollution accumulation and urbanization will raise pollution levels in the area, which will have an indirect negative impact on this species' habitat quality

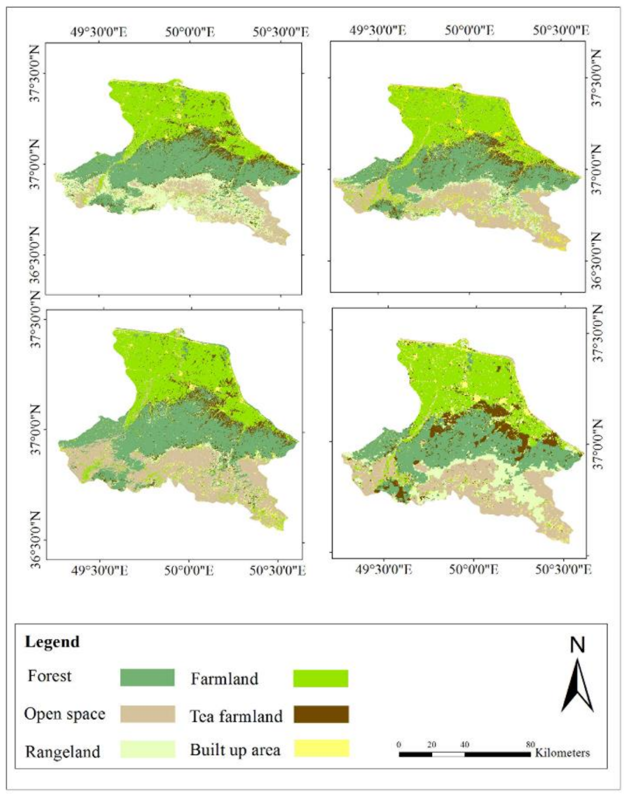

Fig. 1 Land cover maps in 2000, 2010, 2020 and 2040

Table 5 The land cover changes from 2000 to 2040 and rate of changes

Land cover	2000	2010	2020	2040	Change in 2000-2020 (ha)	Change in 2000-2020 (%)
Forest	201624.60	190827.04	181453.14	162579.48	-20171.46	11
Open space	153549.75	100856.89	147723.54	131992.21	-5826.21	300.7
Rangeland	27410.86	80753.311	54668.38	83401.74	+27257.52	100.9
Farmland	188109.07	186881.01	173312.812	157649.24	-14796.258	0.07
Tea farmland	42828.82	44476.06	46646.96	51561.96	+3818.14	100.08
Built up area	25524.56	30893.36	36033.26	48358.40	10508.7	100.4

In addition, between 1999 and 2020, the area under tea cultivation and agricultural land rose by 3818 (ha) and reduced by 14796(ha), respectively, owing to forest degradation and conversion to tea farmland. This usage and destruction of rural land for development and conversion of use to urban land is suitable for this purpose. Results of the modeled map of 2020, which was modeled according to 2000 and 2020 LC map, were compared with actual land cover map of 2020. The comparison of sample points on the ground with the results of the classification map showed that 91% (K=0.91) of predictions and development trends were anticipated correctly. Thus, the model has sufficient accuracy and efficiency. The predicted map for 2040 indicates that, if the current trend continues, the amount of constructed and open space areas that are unable to offer habitat services for pheasant species would expand by 180350.6 hectares. In addition, hectares of tea farmland areas have been added, while hectares of forest lands have been removed. Deforestation and conversion of forest areas to agricultural fields and tea production in the northern section of the Hyrcanian woods, which affects pheasant habitat to the south and higher slopes, are key factors in this respect.

3.2. Habitat quality modeling

The results of the habitat quality in study area in 2020, which is variation varied by habitat types, are shown in figure 2. Habitat quality values are assigned to each grid and displayed as a continuous value. From the aspect of land cover types, open space and built up area had no habitat quality and farmland, tea farmland, garden, had relatively high HQ because of their high habitat suitability (Table 2).

Phasianus colchicus species have the best habitat in the southern lands of forests, where the presence of tea farmlands, agricultural lands, and rangeland next to the forest offer appropriate locations for hiding, nesting, and feeding. A major loss in habitat quality may be noted as distance from these locations increases, as can the height of trees in forests, as well as the height and slope of the ground. Agricultural lands in the northern part of the area, which are distant from woods and are situated at a suitable height and slope and have excellent humidity and temperature, are also of rather low quality. In addition, the region's southern lands, which are high in elevation, lack adequate flora, and have a dry and cold climate, are regarded poor habitats for such species.

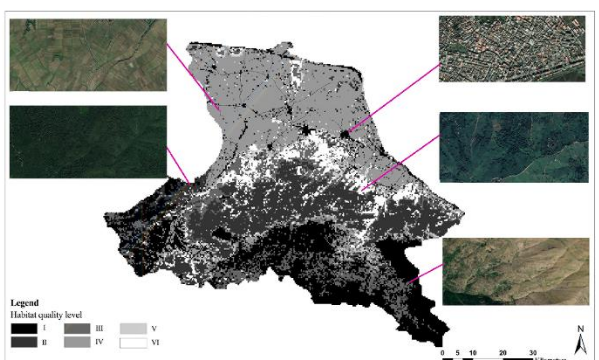

Fig. 2 Phasianus colchicus habitat quality map for 2020

3.3. Ecological network Analysis

As previously stated, pheasant habitat and other forms of land cover were utilized as background and background data for the morphological spatial pattern analysis model, respectively, based on the output of the InVEST model. The MSPA model was used to create an ecological network map of these habitats, which can be shown in Figure 3.

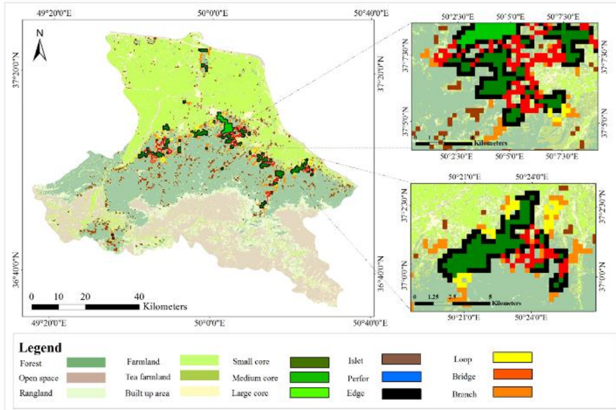

Fig. 3 Spatial distribution of landscape pattern of the Phasianus colchicus highest quality habitats based on MSPA

The findings reveal that the most acceptable Phasianus colchicus habitat is 6347.32 square kilometers of the research region. With an essentially continuous geographical structure, the primary regions, known as the habitat cores, are centered in the middle section of the region and north of the Hyrcanian forest. The primary areas are more dispersed in the eastern and western parts of the region, which may be explained by the decline of agricultural lands and high tree canopy density, which has resulted in fewer habitats and their disintegration. In general, the number of main cores is unequally distributed over the network, accounting for 16.21% of the entire network area (Table 6). The ecological network's bridges, which serve as linking corridors and allow species movement across habitats, took up 34 hectares of the habitat network's total area. Due to the cores fragmentation, this sort of structure is more noticeable in the western half of the area than in the eastern half. The absence of perforation into the core of the habitats also implies that the cores are linked. The number of islands in this region as isolated areas with no connection to other habitats is quite high, occupying a total of 513 hectares of total area, indicating the species' negative habitat status in the area.

Table 6. Statistical areas of each landscape type.

Landscape Type		Accounting for the habitat Area (%)
Core	Large	0
Core	Medium	3.36
	Small	12.85
Islet		34.47
Edge		24.67
Bridge		5.63
Loop		3.09
Branch		15.92
Perforation		0

3.4. Evaluation of landscape connectivity and ecological corridor construction

The value of dPC and dIIC of each habitat nucleus with a dispersion distance of 3.2 km2 is computed using the Confore2.6 program output. The findings suggest that the overall level of dPC and dIIC in the studied area is more than 0.0004, indicating the presence of isolated habitats, as well as a lack of relevance and continuity in the region's ecological network of Phasianus colchicus habitats. As previously stated, the top 10 patches with a dPC value greater than 4 have been chosen as the most significant Phasianus colchicus habitats in this research for future investigation. Because the size of the habitat space is an essential consideration in design, Table 10 shows the estimated measures and area of each of the cores. The most significant habitat nucleus for Phasianus colchicus among the analyzed habitats is nucleus No. 329, with dPC and dIIC equal to 54.64 and 48.09, respectively, while nuclei Nos. 486, 1013, 395, 1062 and 909, respectively, have been recognized as the most important habitat nuclei.

Table 7 Evaluation of the landscape connectivity index of the core areas

Rank	Core code	dIIC	dPC	Area (ha)
1	329	48.09342	54.64138	1561.37
2	1062	26.65506	8.434121	510.52
3	782	21.58754	4.378782	212.63
4	1013	20.15743	11.22601	766.81
5	523	20.10818	2.642042	91.63
6	670	18.73592	4.679809	30.72
7	909	13.40127	8.540193	486.60
8	486	11.71476	17.61406	365.82
9	395	8.757191	7.316922	273.54
10	709	4.982706	54.64138	350.60

The prioritizing of the eight major cores is shown in Figure 4. The geographical distribution of the connection in the region, as shown in this diagram, suggests that there is a need to enhance the connections of the spots owing to the existence of noticeable interruptions. The central part of the study area occupy important Phasianus colchicus habitats with the most connections, due to its appropriate distance from residential areas and the presence of agricultural lands and pastures in the forest, which have the potential to provide food for pheasants and are a good place for nesting and breeding. As a consequence of their lesser size and dPC, cores on the western and eastern boundaries have a lower priority for constructing a communication corridor. At last, the optimal corridors among two habitats were identified applying the method of least-cost analysis with a maximum distance of 3200 meters. Total length of these corridors is 35.9 km.

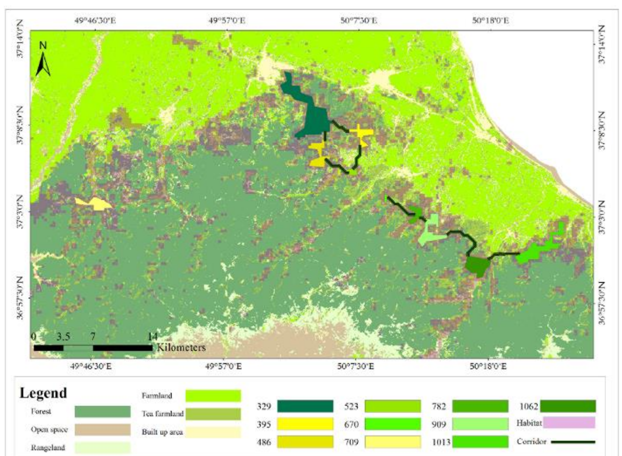

Fig. 4 Cores with the highest priority in Phasianus colchicus habitats and potential corridors between the target cores

Regarding the amount of land cover resistance, these corridors are basically forest lands or tea fields, mixed with pastures which have the capability to upgrade and enhance considerable ecological network.

As previously stated, the predicted land cover map for 2040 indicates a growth in the area of developed locations as well as forest degradation and conversion to tea farmland and farmland. Putting together a land cover map, habitat attractiveness, and built-in corridors to boost core link demonstrates that if the present trend continues, some of the finest habitats for this species in the area will still be desired in the future, but many of them will be lost due to development. On the one hand, the conversion of deciduous forest lands, the retreat of forest boundaries to highlands, and the spread of cities into forests, and on the other hand, this species' simultaneous demand for forest for nesting and agricultural areas and pastures for sustenance, will be eliminated. Furthermore, as the process progresses, some of the intended corridors may lose their function and will no longer be ideal passageways for the transit and migration of this species across ecosystems (fig. 5).

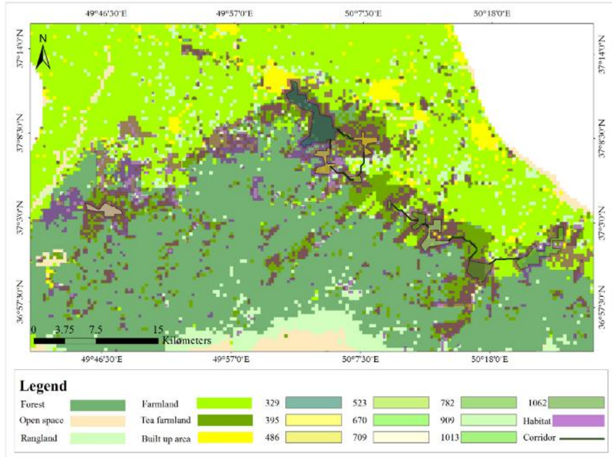

Fig. 5 The structure of selected Phasianus colchicus habitats and connecting corridors in 2040

4. Conclusions:

Human activities have steadily impacted and destroyed animal and plant habitats in recent years, as cities have grown rapidly and land cover has changed. Meanwhile, the Northern provinces are no exception, and their species diversity has constantly been declining. As a result, how to build ecological networks and plan to enhance their structure has become a solution to this dilemma and the conservation of species habitats in recent years. Corridors are one of the key components of the ecological network structure that allow species movement by strengthening habitat structural cohesion.

This research explains a technique for recognizing existing structural land characteristics, assessing the link, and building an environmental network utilizing MSPA and graph theory (using Conefor 2.6 software). This combined approach of MSPA, Graph Theory, and least-cost path analysis may convert environmental networks from structural to functional connectedness, which is crucial for Phasianus colchicus mobility across portions of such habitats in the research region. The integration of the CA-Markov model with the ecological network and InVEST was also successful in predicting the possible impacts of future land cover changes on ecosystem habitat services and the ecological network in this research. The combination of the software and models stated above provides two benefits. It can first assist planners in identifying the most important habitats, increasing their yield and improving their structure, and then measuring the effects of LCLU as a complex social-ecological system on habitat ecosystem services as one of the most important services provided by ecosystems in the second step.

The results of this study suggest that the study area's foothills, which serve as a crossroads for Hyrcanian forests, agricultural regions, and tea farmland, have the greatest priority for pheasant habitat. The situation is somewhat better in terms of continuity in the middle portion of these habitats, and the farther we go from the center to the west and east of the region, the more dispersed and less distributed observed from this place owing to the loss of farm lands and rangelands. The modest number of bridges serving as corridors linking habitats in this ecological network, along with the significant number of essential components, suggests that planners and specialists believe this network requires corridors. The lack of perforation within the cores, on the other hand, verifies the network's advantageous position in terms of core internal connection. The large proportion of isolated areas in the region, on the other hand, shows a high level of habitat disintegration and, as a consequence, a bad state of this species in the area, emphasizing the need for effective planning to enhance the structure and function of this land.

The loss of desirable habitats in terms of severe deforestation and land use change over the next twenty years, which causes the habitat of this species to be limited and regress to higher altitudes, which is not physically suitable for this species, and thus we will see a significant decrease in the population of this species in the future if the current trend continues.

Based on the results of this study, it can be concluded that the approach utilized in this study may be used to a variety of studies on big and small sizes to identify prospective corridors, with a long-term perspective and taking into account the current trend. This strategy may also be used to manage habitats based on the species' demands and sensitivity, as well as the resistance of each user and the species' capacity to travel across habitats. Finally, the identified corridors as the optimal pathways for pheasant movement across habitat cores should be extensively studied and safeguarded against cover changes, in addition to conserving the ecological network's bridges and turns and avoiding perforation in the cores. Furthermore, encouraging awareness of indigenous populations to invade in this manner leads marginalized and inter-habitat farms to function as stepping stones for pheasant migration, which will play an essential role in strengthening habitat coherence and enabling migration across habitats.

Confict of interest Authors declare not confict of interest.

References

- Abdollahi S, lIdoromi A (2018) Assessment of Spatial arrangement of Landscape in order to access to conservation actions. Environmental Researches 8(16): 5-18. http://www.iraneiap.ir/article_81198.html?lang=en
- Alves RR, Rosa IM (2007) Biodiversity, traditional medicine, and public health: where do they meet?. Ethnobiology Ethnomedicine 3: 14-23. https://link.springer.com/content/pdf/10.1186/1746-4269-3-14.pdf
- An Y, Liu S, Sun Y, Shi F, Beazley R (2020) Construction and optimization of an ecological network based on morphological spatial pattern analysis and circuit theory. Landscape Ecology 36(7): 1-18. https://link.springer.com/article/10.1007/s10980-020-01027-3
- Arsanjani J, Helbich M, Kainz W, Darvishi Boloorani A (2013) Integration of logistic regression, Markov chain and cellular automata models to simulate urban expansion. International Journal of Applied Earth Observation and Geoinformation 21: 265-275. https://www.sciencedirect.com/science/article/abs/pii/S0303243411002091
- Ashoori A (2009) Endangered and protected birds of Gilan province. Iran. Katibeh Gil, Gilan
- Ashoori A, Kafash A, Varasteh Moradi H, Yousefi M, Kamyab H, Behdarvand N, Mohammadi S (2018) Habitat modeling of the common pheasant Phasianus colchicus (Galliformes: Phasianidae) in a highly modified landscape: application of species distribution models in the study of a poorly documented bird in Iran. The European Zoological Journal 85(1): 372-380. https://www.tandfonline.com/doi/full/10.1080/24750263.2018.1510994
- Ashoori A, Kafash A, Varasteh Moradi H, Yousefi M, Kamyab H, Behdarvand N, Mohammadi S (2018) Habitat modeling of the common pheasant Phasianus colchicus (Galliformes: Phasianidae) in a highly modified landscape: application of species distribution models in the study of a poorly documented bird in Iran. The European Zoological Journal 85(1): 372-380. https://www.tandfonline.com/doi/full/10.1080/24750263.2018.1510994
- Baranyi G, Saura S, Podani J, Jordán F (2011) Contribution of habitat patches to network connectivity: redundancy and uniqueness of topological indices. Ecol. Indic 11 (5): 1301–1310. https://www.sciencedirect.com/science/article/abs/pii/S1470160X11000379
- Bennett AF, Radford JQ, Haslem A (2006) Properties of land mosaics: implication for nature conservation in agricultural environmets. Bio Conserve 133: 250- 264. https://www.sciencedirect.com/science/article/abs/pii/S0006320706002850
- Berta Aneseyee A, Noszczyk T, Soromessa T, Elias E (2020) The InVEST habitat quality model associated with land use/cover changes: A qualitative case study of the Winike Watershed in the Omo-Gibe Basin, Southwest Ethiopia. Remote Sensing 12(7): 1103-1132. https://www.mdpi.com/2072-4292/12/7/1103
- Bodeker G, van Charlotte K, Emma W (2014) The Journal of Alternative and Complementary Medicine 6(1): 810-822. https://bit.ly/2XVCng
- Bodin Ö, Saura S (2010) Ranking individual habitat patches as connectivity providers: Integrating network analysis and patch removal experiments. Ecological Model 221: 2393–2405. https://www.sciencedirect.com/science/article/abs/pii/S0304380010002863
- Bright PW (1993) Habitat fragmentation-problems and predictions for British Mammals. Mammal Review 23: 101-112. https://bit.ly/39LPNRQ
- Bunn AG, Urban DL, Keitt TH (2000) Landscape connectivity: A conservation application of graph theory. Environ. Manag 59: 265–278. https://www.sciencedirect.com/science/article/pii/S0301479700903736
- Carrete M, Tella JL, Balanco G, Bertellotti M (2009) Effects of habitat degradation on the abundance, richness, and diversity of raptors across Neotropical biomes. Biological Conservation 142: 2002-2011. https://bit.ly/3bTZIr2
- Chapin FS, Díaz S (2020) Interactions between changing climate and biodiversity: Shaping humanity’s future. Proceedings of the National Academy of Sciences 117(12): 6295-6296. https://www.pnas.org/doi/abs/10.1073/pnas.2001686117
- Chhetri B, Badola HK, Barat S (2021) Modelling climate change impacts on distribution of Himalayan pheasants. Ecological Indicators 123: 107368-107378. https://www.sciencedirect.com/science/article/pii/S1470160X21000339

- Choudhary A, Deval K, Joshi PK (2021) Study of habitat quality assessment using geospatial techniques in Keoladeo National Park, India. Environmental Science and Pollution Research 28(11): 14105-14114. https://link.springer.com/article/10.1007/s11356-020-11666-3
- Cook EA (2002) Landscape structure indices for assessing urban ecological networks. Landsc. Urban Plan. 58: 269–280. https://www.sciencedirect.com/science/article/abs/pii/S0169204601002262
- Cotter M, Häuser I, Harich FK, He P, Sauerborn J, Treydte AC, Martin K, Cadisch G (2017) Biodiversity and ecosystem services−A case study for the assessment of multiple species and functional diversity levels in a cultural landscape. Ecol. Indic. 75: 111–117. https://www.sciencedirect.com/science/article/abs/pii/S1470160X16306860
- Cui N, Feng CC, Wang D, Li J, Guo L (2018) The effects of rapid urbanization on forest landscape connectivity in Zhuhai City, China. Sustainability 10: 3381-3398. https://www.mdpi.com/2071-1050/10/10/3381
- Dai L, Liu Y, Luo X (2021) Integrating the MCR and DOI models to construct an ecological security network for the urban agglomeration around Poyang Lake, China. Science of The Total Environment 754: 141868-141883. https://www.sciencedirect.com/science/article/abs/pii/S0048969720353973
- Deep S, Saklani A (2014) Urban sprawl modeling using cellular automata. The Egyptian Journal of Remote Sensing and Space Sciences 17: 179-187. https://www.mdpi.com/2073-445X/9/8/265
- Dos Santos AR, Araújo EF, Barros QS, Fernandes MM, de Moura Fernandes MR, Moreira TR, de AlmeidaTelles LA (2020) Fuzzy concept applied in determining potential forest fragments for deployment of a network of ecological corridors in the Brazilian Atlantic Forest. Ecol. Indic 115: 106423-106437. https://www.sciencedirect.com/science/article/abs/pii/S1470160X20303605
- Etherington TR (2016) Least-cost modelling and landscape ecology: concepts, applications, and opportunities. Current Landscape Ecology Reports 1(1): 40-53. https://link.springer.com/article/10.1007/s40823-016-0006-9
- Foltête JC, Girardet X, Clauzel C (2014) A methodological framework for the use of landscape graphs in land-use planning. Landscape and Urban Planning 124: 140-150. https://www.sciencedirect.com/science/article/abs/pii/S0169204613002430
- Frazier AE, Bryan BA, Buyantuev A, Chen L, Echeverria C, Jia P, Liu L, Li Q, Ouyang Z, Wu J, Xiang WN, Yang J, Yang L Zhao S (2019) Ecological civilization: perspectives from landscape ecology and landscape sustainability science. Landscape ecology 34: 1-8. https://link.springer.com/article/10.1007/s10980-019-00772-4
- Fuentes M, Millard K, Laurin E (2020) Big geospatial data analysis for Canada's Air Pollutant Emissions Inventory (APEI): using google earth engine to estimate particulate matter from exposed mine disturbance areas. GIScience & Remote Sensing 57(2): 245-257. https://www.tandfonline.com/doi/full/10.1080/15481603.2019.1695407
- Gorelick N, Hancher M, Dixon M, Ilyushchenko S, Thau D, Moore R (2017) Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote sensing of Environment 202: 18-27. https://www.sciencedirect.com/science/article/pii/S0034425717302900
- Guo M, Ma S, Wang L J, Lin C (2021) Impacts of future climate change and different management scenarios on water-related ecosystem services: A case study in the Jianghuai ecological economic Zone, China. Ecological Indicators 127: 107732-107745. https://www.sciencedirect.com/science/article/pii/S1470160X21003976
- Guo S, Saito K, Yin W, Su C (2018) Landscape connectivity as a tool in green space evaluation and optimization of the haidan district, beijing. Sustainability 10(6): 1979-1983. https://www.mdpi.com/2071-1050/10/6/1979
- Guo S, Saito K, Yin W, Su C (2018) Landscape connectivity as a tool in green space evaluation and optimization of the haidan district, beijing. Sustainability 10(6): 1979-1983. https://www.mdpi.com/2071-1050/10/6/1979
- Haiping L, Yanan Q, Yunying Q (2018) Use a spatial analysis model to assess habitat quality in Lashihai watershed. Resources and Ecology 9(6): 622-631. https://bioone.org/journals/Journal-of-Resources-and-Ecology/volume-9/issue-6/j.issn.1674-764x.2018.06.005/Use-a-Spatial-Analysis-Model-to-Assess-Habitat-Quality-in/10.5814/j.issn.1674-764x.2018.06.005.short
- Hall L S, Krausman P R., Morrison M L (1997) The habitat concept and a plea for standard terminology. Wildlife society bulletin 25(1): 173-182. https://www.jstor.org/stable/3783301
- Hammerschlag N, Gallagher JA (2017) Extinction risk and conservation of the earth's national animal symbols. Bioscience 67: 744-749. https://bit.ly/391vdxm
- Heal GM, Barbier EB, Boyle KJ, Covich AP, Gloss SP, Hershner CH, Hoehn JP, Pringle CM, Polasky S, Sgerso K, Schrader – Frechette K (2005) Valuing Services: Toward Better Environmental Decision Making. The National Academies Press, Washington DC
- Isbell F, Reich PB, Tilman D, Hobbie SE, Polasky S, et al. (2013) Nutrient enrichment, biodiversity loss, and consequent declines in ecosystem productivity. Proceedings of the National Academy of Sciences of the United States of America 110: 11911-11916. https://www.pnas.org/doi/abs/10.1073/pnas.1310880110

- Jie G,Yuchu XIE, Erjia CAO, Qiuyan H, Hongying LI (2019) Integration of InVEST-habitat quality model with landscape pattern indexes to assess mountain plant biodiversity change: a case study of Bailongjiang watershed in Gansu Province. Geogr Sci 29(4): 1193–1210. https://link.springer.com/article/10.1007/s11442-019-1653-7
- Jiliang X, Zhang X, Zhang Z, Zheng G, Ruan X, Zhu J, Xi B (2006) Multi-scale analysis on wintering habitat selection of Reeves's pheasant (Syrmaticus reevesii) in Dongzhai National Nature Reserve, Henan Province, China. Acta Ecologica Sinica 26(7): 2061-2067. https://www.sciencedirect.com/science/article/abs/pii/S1872203206600310
- Kija HK, Ogutu JO, Mangewa LJ, Bukombe J, Verones F, Graae BJ, Kideghesho JR, Said MY, Nzunda EF (2020) Spatio-temporal changes in wildlife habitat quality in the Greater Serengeti Ecosystem. Sustainability 12(6):2440. https://www.mdpi.com/2071-1050/12/6/2440
- Kilpatrick AM, Salkeld DJ, Titcomb G, Hahn MB (2017) Conservation of biodiversity as a strategy for improving human health and well-being. Philosophical Transactions of the Royal Society B: Biological Sciences 372(1722): 20160131-20160140. https://royalsocietypublishing.org/doi/full/10.1098/rstb.2016.0131
- Kong F, Yin H, Nakagoshi N, Zong Y (2010) Urban green space network development for biodiversity conservation: Identification based on graph theory and gravity modeling. Landsc. Urban Plan 95: 16–27. https://www.sciencedirect.com/science/article/abs/pii/S0169204609002333
- Kumar L, Mutanga O (2018) Google Earth Engine applications since inception: Usage, trends, and potential. Remote Sensing 10(10): 1509-1524. https://www.mdpi.com/2072-4292/10/10/1509
- Lee D J, & Jeon S W (2020) Estimating Changes in Habitat Quality through Land-Use Predictions: Case Study of Roe Deer (Capreolus pygargus tianschanicus) in Jeju Island. Sustainability 12(23): 10123-10142. https://www.mdpi.com/2071-1050/12/23/10123
- Lee DJ, Jeon SW (2020) Estimating Changes in Habitat Quality through Land-Use Predictions: Case Study of Roe Deer (Capreolus pygargus tianschanicus) in Jeju Island. Sustainability 12(23): 10123-10132. https://www.mdpi.com/2071-1050/12/23/10123
- Leif AP (2005) Spatial ecology and habitat selection of breeding male pheasants. Wildlife Society Bulletin 33(1): 130-141. https://onlinelibrary.wiley.com/doi/abs/10.2193/0091-7648(2005)33[130:SEAHSO]2.0.CO;2
- Li HQ, Lian ZM, Chen CG (2009) Winter foraging habitat selection of brown-eared pheasant (Crossoptilon mantchuricum) and the common pheasant (Phasianus colchicus) in Huanglong Mountains, Shaanxi Province. Acta Ecologica Sinica 29(6): 335-340. https://www.sciencedirect.com/science/article/abs/pii/S1872203209000675
- Li Z, Cheng X, Han H (2020) Future Impacts of Land Use Change on Ecosystem Services under Different Scenarios in the Ecological Conservation Area, Beijing, China. Forests 11: 584-604. https://www.mdpi.com/1999-4907/11/5/584
- Lin YP, Lin WC, Wang YC, Lien WY, Huang T, Hsu CC, ... & Crossman ND (2017) Systematically designating conservation areas for protecting habitat quality and multiple ecosystem services. Environmental Modelling & Software 90: 126-146. https://www.sciencedirect.com/science/article/abs/pii/S136481521730021X
- Linders TE, Bekele K, Schaffner U, Allan E, Alamirew T, Choge SK, ... & Eschen R (2020) The impact of invasive species on social-ecological systems: relating supply and use of selected provisioning ecosystem services. Ecosystem services 41: 101055-101069. https://www.sciencedirect.com/science/article/pii/S2212041619306667
- Liu X, Hu G, Chen Y, Li X, Xu X, Li S, Pei F, Wang S (2018) High-resolution multi-temporal mapping of global urban land using Landsat images based on the Google Earth Engine Platform. Remote sensing of environment 209: 227-239. https://www.sciencedirect.com/science/article/abs/pii/S003442571830066X
- Liu X, Hu G, Chen Y, Li X, Xu X, Li S, Pei F, Wang S (2018) High-resolution multi-temporal mapping of global urban land using Landsat images based on the Google Earth Engine Platform. Remote sensing of environment 209: 227-239. https://www.sciencedirect.com/science/article/abs/pii/S003442571830066X
- Liu X, Hu G, Chen Y, Li X, Xu, X, Li S, Pei F, Wang S (2018) High-resolution multi-temporal mapping of global urban land using Landsat images based on the Google Earth Engine Platform. Remote sensing of environment 209: 227-239. https://www.sciencedirect.com/science/article/abs/pii/S003442571830066X
- Lüke A, Hack J (2018) Comparing the Applicability of Commonly Used Hydrological Ecosystem Services Models for Integrated Decision-Support. Sustainability 10: 346-368. https://www.mdpi.com/2071-1050/10/2/346
- McKinney M L (2002) Urbanization, biodiversity, and conservation. Bioscience 52: 883–890. https://academic.oup.com/bioscience/article/52/10/883/354714?login=true
- Meriggi A, Pandini W, Cesaris C (1996) Demography of the pheasant in relation to habitat characteristics in northern Italy. Wildlife Research 1: 15–23. https://www.tandfonline.com/doi/full/10.1080/24750263.2018.1510994

- Mirzaei R, Hemami MR, Esmaili Sari A, Rezaei HR (2015) Determination of habitat suitability for common pheasant (Phasianus colchicus) in Golestan Province, using ecological niche modeling. Animal Environment 7(3): 81-88. https://www.aejournal.ir/mobile/article_11941.html?lang=en
- Mohallem SV, de Araújo Lobo DJ, Pesquero CR, Assunção JV, de Andre PA, et al. (2005) Decreased fertility in mice exposed to environmental air pollution in the city of Sao Paulo. Environ Res 98: 196-202. https://www.sciencedirect.com/science/article/abs/pii/S0013935104001732
- Nelli L, Meriggi A, Vidus-Rosin A (2012) Effects of habitat improvement actions (HIAs) and reforestations on pheasants Phasianus colchicus in northern Italy. Wildlife Biology 18(2): 121-130. https://bioone.org/journals/wildlife-biology/volume-18/issue-2/11-022/Effects-of-habitat-improvement-actions-HIAs-and-reforestations-on-pheasants/10.2981/11-022.full
- Nohegar A, Amiri CHB, Afrakhteh R (2015) Land use analysis on Gilan central district using landscape ecology approach. Geography and Territorial Spatial Arrangement 15: 197–214. https://www.sid.ir/en/Journal/ViewPaper.aspx?ID=482240
- Opdam P, Steingrover E, van Rooij S (2006) Ecological networks: a spatial concept for multi-actor planning of sustainable landscapes. Landsc Urban Plan 75: 322–332. https://www.sciencedirect.com/science/article/abs/pii/S016920460500054X
- Peng J, Pan Y, Liu Y, Zhao H, Wang Y (2018) Linking ecological degradation risk to identify ecological security patterns in a rapidly urbanizing landscape. Habitat Int 71: 110–124. https://www.sciencedirect.com/science/article/abs/pii/S019739751730560X
- Peng Y, Meng M, Huang Z, Wang R, Cui G (2021) Landscape Connectivity Analysis and Optimization of Qianjiangyuan National Park, Zhejiang Province, China. Sustainability 13(11): 5944-5965. https://www.mdpi.com/2071-1050/13/11/5944
- Pirnat J, Hladnik D (2016) Connectivity as a tool in the prioritization and protection of sub-urban forest patches in landscape conservation planning. Landscape and urban planning 153: 129–139. https://www.sciencedirect.com/science/article/abs/pii/S0169204616300809
- Qi K, Fan Z, Ng CN, Wang X, Xie Y (2017) Functional analysis of landscape connectivity at the landscape, component, and patch levels: A case study of Minqing County, Fuzhou City, China. Appl. Geogr 80: 64-77. https://www.sciencedirect.com/science/article/abs/pii/S0143622817301091
- Robertson P (1997) A Natural History of the Pheasant. Swan Hill Press, Shrewsbury.
- Roe D, Seddon N, Elliott J (2019) Biodiversity loss is a development issue: a rapid review of evidence. IIED Issue Paper, IIED London. https://bit.ly/2LRF2oV
- Sadat M, Salehi E, Amiri MJ, Ehsani AH (2021) Optimization of landscape structure based on ecological network analysis and graph theory. Environmental Studies 46(4): 509-524. https://jes.ut.ac.ir/mobile/article_83012.html?lang=en
- Sadat M, Zoghi M, Malekmohammadi B (2019) Spatiotemporal modeling of urban land cover changes and carbon storage ecosystem services: case study in Qaem Shahr County, Iran. Environment, Development and Sustainability 22(8): 8135-8158. https://link.springer.com/article/10.1007/s10668-019-00565-4
- Salman Mahiny A, Kamyab H (2009) Applied remote sensing and GIS with the software IDRISI. Mehre Mahdis Press, Tehran
- Sanderfoot OV, Holloway T (2017) Air pollution impacts on avian species via inhalation exposure and associated outcomes. Environmental Research Letters 12 (8): 083002-083019. https://iopscience.iop.org/article/10.1088/1748-9326/aa8051/pdf
- Saura S, Pascual-Hortal L (2007) A new habitat availability index to integrate connectivity in landscape conservation planning: Comparison with existing indices and application to a case study. Landsc Urban Plann 83(2): 91–103. https://www.sciencedirect.com/science/article/abs/pii/S0169204607000709
- 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. Ecological Management 262: 150–160. https://www.sciencedirect.com/science/article/abs/pii/S0378112711001605
- Schmitz RA, Clark WR (1999) Survival of ring-necked pheasant hens during spring in relation to landscape features. The Journal of wildlife management 63(1): 147-154. https://www.jstor.org/stable/3802495
- Shafinejad S, Poodat F, Farrokhian F (2018) Assessment of ecological connectivity of urban green patches using graph theory: The Case study of Ahvaz metropolitan area. Applied ecology 7(1): 1-11. https://www.sid.ir/en/Journal/ViewPaper.aspx?ID=754179
- Sharp R, Tallis H T, Ricketts T, Guerry A D, Wood S A, Chaplin-Kramer R, Nelson E, Ennaanay, D, Wolny S, Olwero N, et al. (2018) InVEST 3.7.0.post9+ug.h12fcefd18548 User's Guide; The Natural Capital Project,

Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund. http://releases.naturalcapitalproject.org/investuserguide/latest/InVEST_3.7.0.post10+h2ce175de3cea_Documentation.pdf (accessed on 4 May 2019).

- Sharp R, Tallis HT, Ricketts T et al (2018) InVEST+ VERSION+ User's guide. The natural capital project. https://invest-userguide.readthedocs.io/_/downloads/en/3.6.0/pdf/ (accessed on 3 June 2019). Gong J, Xie Y, Cao E, Huang Q, Li H (2019) Integration of InVEST-habitat quality model with landscape pattern indexes to assess mountain plant biodiversity change: A case study of Bailongjiang watershed in Gansu Province. Journal of Geographical Sciences 29(7): 1193-1210. https://link.springer.com/article/10.1007/s11442-019-1653-7 Terrado M, Sabater S, Chaplin-Kramer B, Mandle L, Ziv G, Acuña V (2016) Model development for the assessment of terrestrial and aquatic habitat quality in conservation planning. Sci. of the Total. Environ 540: 63–70. https://www.sciencedirect.com/science/article/abs/pii/S0048969715003393
- Shelestov A, Lavreniuk M, Kussul N, Novikov A, Skakun S (2017) Exploring Google Earth Engine platform for big data processing: Classification of multi-temporal satellite imagery for crop mapping. frontiers in Earth Science 5: 17-27. https://www.frontiersin.org/articles/10.3389/feart.2017.00017/full
- Shi F, Liu S, An Y, Sun Y, Zhao S, Liu Y, Li M (2020) Spatio-temporal dynamics of landscape connectivity and ecological network construction in Long Yangxia basin at the upper Yellow river Land 9(8): 265-284. https://www.mdpi.com/2073-445X/9/8/265
- Shi F, Liu S, An Y, Sun Y, Zhao S, Liu Y, Li M (2020) Spatio-temporal dynamics of landscape connectivity and ecological network construction in Long Yangxia basin at the upper Yellow river. Land 9(8): 265-285. https://www.mdpi.com/2073-445X/9/8/265
- Shi X, Qin M (2018) Research on the optimization of regional green infrastructure network. Sustainability 10(12): 4649-4664. https://www.mdpi.com/2071-1050/10/12/4649
- Singh V, Shukla S, Singh A (2021) The principal factors responsible for biodiversity loss. Plant Science 6(1): 011-014. https://www.peertechzpublications.com/articles/OJPS-6-126.php
- Soille P, Vogt P (2009) Morphological segmentation of binary patterns. Pattern Recognition Letters 30: 456–459. https://www.sciencedirect.com/science/article/abs/pii/S0167865508003267
- Song Y, Wang M, Sun X, Fan Z (2021) Quantitative assessment of the habitat quality dynamics in Yellow River Basin, China. Environmental Monitoring and Assessment 193(9): 1-17. https://link.springer.com/article/10.1007/s10661-021-09404-4
- Symes WS, Edwards DP, Miettinen J, Rheindt FE, Carrasco LR (2018) Combined impacts of deforestation and wildlife trade on tropical biodiversity are severely underestimated. Nature Communications 9: 4052. https://go.nature.com/35WtyaC
- Taylor PD (2006) Landscape connectivity: a return to the basics. Connectivity conservation. Cambridge, University Press Cambridge
- Thellmann K (2021) Simulating the impact of land use change and climate change on the supply of ecosystem services in a rubber-dominated watershed in Southwestern China. Dissertation, University of Hohenheim
- Upland habitat basics (2021) Essential habitat components for pheasants. https://www.pheasantsforever.org/Habitat/Pheasant-Facts/Upland-Cover-Basics.aspx
- Venter ZS, Aunan K, Chowdhury S, Lelieveld J (2020) COVID-19 lockdowns cause global air pollution declines with implications for public health risk. Proceedings of the National Academy of Sciences 117(32): 18984-18990. https://www.pnas.org/doi/abs/10.1073/pnas.2006853117
- Verburg PH, Schot PP, Dijst MJ, Veldkamp A (2004) Land use change modelling: current practice and research priorities. GeoJournal 61(4): 309-324. https://link.springer.com/article/10.1007/s10708-004-4946-y
- Vogt P (2018) European Commission. User Guide of GuidosToolbox. https://ies-ows.jrc.ec.europa.eu/gtb/GTB/GuidosToolbox_Manual.pdf
- Wang LJ, Ma S, Qiao YP, Zhang JC (2020) Simulating the Impact of Future Climate Change and Ecological Restoration on Trade-Offs and Synergies of Ecosystem Services in Two Ecological Shelters and Three Belts in China. Environ. Res. Public Health 17: 7849- 7875. https://www.mdpi.com/1660-4601/17/21/7849
- Wei J, Qian J, Tao Y, Hu F, Ou W (2018) Evaluating spatial priority of urban green infrastructure for urban sustainability in areas of rapid urbanization: A case study of Pukou in China. Sustainability 10(2): 327-341. https://www.mdpi.com/2071-1050/10/2/327
- Wilson E O (ed.) (1988) Biodiversity. The National Academic Press, Washington DC
- Worboys GL, Francis WL, Lockwood M (Eds.) (2010) Connectivity conservation management: a global guide. Earthscan, London

- Wu J, Li X, Luo Y, Zhang D (2021) Spatiotemporal Effects of Urban Sprawl on Habitat Quality in the Pearl River Delta from 1990 To 2018. Scientific Reports 11(1): 1-15. https://www.nature.com/articles/s41598-021-92916-3
- Wu L, Sun C, Fan F (2021) Estimating the Characteristic Spatiotemporal Variation in Habitat Quality Using the InVEST Model—A Case Study from Guangdong–Hong Kong–Macao Greater Bay Area. Remote Sensing 13(5): 1008-1032. https://www.mdpi.com/2072-4292/13/5/1008
- Xiao L, Cui L, Jiang QO, Wang M, Xu L, Yan H (2020) Spatial Structure of a Potential Ecological Network in Nanping, China, Based on Ecosystem Service Functions. Land 9(10): 376- 394. https://www.mdpi.com/2073-445X/9/10/376
- Xiao L, Cui L, Jiang QO, Wang M, Xu L, Yan H (2020) Spatial structure of a potential ecological network in Nanping, China, based on ecosystem service functions. Land 9(10): 376- 395. https://www.mdpi.com/2073-445X/9/10/376
- Xiong J, Thenkabail PS, Gumma MK, Teluguntla P, Poehnelt J, Congalton, RG, Yadav K Thau D (2017) Automated cropland mapping of continental Africa using Google Earth Engine cloud computing. Photogrammetry and Remote Sensing 126: 225-244. https://www.sciencedirect.com/science/article/pii/S0924271616301575
- Yang H, Chen W, Chen X (2017) Regional Ecological Network Planning for Biodiversity Conservation: A Case Study of China's Poyang Lake Eco-Economic Region. Environmental Studies 26(4): 1825-1833. http://www.pjoes.com/Regional-Ecological-Network-Planning-for-Biodiversity-Conservation-A-Case-Study-of,68877,0,2.html
- Yang, Y (2021) Evolution of habitat quality and association with land-use changes in mountainous areas: A case study of the Taihang Mountains in Hebei Province, China. Ecological Indicators 129:107967-107979. https://www.sciencedirect.com/science/article/pii/S1470160X21006324
- Ye H, Yang Z, Xu X (2020) Ecological Corridors Analysis Based on MSPA and MCR Model—A Case Study of the Tomur World Natural Heritage Region. Sustainability 12(3): 959-974. https://www.mdpi.com/2071-1050/12/3/959
- Zang SY, Yuan H, Ning J (2002) The landscape ecological assessment and planning in the control watershed by reservoir of erlong mountain. Chinese Geographical Science 12: 176–181. https://link.springer.com/article/10.1007/s11769-002-0028-6
- Zhang X, Song W, Lang Y, Feng X, Yuan Q, Wang, J (2020) Land use changes in the coastal zone of China's Hebei Province and the corresponding impacts on habitat quality. Land Use Policy 99: 104957. https://www.jstor.org/stable/3783301
- Zhao SM, Ma YF, Wang JL, You XY (2019) Landscape pattern analysis and ecological network planning of Tianjin City. Urban Forestry & Urban Greening 46: 126479. https://www.sciencedirect.com/science/article/abs/pii/S1618866719302602
- Zhao, S. M., Ma, Y. F., Wang, J. L., & You, X. Y. (2019). Landscape pattern analysis and ecological network planning of Tianjin City. Urban Forestry & Urban Greening, 46: 126479-126507. https://www.sciencedirect.com/science/article/abs/pii/S1618866719302602
- Zhou ZX, Li J (2015) The correlation analysis on the landscape pattern index and and hydrological processes in the Yanhe watershed, China. Hydrology 524: 417- 426. https://www.sciencedirect.com/science/article/abs/pii/S0022169415001407