

Article

Methodology for Identifying Ecological Corridors: A Spatial Planning Perspective

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Abstract: Recent studies carried out by landscape and urban ecologists have shown that habitat fragmentation has negative environmental effects and is accountable for the loss of biodiversity. The development and extension of road infrastructure to support economic growth, the urbanization and the land-use changes are major drivers of habitat fragmentation. Planners have attempted to develop tools for restoring connectivity and stopping biodiversity loss at the landscape scale and which can be applied at the urban scale, too. The study fills in the gap by developing a methodology for identifying the ecological corridors of a Romanian large carnivore (brown bear) in the Romanian Carpathian Mountains at several spatial scales. The methodology relies on geospatial data; this is equally its most important advantage and challenge. Our findings suggest that the implementation of ecological corridors in current planning practice must be completed cautiously, provided the possible restrictions are imposed on economic activities by plans, and highlight the importance of field data in increasing the scientific soundness of the results. In addition, the findings show the need to interconnect spatial planning policies with environmental policies by improving the actual legislation.

Keywords: ecological connectivity; ecological corridors; ecological networks; geospatial data; habitat fragmentation; legislation; spatial planning; regulation



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1. Introduction

Climate change and human activities are the main cause of accelerating biodiversity loss, habitat fragmentation and species isolation [1–3] which, according to official reports [4], have led to a 47% decrease in the number of ecosystems globally. Urbanization, economic development, expansion of transport networks and land-use change are causing habitat fragmentation, reducing connectivity and creating artificial barriers along wildlife routes [5,6]. The decline in biodiversity and the loss of ecosystem services can be avoided by increasing ecological connectivity. Connectivity can be achieved by creating interconnected corridors and ecological networks, one of the most common recommendations for biodiversity protection [7,8].

The concept of connectivity was first addressed at the level of landscape and protected natural areas, and later in ecology. Certain animal species, with different behaviors, need connectivity of their habitats, on which they depend. Landscape connectivity is demonstrated by taking into account information on the spatial and functional relationships in the landscape, i.e., the different categories of structural elements, and on the spatial behavior of those animal species considered to be indicator species [9]. According to the Convention on Migratory Species [10], “ecological connectivity is the unimpeded movement of species and the flow of natural processes that sustain life on Earth”. IUCN elaborates on the above

definition, ecological connectivity being seen as the “movement of populations, individuals, genes, gametes and propagules between populations, communities and ecosystems, as well as that of non-living material from one location to another” [11].

Ecological connectivity can be maintained by ecological networks, which are also an effective way of conserving biodiversity [12]. A definition of the ecological network, accepted and used by the scientific community, is given by Bennett [13], in 2004: “A coherent system of natural and/or semi-natural landscape elements that is configured and managed with the objective of maintaining or restoring ecological functions as a means to conserve biodiversity while also providing appropriate opportunities for the sustainable use of natural resources”.

The ecological network is a model that emerged in the 1980s with the idea of maintaining and protecting environmental processes [14]. The remark that human-dominated systems behave as filters that prevent the passage of all the individuals of a certain wildlife species was the basis of the theory of island biogeography, comparing protected areas with islands in an ocean of human-dominated systems [15]; also, the basis of the meta-population theory, which states that the movement of individuals can reconnect certain spatially separated subpopulations and restore extinct populations [16,17]. These remarks led many countries in the 1990s to develop national, regional and local programs aimed at integrating protected areas through extensive networks.

In general, an ecological network is composed of a “system of core habitats (protected areas, OECMs—Other Effective Area-Based Conservation Measures, and other intact natural areas), connected by ecological corridors, which is established, restored as needed and maintained to conserve biological diversity in systems that have been fragmented” [11]. Ecological networks aim, on the one hand, to facilitate the conservation of species and habitats, and, on the other hand, to reduce the impact of human activities by promoting the sustainable use of natural resources [18]. This means that the creation of ecological networks requires a joint environmental and spatial planning approach.

Ecological corridors, an important component of ecological networks, are “clearly defined geographical spaces that are governed and managed over the long term to maintain or restore effective ecological connectivity” [11], consisting of “landscape structures of various size, shape and vegetation cover that mutually interconnect core areas and allow migration of species between them” [19]. The size, shape and spatial configuration of the patches are important, so that the different types of corridors and networks are “major integrative structural characteristics of landscapes” [20]. When the ecological corridors intersect one or more linear barriers (water courses, roads, railroads, etc.), these critical areas need to be evaluated, because they weaken connectivity and limit the movement of species.

The new EU Biodiversity Strategy for 2030 [21] calls for the establishment of ecological corridors for species migration, and the consolidation of healthy ecosystems. In this regard, many of the projects aimed at improving connectivity by creating ecological corridors received funding, for example, under the LIFE program [22].

Ecological corridors and their critical areas are of the utmost importance in terms of planning [23]. The EU Territorial Agendas consider that developing green infrastructure networks at all spatial levels is a priority, as they can mitigate the fragmentation of natural habitats through green corridors [24]. The link between environmental policies related to green infrastructure networks and spatial development policies as a way to prevent urban sprawl and biodiversity loss is also emphasized [25].

Not all of the European countries have implemented the legal obligation to address ecological connectivity and networks in spatial planning legislation; however, the concept has been introduced in both environmental and planning regulations.

Table 1 shows the lack of legal binding norms in many countries, while most countries have implemented, to different degrees, the design of ecological networks.

Table 1. The degree of implementation of ecological networks in the legislation of selected European countries. The degree is assessed on a decreasing scale from strong (dark green), moderate (light green), weak (yellow) down to the lack of implementation (gray) (Data source: [26]).

Criteria		DE	SK	CZ	HU	BG	PL	IT	RO	MK	
Ecological network design	Strategic approach	Strong				Moderate	Strong		Moderate	Weak	
	Legal approach	Strong				Moderate	Strong		Moderate	Weak	
Degree of ecological knowledge considered	Scientific research methods	Strong				Moderate	Strong		Moderate	Weak	
	Field assessment methods	Strong				Weak	Moderate	Strong	Weak	Strong	
Ecological networks in spatial planning	Strategic documents	Strong									
	Legally binding norms at national level	Strong				Weak	Strong	Moderate	Lack		
	Legally binding norms at regional level	Moderate	Strong				Weak	Moderate		Lack	
	Legally binding norms in general land use plans	Moderate				Weak	Lack		Moderate	Lack	
	Legally binding norms in detailed land use plans	Moderate				Weak	Lack		Weak	Lack	
Strong		Moderate				Weak		Lack			

In Romania, both the environmental and spatial planning legislation provide for the need to identify and designate ecological corridors in order to ensure the environmental coherence of the protected areas network, but an analysis completed by Popescu and Petrișor in 2021 [23] shows that the legislation of the two sectors is not synchronized or harmonized. Romanian legislation recently included the concepts related to green infrastructure, connectivity, ecological networks and corridors in environmental policy, but not in spatial planning.

However, the issue is quite sensitive, as it implies the need to harmonize conservation requirements with the development interests of the areas included in an ecological corridor. The planning provisions, especially at the local level, involve regulations or restrictions that may affect the lives of the local population. Therefore, the importance of the topic addressed by the present study is based on the premise that planning ecological corridors for certain species can protect biodiversity and mitigate the impact of human activities in the areas that require connectivity.

From a technical point of view, the methods for identifying ecological corridors and assessing connectivity are needed; however, there is no single method for identifying ecological networks and corridors at a macro-territorial or local scale, because the networks depend on the species to which they are addressed, and the spatial scale of application. However, ecological connectivity has been assessed using computer tools developed in the 1990s by environmentalists along with Geographic Information Systems (GIS) specialists. With such tools, the models of connectivity of ecological corridors between habitats were obtained. Their accuracy depended on their integration into the characteristics of landscape, the behavior of certain species [27] and application at an appropriate spatial scale [28]. The most widely used methods for assessing environmental connectivity include the least cost path method (a widely used GIS application), the graph theory, the circuit theory, individual movement models or landscape networks [29]. At the same time, several methodologies for identifying ecological corridors have been developed [30,31] for the needs of the moment. These methodologies have been developed mainly in projects on a national or transnational scale, in conjunction with the identification of action plans for their implementation and management.

The present research aims to identify a methodology for identifying ecological networks and corridors in Romania for the brown bear, and shows how it can be adapted

and applied to different spatial scales, starting from the national one. The adaptation is necessary because currently there is no such agreed methodology. In the spatial planning area there is a need to include environmental information—such as ecological corridors—in the planning documentation, substantiating the spatial development proposals. The novelty of this study is that it approaches the subject not only from a technical point of view, presenting the steps needed to identify ecological networks and corridors at two different spatial scales, but also from a practical one, allowing the ecological corridors to be implemented in spatial planning documentation. Finally, the need for a legislative harmonization of the two fields dealing with the ecological corridors is demonstrated.

2. Materials and Methods

2.1. Study Area

In recent years, the drastic changes in land use that have occurred at a large and local scale (road infrastructure development, urbanization, the unsustainable development of tourism and recreational facilities) have influenced the ecological connectivity in an irreversible way [32] by land fragmentation. A similar situation is found in the mountainous areas, such as the Romanian Carpathians, which have undergone profound changes in the landscape and land cover.

For this reason, we have developed a methodology for identifying the ecological corridors used by the brown bear (*Ursus arctos* L. 1758), a species often found in the Romanian Carpathians. The brown bear travels long distances (even 150 km daily), and the destruction of its habitat, together with the lack of corridors through which it can move safely, often lead to unwanted interactions with humans [19]. We also chose this species due to the availability of data on its occurrence in the study area, which provided us with the necessary information for modeling the connectivity maps. As the brown bear is considered to be an “umbrella species”, which also meets the migration requirements of other species living in the same areas, the identified ecological corridors are also valid for those other species.

The proposed methodology consists of two approaches for assessing the ecological corridors for the brown bear on two spatial scales, in the Romanian Carpathians and in a Romanian county, namely Buzău (Figure 1). It is hoped that these ecological corridors, once identified, will be included in spatial plans and able to represent the scientific basis for development-related decisions at any spatial level.

2.2. Main Steps of the Methodology

The methodology aims to identify the movement corridors of the brown bear on the two aforementioned spatial scales, i.e., the Romanian Carpathians and Buzău County. Both cases considered the movement of the brown bear between Natura 2000 sites, which coincided with the core areas.

In the present study, we considered that the ecological network is composed of favorable habitat areas and ecological corridors, which in turn are made up of movement areas and critical connectivity areas; their identification is of the utmost importance for local planning [30].

The methodology, which is based on GIS, has the advantage that its results can be easily implemented in spatial planning documentation. Although the proposed methodology can be applied beyond the national level at a NUTS 3 level (i.e., county level in the case of Romania), it can be further adapted to a smaller scale, that of a settlement (LAU) where the identified ecological corridors can be implemented in the General Urban Plans (the Romanian equivalent of Master Plans). This turns the proposed method into a tool for integrating the ecological network for the brown bear on all of the spatial planning levels [31,33], meeting the requirement of embedding the ecological dimension into the spatial planning concept [34].



Figure 1. Location of the study area in European context (the national level—Romania and the county level—Buzău County). The map also displays the elevation, based on a Digital Elevation Model (map created by the authors).

The methodology for identifying the ecological network and corridors consists of developing two models in three steps (Figure 2):

- Step 1: Brown bear habitat suitability model: allows the identification of core areas and stepping stones that ensure the living and moving conditions of brown bear;
- Step 2: Connectivity model: ensures the interconnection of favorable habitats through corridors creating a coherent network. It establishes and adds *resistance surfaces*, consisting of linear elements that create barriers in the movement of the brown bear (such as settlements, road infrastructure);
- Step 3: Identification of ecological networks and corridors for the brown bear species at a national and county level, identification of critical areas according to the working scale.

Figure 3 shows the proposed methodology, containing the two methods—on the national and county spatial scales. As shown, the first step was to model the suitability of brown bear habitat at a national and county level. The second step consisted of modeling connectivity at the national level and at the county level, this was executed by assessing the habitat and the permeability, which allowed for the identification of the ecological networks in both cases, and the corridors in the third step.

The methodology requires discussions with national and local specialists at all of the steps, in order to verify and modify each layer obtained. The results must be verified by analyzing the existing documents (such as maps), in order to establish or improve the boundaries of the ecological networks and corridors, according to the presence of specific elements. The boundaries of favorable habitats must be located outside settlements or arable land, and local fixed boundaries (watercourses, roads, railways, etc.) must also be taken into account. In particular, in Buzău County, the verification of the existing connectivity barriers is necessary to identify the critical connectivity areas.

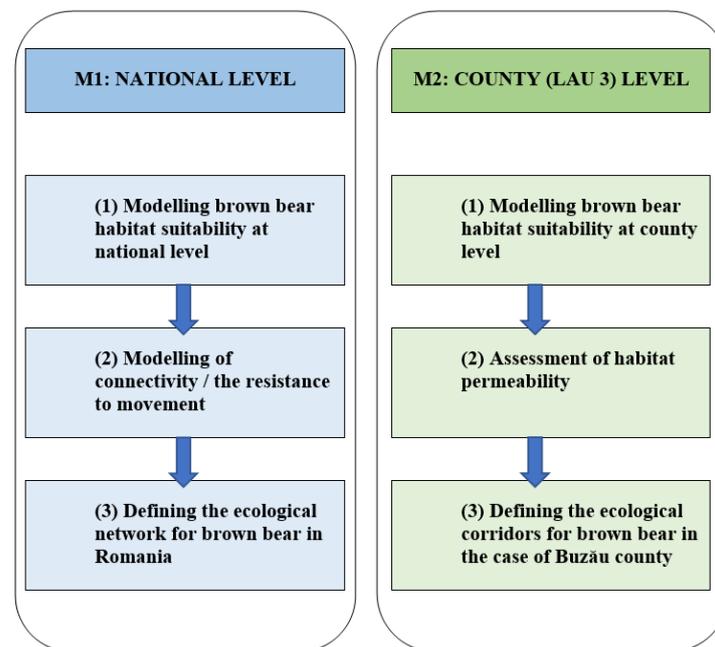


Figure 2. Methodology for identifying ecological networks and corridors for the brown bear species.



Figure 3. Map of habitat suitability for the brown bear in Natura 2000 sites from the Romanian Carpathian Mountains. The favorable habitat is represented by core areas (large areas that meet the requirements for permanent occurrence of the brown bear).

The on-site verification can be completed by mapping the barriers and their technical structures (small vegetation structures that could not be detected on the scale of the Carpathians) and the occurrence of the bears. These elements are digitized and also inserted into the GIS layer to refine the connectivity model, resulting in the critical areas.

2.2.1. The National Scale

To obtain the habitat suitability model, we chose a GIS-based approach combining ArcGIS 10.6, Corridor Design and Linkage mapper tools. The proposed methodology is based on the least cost path model, which is used to design roads or corridors with minimal cost on a surface divided into a network, where each cell is assigned a cost value.

The methodology applied on a national scale is explained in Table 2, which shows the activities required for each step, the IT tools used, the results obtained and presents several additional details related to each activity.

Unlike the county level, on the national scale the methodology took into account the different behavioral characteristics of brown bear in four periods of the year: winter (sleep period), spring (period of hypophagy and reproduction), summer (period of berries) and autumn (period of autumn hypophagy). The four periods were considered when making the maps of the national land cover, DEM and built-up areas. At the county level, these data were replaced with the occurrence data of the brown bear, collected in the field.

The habitat factors were assigned different weights for each layer, in order to be standardized by rasterizing the input datasets, as seen in Table 3, which also presents the final weights obtained by choosing an algorithm—the weighted geometric mean—that better reflects the real situation. Weights and their combination for both the habitat suitability model and habitat resistance model were defined based on national studies conducted over time and the BioREGIO Carpathian project, according to the study area and ecological status of the brown bear.

Table 2. Methodology: The three steps to identify ecological networks for the brown bear at national level. Each step is described in terms of sub-steps, activities, software and results. Habitat factors used as input data, intermediate and final results and maps are also described.

Steps	Activities	IT Tools	Results (R)	Remarks/Details
Step 1: Modeling the brown bear habitat suitability at national level	1.1. Collecting input data at national level: - Environmental variables - Occurrence data	Standardization of input data sets by rasterization	R1: A raster (30 × 30 m)	Environmental variables: CORINE (2018) National road network The railway network Traffic on national roads (2015) Built-up areas in localities DTM based on contour lines (10 m) Slopes derived from DTM Map of the occurrence of brown bear in the Romanian Carpathians
	1.2. Development of 4 habitat suitability models for the brown bear, for 4 characteristic periods of behavior, on 4 permeability classes	Parametrization of habitat factors using ArcGIS 10.6 Corridor Design (create suitability model)	R2: 4 maps of suitable habitat	The 4 characteristic behavioral periods of the brown bear are: winter sleep, period of hypophagy and reproduction, period of berries, period of autumn hypophagy
	1.3. Combining the 4 maps of suitable habitat	Using ArcGIS 10.6 Corridor Design and taking into account the classification of habitat factors	R3: Map of brown bear habitat suitability in Romania	4 classes of suitability were used, from 75–100% (optimal habitat) to 10–25% (barrier)
	1.4. Overlapping the digital map of Natura 2000 sites with the map of brown bear habitat suitability in Romania	ArcGIS 10.6 Selection Tool	R4: Brown bear habitat map in Natura 2000 sites	It has been observed that the most compact areas of habitat are those belonging to Natura 2000 sites
Step 2: Connectivity modeling	Establishing resistance surfaces	Analysis of the least travel cost (ArcGIS 10.6 Linkage Mapper)	R5: Map of resistance areas in the brown bear movement on national scale	Natura 2000 sites have been considered as favorable habitat areas. Resistance is the opposite of permeability
Step 3: Defining the ecological network for brown bear in Romania	Establishing possible ecological corridors in the case of brown bear	With the ArcGIS 10.6 Linkage Mapper application (Build Network and Map Linkages)	R6: Map of the ecological network for brown bear at the level of the Romanian Carpathians	The map of the habitat of brown bear from Natura 2000 sites and the map of the resistance areas have been combined

Table 3. Weights used for each habitat factor and each layer. The figure also presents the final weights obtained by choosing the weighted geometric mean (data processed after [35–37]).

Layers	National Level				County Level (Buzău County)		
CORINE land cover	Land cover categories	Weight (%), by Season				Categories	Weight (%)
		S1	S2	S3	S4		
		0	0	0	0	1	0
		80	50	70	40	2	40
	According to Table 4	90	60	80	70	3	60
		100	90	100	80	4	70
		100		100	5	80	
	<i>FINAL WEIGHT</i>	30%		40%			
DEM	Altitude (m)	Weight (%), by Season				Altitude (m)	Weight (%)
		S1	S2	S3	S4		
	<800	20	80	20	100	0–200	0
	801–1200	100	100	100	100	201–500	20
	1201–1600	80	70	100	60	501–800	60
	>1601	20	20	60	20	>801	100
	<i>FINAL WEIGHT</i>	10%		15%			
Built-up areas	Distance (m)	Weight (%), by Season				Distance (m)	Weight (%)
		S1	S2	S3	S4		
	<500	0	0	10	0	0–200	0
	501–1500	10	60	60	90	201–500	25
	1501–3000	60	100	80	100	501–800	60
	>3001	100	100	100	100	>801	100
	<i>FINAL WEIGHT</i>	20%		15%			
Roads, railroads	National roads	Distance (m)	Weight (%)			Distance (m)	Weight (%)
			0–100	30	DN10	0–100	30
			101–500	50		101–500	60
			501–1500	80		501–1000	80
	Railroads		>1500	100		>1001	100
			0–100	10	County roads	0–10	85
			>100	100	Communal roads	0–10	95
					Railroads	0–50	80
	<i>FINAL WEIGHT</i>	20%		15%			
Terrain slope	Slope	Weight (%)			Slope	Weight (%)	
	Deep valley	35		Deep valley	35		
	Mild slope	70		Mild slope	70		
	Steep slope	100		Steep slope	100		
	Ridge	60		Ridge	60		
	<i>FINAL WEIGHT</i>	30%		15%			

Table 4. Parameterization of habitat factors-land use categories.

	Season	I	II	III	IV
Code	Land use category according Corine Land Cover				
0	112 Discontinuous urban fabric				
1	121 Industrial or commercial units				
2	211 Non-irrigated arable land				
3	231 Pastures		100		
4	242 Complex cultivation patterns				
5	311 Broad-leaved forest	80	100	70	100
6	221 Vineyards				
7	243 Land principally occupied by agriculture, with significant areas of natural vegetation		60		70
8	122 Road and rail networks and associated land				
9	411 Inland marshes				
10	123 Port areas				
11	131 Mineral extraction sites				
12	132 Dump sites				
13	133 Construction sites				
14	141 Green urban areas				
15	142 Sport and leisure facilities				
16	222 Fruit trees and berry plantations				80
17	324 Transitional woodland-shrub	80	50	100	80
18	312 Coniferous forest	100	60	100	40
19	313 Mixed forest	100	90	100	80
20	321 Natural grasslands		100		
21	322 Moors and heathland				
22	512 Water bodies				
23	331 Beaches, dunes, sands				
24	332 Bare rocks	90			
25	333 Sparsely vegetated areas				
26	412 Peat bogs			80	
27	511 Water courses				

For the land cover categories, a different number of weights was used (four and five categories), considering that in Season 2 and Season 4 (spring and autumn, with five categories) the brown bear has a larger area of movement, due to its needs (see Table 4) (our contribution on the basis of [36]).

The brown bear occurrence data were used in the statistical model for assessing the resistance of movement through the habitat at the national level, which was developed using the Gnarly Landscape utilities that allow for the combination of all of the component raster with their unique table of weights. Thus, if the input data are integer, then the output data are also integer for each cell. If one element of the input data is a floating point, then the output data will also be a floating point for the cell. Based on this resistance raster and

the Natura 2000 areas that correspond to the bear's habitat, we computed cost weighted distance and least cost paths, using ArcGIS 10.6 Linkage Mapper.

2.2.2. The County Scale

The methodology also contains the necessary steps needed to obtain the brown bear ecological corridors applied on a smaller scale, namely at the level of Buzău County. The county was chosen not only because it has a significant population of brown bears, but also because input data were available from the Buzău County Land Use Plan-PATJ Buzău.

Table 5 shows, as in the previous case, the steps and sub-steps used to identify the ecological corridors in Buzău County. The table also provides details about the computer tools and input data used.

Table 5. Methodology: Steps to identify ecological corridors for the brown bear at county level. Each step is described in terms of sub-steps, activities, software and results. Habitat factors used as input data, chosen weights, intermediate and final results are also described. At this scale more attention was given to details of the transport infrastructure.

Steps	Activities	IT Tools	Results (R)	Remarks/Details
Step 1: Modeling the brown bear habitat suitability at County level	1.1. Input data collection: - Environmental variables (national and County scales) - Map of the brown bear habitat in Buzău County	Rasterization and standardization of input data series	Raster maps (30 × 30 m)	Habitat factors: CORINE (2018) for Romania National road and railroad network Traffic on national, county and communal roads in the County (2018) Built-up areas of all settlements from the County DTM based on contour lines (10 m) at County level Slopes derived from DTM Map of the occurrence of brown bear in Buzău County
	1.2. Rasterization and standardization of input datasets	Spatial Analyst–ArcGIS 10.6	The layer of land cover in Buzău County (R1) The layer of built-up areas of the settlements in Buzău County (R2) The layer of roads and railways in Buzău County (R3) The digital terrain model for Buzău County (R4) The digital model of the land slope in Buzău County (R5)	Weights identical to those of the 2018 CORINE raster Weights depending on the distances between these areas Weights depending on the distance between them and the existing traffic Weights depending on altitude (from 0 to over 1000 m) Weights according to Corridor Design–Create topographic position raster application
Step 2: Assessment of brown bear habitat permeability at County level	Establishing the permeability of the landscape according to the behavioral characteristics of brown bear	Standardization by reclassification: ArcGIS 10.6 Corridor Design (Create habitat suitability model)	Permeability map of Buzău County (R6)	Weighting of all habitat factors used: 40 for land cover and 15 for all other raster
Step 3: Defining ecological corridors for brown bear in Buzău County	Establishing potential ecological corridors in the case of brown bear for Buzău County	Corridor Design (Create corridor model)	Map of potential ecological corridors for brown bear in Buzău County (R7)	Natura 2000 sites in the county were considered as core areas Ecological corridors were calculated for each 2 core areas

3. Results

3.1. Map of Ecological Networks for the Brown Bear at the National Level

At county level, it is easier to utilize the Corridor Design tool, because it uses a reclassification text file for each component raster (according to Tables 3 and 4). We used these reclassification text files to create the brown bear habitat suitability model. This tool allows for reclassifying and combining two–six different habitat factors, and also provides two algorithms for combining the habitat factors—geometric mean and additive mean. For our purpose, the geometric mean was chosen because it automatically assigns a score of 0 to all of the pixels in areas unsuitable for bear presence (as opposed to additive mean where habitat quality reclassification is required to avoid scoring errors in areas where brown bear presence is excluded).

Applying the methodology and IT tools presented, we obtained some partial results, which helped to finally determine the map of the ecological corridors of brown bear in Romania. The maps corresponding to each step are presented below, namely:

- Step 1: Habitat suitability map for brown bear in Natura 2000 sites in Romania (Result R4 in Table 2, presented in Figure 3);
- Step 2: Map of the resistance to movement for the brown bear in Romania (Result R5 in Table 2, presented in Figure 4);
- Step 3: Map of the ecological network for the brown bear on the scale of the Carpathian Mountains in Romania (Result R6 in Table 2, presented in Figure 5).

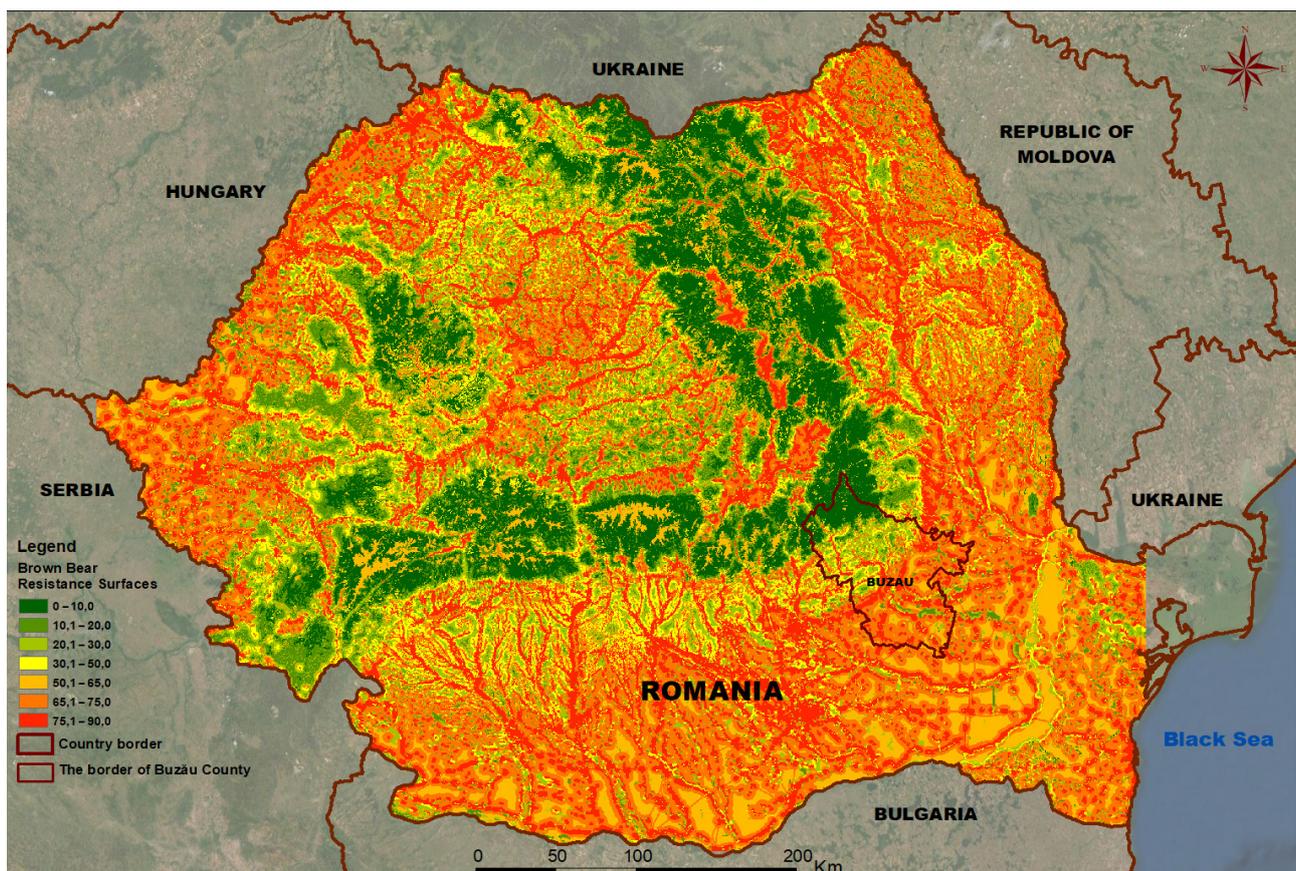


Figure 4. Map of the resistance to movement of the brown bear in Romania. The map presents resistance surfaces for the brown bear, which represent the degree to which landscape features impedes/facilitates its movement (modeled with ArcGIS 10.6 Linkage Mapper).

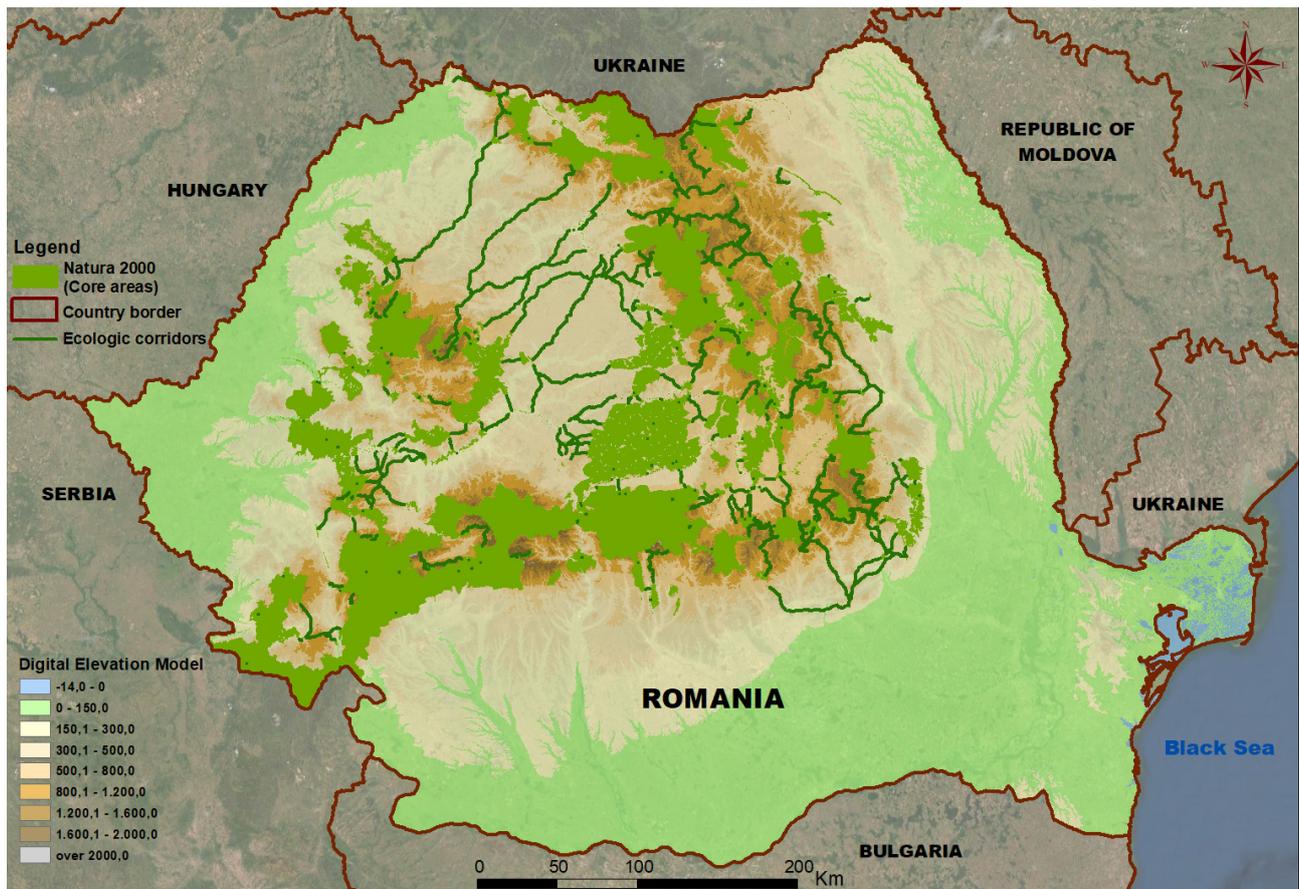


Figure 5. Map of the ecological network for the brown bear in the Romanian Carpathian Mountains (ecological corridors and core areas). The final map shows the possible ecological corridors for the brown bear between core areas (Natura 2000 sites).

3.2. Map of Potential Ecological Corridors for the Brown Bear at County Level

Applying the proposed methodology at the level of a county in Romania and determining the critical areas, we obtained the final results for each step, namely:

- Step 1: Figures 6–8 show the results of step 1—modeling the habitat suitability of the brown bear at county level (Results R1–R5 from Table 5 presented in Figures 6–8);
- Step 2: Habitat permeability map for Buzău County in the case of the brown bear (Result R6 from Table 5, presented in Figure 9a);
- Step 3: Map of potential ecological corridors for the brown bear, identified according to the proposed methodology (Result R7 from Table 5, presented in Figure 9b).

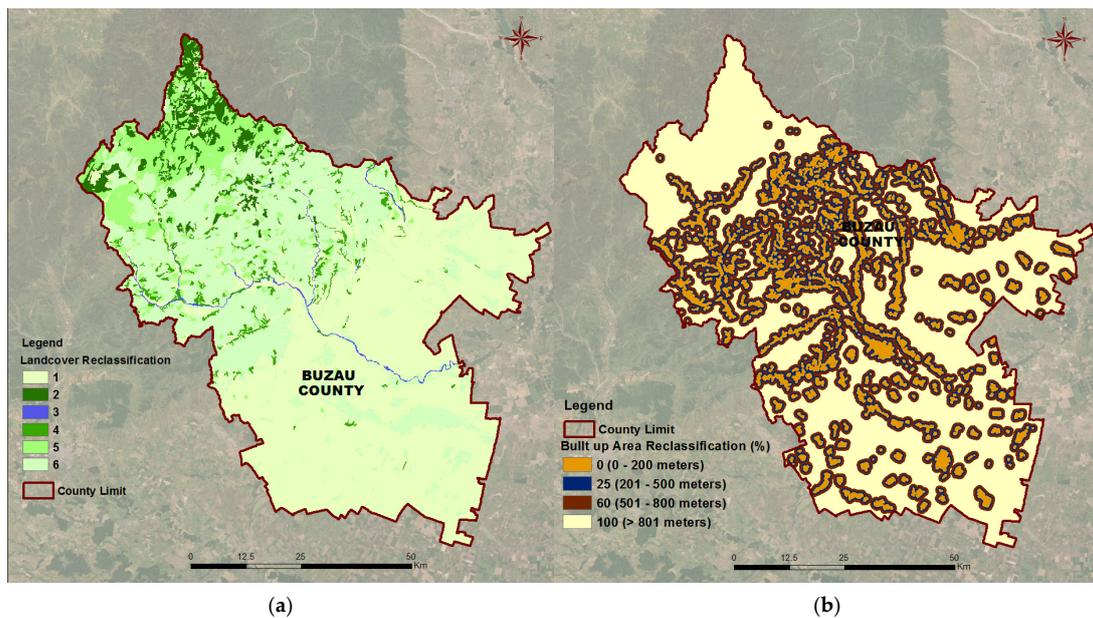


Figure 6. Results obtained by rasterization and standardization of the input datasets for the following habitat factors: (a) *Land cover*, according to CORINE 2020. The northern part of the county has forest cover and after the reclassification operation, favorable areas for the brown bear habitat and movement were identified (dark green spots and light green spots); (b) *Built-up areas*. The northern part of the county has many small, adjoined settlements. After the reclassification operation, the most favorable areas for the brown bear movement are seen on the map (the white ones, showing that the continuity of built-up areas is a major impediment in the brown bear movement) (maps created by the authors).

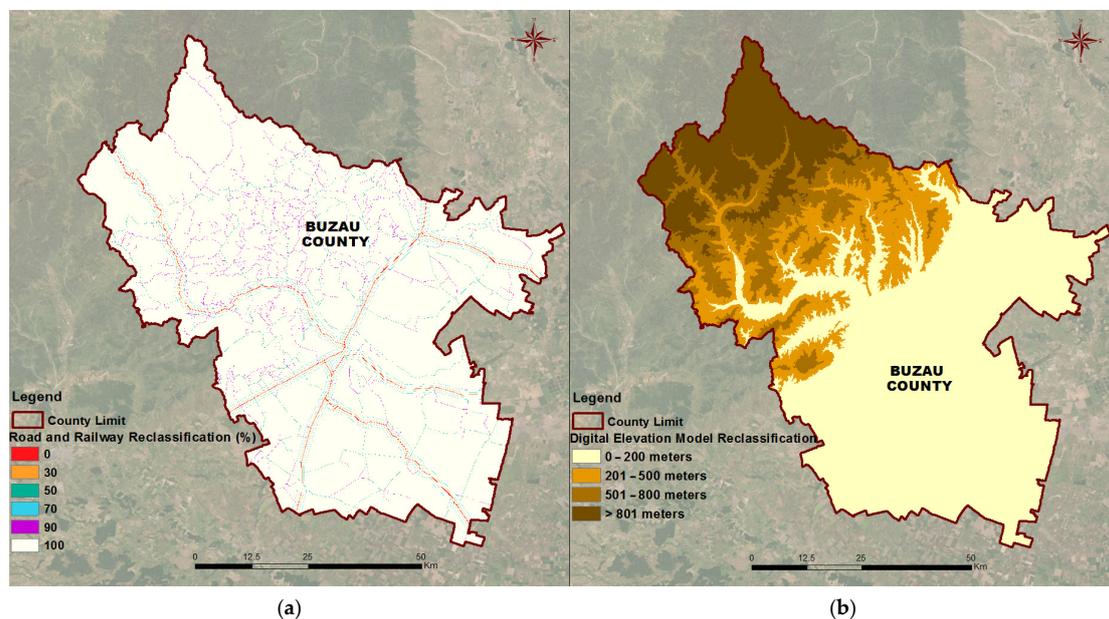


Figure 7. Results obtained by rasterization and standardization of the input datasets for the following habitat factors: (a) *Roads and railroads*. For the reclassification, we have obtained the map of travel restrictions for the brown bear movement. Most barriers are represented by the national roads and railroads of the county (the county and communal roads in the northern part are not real barriers due to their poor quality which results in restricted and low traffic on these secondary roads); (b) *Digital Elevation Model (DEM)*. The occurrence of the brown bear is higher in the northern part of the county, at altitudes starting with 300 m. After reclassification, the map shows that the brown bear habitat is present in the northern part of the county, which is favorable for the brown bear presence (maps created by the authors).

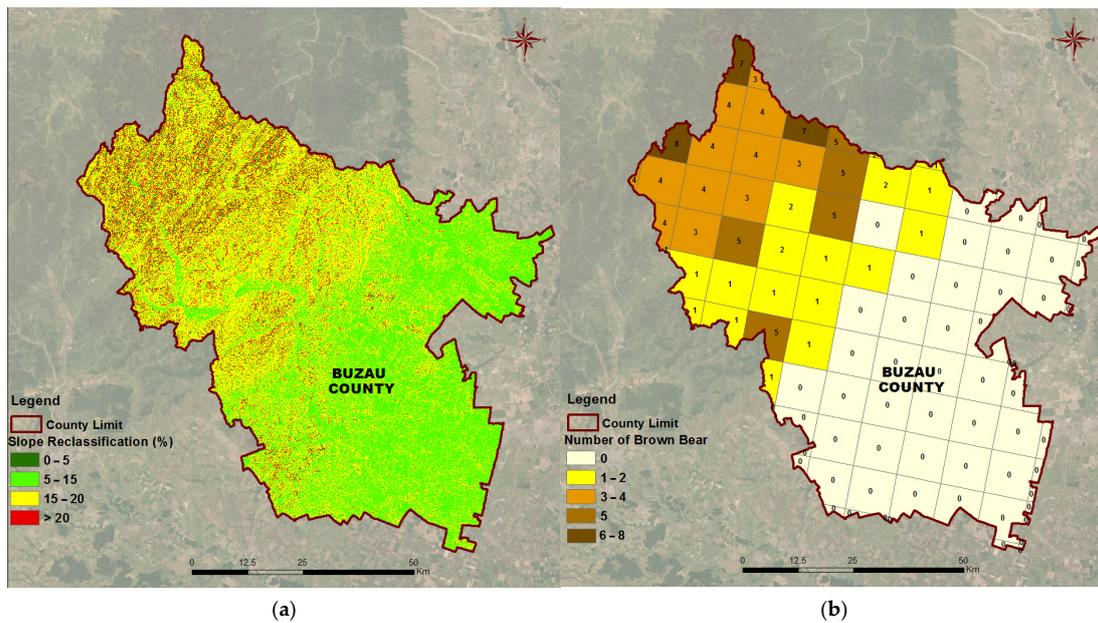


Figure 8. Results for the input data *Terrain Slope* (a). Following rasterization and standardization of this dataset, it is observed there are few steep slopes in the mountainous area of the county (the Buzău Mountains), which makes the brown bear move more easily in its habitat (map created by the authors); (b) Brown bear habitat in Buzău County. The map shows that the bear occurrence is higher in the northern part of the county (map processed after [34]).

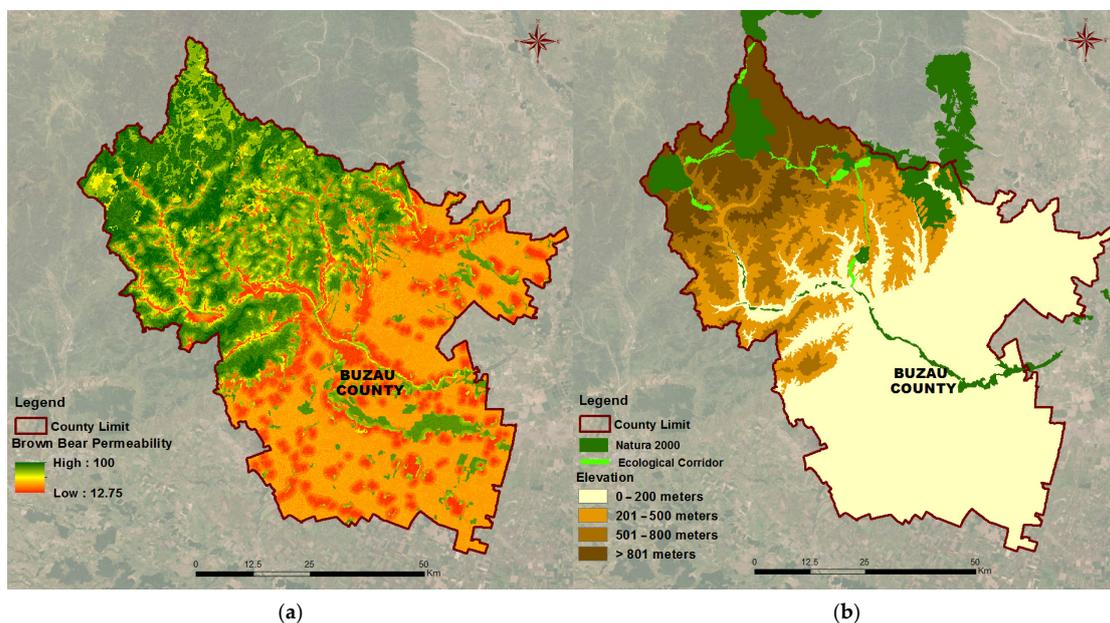


Figure 9. (a) *Habitat permeability map* of brown bear (Buzău County). The map indicates a higher permeability in the northern part of the county, unlike the southern part of the territory, having many barriers that lower the permeability; (b) *The potential ecological corridors for the brown bear* (in light green) obtained by applying the methodology. The map shows that they connect the Natura 2000 sites from the county and, according to the elevation, the potential ecological corridors are located between 500 and 1737 m (map created by the authors).

4. Discussion

Today, due to anthropogenic pressures, natural landscapes are undergoing drastic changes globally, such as the loss and fragmentation of species habitats [1,38]. This results

in the isolation and decrease in their resistance to climate change or human-induced change [39,40]. One of the most common recommendations for protecting biodiversity is to increase connectivity and create ecological networks that connect natural habitats [41], a conservation practice that is becoming even more relevant in the face of impending climate change [5,42,43].

4.1. Validation of Results

The proposed methodology for identifying the ecological networks and corridors for the brown bear in Romania, both nationally and regionally or locally, is a useful tool for central and local authorities involved in environmental and spatial planning and for all of the organizations interested in maintaining conservation connectivity and the migration of large carnivores [44]. It has been demonstrated that the methodology can be adapted to a smaller scale, so that the results can be integrated into territorial planning and, in the future, urban planning documentation. Moreover, the presented methodology shows that the ecological corridors for brown bear obtained on a national scale coincide with those on a county scale, even if we used different computer tools.

A positive side of the results obtained is the fact that the network of ecological corridors identified applying the methodology are characterized by a better resolution than in other previous studies (e.g., in the BioREGIO Carpathian project), allowing for the identification of ecological corridors on a local scale.

The implementation of the results obtained makes clear the need for more comprehensive legal provisions regarding ecological connectivity, and the identification and designation of ecological corridors in Romania, so that ecological networks and corridors are included especially in the environmental and spatial planning legislation.

The integration of clear provisions related to the ecological networks and corridors in spatial and urban planning is necessary when talking about development at the territorial level. First of all, the environmental legislation must establish the main guidelines and clarify the way in which the ecological corridors are identified and implemented, as well as the responsibilities for their management and monitoring. At the same time, the Romanian legislation for spatial planning should be harmonized with the environmental legislation, and specific documentation should also refer to the ecological corridors (for example, in the chapters dedicated to the natural environment). The regulations that are mandatory in urban plans represent a sensitive issue, because the type of human activities (either prohibited or allowed) developed in an ecological corridor must take into account the possible management plans of the existing protected areas in their proximity.

In Romania, the most important thing is that the results obtained by applying the proposed methodology are implemented in practice on all spatial scales and reflected in the spatial planning system. However, this will require political will and support from ministries and administrations, and effective dialogue and cooperation between the stakeholders involved in nature conservation and spatial planning, to make the protection of connectivity a priority. This is why, at this moment in Romania, it is very important to understand what the ecological corridors mean, what their future position is in terms of protection, and what the consequences are of their implementation in spatial planning. It must be legally specified whether the corridors will be protected areas, or will represent only distinct areas where certain restrictions apply.

4.2. Comparison with Other Identified Ecological Networks-TSES Network

As in other cases, where the ecological networks and corridors have been identified in Europe, this methodology requires a top-down approach, from national to regional/county/local levels. An example of a similar approach through which ecological continuity has been achieved is the Territorial System of Ecological Stability (TSES) in Slovakia, created in 1985 and adopted in 1991, together with the concept of ecological networks [45]. The TSES system is based on a methodology that used a top-down approach,

starting with the Supraterritorial Ecological Stability Plan (STSES) and moving to regional (RTSES) and local (LTSES) plans.

Figure 10 shows the TSES in Slovakia and the elements that make up this system. As can be seen, a TSES system consists of biocenters (in Slovakia there are 87 biocenters of supra-regional importance occupying 5.5% of the country's territory), biocorridors and interactive elements (2.66 km of supra-regional biocorridors that were determined on the basis of the migratory routes of flora and fauna).

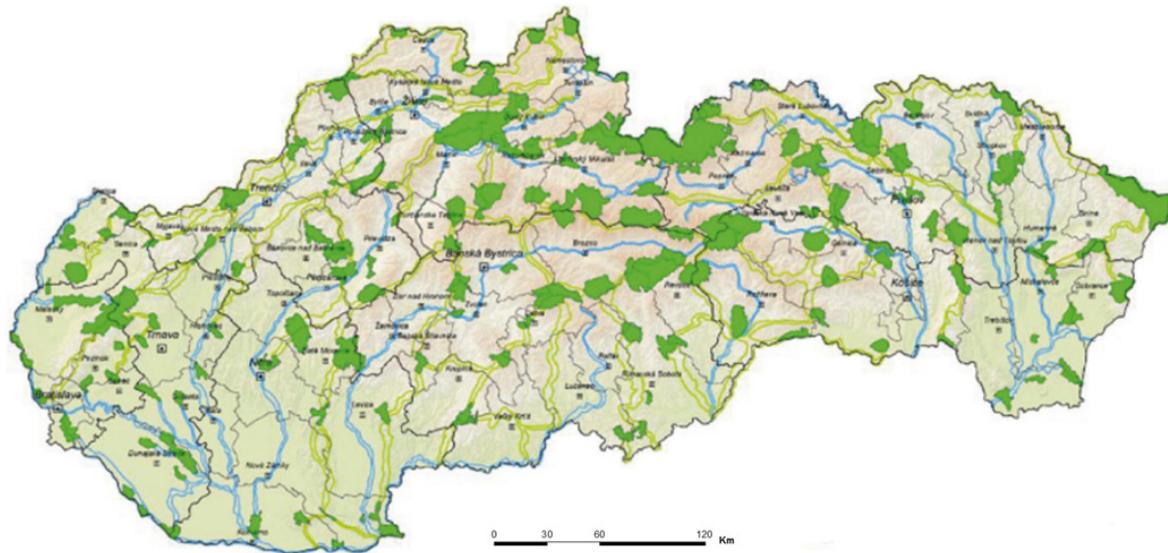


Figure 10. A similar ecological network: the Territorial System of Ecological Stability in Slovakia, containing supra-regional bio-centers, hydric bio-corridors, terrestrial bio-corridors (processed based on [45]).

With respect to the harmonization of legislation, the TSES can be found in many planning areas, such as nature and landscape protection, which define the TSES alongside the Natura 2000 network, spatial planning and construction, i.e., an area where the elements of the TSES are regulatory, therefore, mandatory at all levels of planning, environmental impact assessments and water or flood protection.

This example shows that our top-down approach is viable, meaning that in Romania the ecological networks must be identified at a national level first, and then move to the regional and local scales. It also demonstrates the need for harmonizing the many areas of territorial development, including legislation. Last, but not least, it is not only necessary to identify the elements of the ecological networks, but also to develop an approach that covers the whole territory, involving plans, measures and proposals for reducing the potential negative impact of anthropogenic activities on the elements of ecological networks.

4.3. Advantages of the Methodology and Contribution in the Field

So far there is no methodology unanimously approved by the scientific community or recommended by legislation for identifying the ecological corridors used by the brown bear anywhere in the world. The proposed methodology has the advantage of combining several existing methodologies and their strengths, approaching ecological connectivity in a holistic way, by including elements of environmental and spatial planning natures.

From the technical point of view, the proposed methodology combines GIS techniques and tools with mathematical modeling, combining environmental, geographical and land use information. The methodology includes a technically accessible approach in which the mathematical tools consider important habitat factors, and the GIS tools and rasterization methods are used to develop an application for assessing habitat permeability. From an environmental protection and ecology standpoint, the methodology has the advantage of considering the behavior of brown bear in four periods of the year, which allows for better

and more accurate identification. By combining the four models, we have obtained a more precise model of the habitat suitability for the brown bear.

The methodology makes an important contribution to environmental protection and spatial planning by creating a synergy between biodiversity conservation and spatial planning. The method takes into account many of the elements of biodiversity and ultimately seeks to protect both the brown bear and humans, by increasing the ecological connectivity.

The contribution of this methodology to spatial planning is very significant, because the results obtained on national and county scales provide core information for the spatial planning. Any spatial plan must include this information, and development projects and strategies are proposed based on the spatial plans. An important advantage is that by applying this methodology the ecological corridors are identified with greater precision, given the use of GIS, which allows for knowledge of the precise location of the corridors on a local scale. This process is a starting point for refining the results on a local scale, where the main barriers to the movement of analyzed animals must be checked in the field, along with the critical areas represented by the intersections of ecological corridors with the main transport infrastructures, waterways, construction, fences, etc. It is essential for the identified critical areas to be included in the spatial plans at any spatial level, in order to avoid the fragmentation of green corridors caused by potential negative impact investments.

Another advantage of the methodology is that its results can be easily included in spatial and urban planning documents, both in maps (since GIS applications integrate the exact location) and written materials (studies). The spatial and urban planning documents will have to take into account the ecological corridors theoretically identified based on this model and establish their opportunity, including presenting scenarios, forecasts, and alternatives on the impact of activities on the ecological corridors.

The establishment of ecological corridors helps with determining land use change in urban areas, delimiting the areas affected by public easements, or establishing the areas requiring a special protection regime provided for in the current legislation. By applying the proposed methodology and movement corridors, the increasing occurrence of the brown bear in the inhabited areas, and subsequent conflicts with people, can be avoided.

4.4. Methodological Limitations

- **Scale**

The proposed methodology has been designed at the level of spatial planning plans, which can be considered a limitation, but the way this methodology was conceived offers the possibility for testing it on the urban scale in the future. Applying the methodology at a local level is a future direction of research, along with investigating the degree of protection assigned to ecological networks and corridors (as areas sensitive to human intervention), including at the legislative level. However, a smaller scale will require consideration of the several barriers that have a strong impact on connectivity (roads, railways, fences, waterways, built-up areas, etc.). The differences between settlements make it impossible to find unique solutions for the identification of the corridors.

It should be noted that, when switching from spatial to urban planning, all of the potential critical areas, such as the corridors intersected by linear infrastructures, must be identified, and measures must be proposed to ensure the necessary permeability for the species at stake. In fact, another limitation of the study is that it refers to a single species.

In natural areas, (which are the core areas of ecological networks) the relationship between anthropogenic activities and development within the areas is provided in their management plans (if any) or regulations, meaning that certain anthropogenic activities are allowed or restricted, depending on the type of protected area [46]. On the other hand, in the areas corresponding to the ecological corridors and especially in their critical areas, human activities compatible with the sustainable use of natural resources may be allowed, to support conservation objectives (housing, agriculture, forestry, grazing, fishing, ecotourism); they must be included in special management plans for the ecological corridors.

Adequate land use management in the ecological corridors is very important for urban planning documents (at the settlement level), where the design and operation of the ecological corridors are not easy, because they relate to the issue of regulating land use types and restricting human activities. In an ecological corridor, the protection of land from future development can be completed either by zoning restrictions, which limit the subsequent construction of housing in certain areas, or by prohibiting certain activities (such as the extraction of raw materials) for certain periods. To do this, it is necessary to know how human actions influence the dynamics of a species, but also the compensation that should be granted to landowners and owners, in case they can no longer perform certain activities.

- Restrictions on ecological corridors

The over-regulation of corridors through urban plans does not seem to be a solution, either technically or administratively, but measures must be taken and adjusted, according to the importance of each corridor and by the involvement of local communities [47].

- Legislative changes

The Romanian accession to the European Union also imposed changes on the environmental legislation. The initial national system of natural protected areas was inspired and developed by the recommendations of the International Union for the Conservation of Nature, including the different types of natural protected areas and their management, even during the communist times [48]. However, at the accession time, Romania was found to have an insufficient share of its territory included in the natural protected areas, and also lacked the integration of its protected natural areas in the Natura 2000 network. As a result, numerous protected areas were declared over a short time, with a poor substantiation. Although the conditions for accession were met, the way of declaring the new areas caused problems later, including the spatial overlap of different categories, in particular of the new Natura 2000 sites over the existing sites belonging to other categories [49], and the difficulty of finding custodians to take charge of them. As a result, Romania was subject to a lawsuit from the European Union for the way of devising its network of natural protected areas [50]. Currently, accounting for the overlap, the natural protected areas cover 18% of the territory, and only 50% are providing an effective protection, achieved by the presence of a custodian and a management plan [51].

Today, in Romania, there are premises for legislative improvements and for harmonization of the legislation, by integrating the issues regarding ecological connectivity. In order to achieve this harmonization, it is necessary to change the environmental legislation (especially by improving the Government Emergency Ordinance no. 57/2007 on the regime of protected natural areas, conservation of natural habitats, wild flora and fauna [52]), spatial planning legislation (supplementing the Methodological Norms to Law 350/2001 on spatial planning and urbanism [53]), introducing aspects of ecological connectivity in environmental assessments for plans and programs [54] and in the assessment of the impact of public and private projects on the environment [55], development of a new biodiversity strategy and integrated action plans containing the necessary actions for the ecological corridors for different species.

4.5. Directions for Further Research: Implementing Identified Ecological Corridors in Spatial and Urban Planning Documentation

This methodology has the important advantage of addressing both biodiversity and spatial planning issues, which makes it usable by specialists in both fields. From the spatial planning viewpoint, the identification of the ecological corridors and their subsequent inclusion in development plans is important, because it helps in setting up measures to minimize the potential negative impact of development on biodiversity.

The Romanian spatial planning framework and its dynamics make up a very interesting case study, summarized by previous studies [56–58]. In summary, the initial planning framework was of French inspiration. During the communist times, all planning was

centralized, and mirrored the megalomaniac dreams of the president [59]. After the end of the communist regime (1989), Romania returned to the French-inspired system, but at the point of its accession to the European Union (2007), the Anglo-Saxon planning system was preferred, so the current system mixes the two, superimposing Anglo-Saxon practices, especially related to public participation, over an administrative structure of French inspiration. The spatial levels are, as in the French system, territorial planning, at the level of counties, regions, and the whole country, and urban planning, for cities and rural settlements; territorial plans have a strategic character, and urban plans are seen as operational zoning regulations. In all of the cases, the plans consist of images and text; they have specific chapters, some dealing with the environment and its protection, showing the existing status, underlining the problematic issues and proposing solutions for solving them; one of the key requirements is to include all of the protected elements, including the natural protected areas [58,60–63].

In Romania, planning takes place at national and local levels, with the common aim of achieving a balanced development of the entire territory, including by limiting sprawl. There is a distinction between territorial planning at a national, regional and county level and local planning, which takes place on the scale of a settlement, or an area of it, representing urban planning. Both of the activities result in the drafting of specific documentation and normative acts. Spatial and urban planning documentation include “spatial plans, urban plans, the general urban planning Regulation and local urban planning regulations, approved and authorized by law” [56,64]. Depending on the scale to which it applies, there is a difference between these documents; due to it, they reflect the identified ecological corridors differently.

- Implementation of ecological corridors in spatial planning documents

Once the ecological corridors have been identified, they must be included in the spatial planning documents at a national, zonal and county level. These documents include proposals for development that are of a *guiding* nature, but correlate with each other in the sense that the provisions of those of a higher spatial rank are binding on those of a lower spatial rank detailing them, and all of them are binding for all of the public administration authorities.

The most important plan is the National Spatial Planning Plan (NSPP), which includes several thematic sections. This means that, once identified, the ecological networks and corridors can be introduced into the NSPP Section III-Protected Areas [65], which so far does not contain any clear references to the ecological corridors or their degree of protection. This determines the inclusion and takeover of ecological corridors in all of the other lower-ranking land use plans—a similar situation with the Slovakian territorial systems of ecological stability, previously described. In other words, the ecological networks and corridors identified at a national level can be used and implemented in the lower level spatial planning plans, such as each County Spatial Planning Plan, which can be further refined, as we have shown in the methodology, e.g., Buzău County. Based on the ecological corridors identified at the county level, development proposals will be generated at the county level which, despite their guiding character, provide a good starting point for the urban planning documents. The latest proposals will detail them at the settlement level and generate operational regulations (zoning restrictions) for the areas containing ecological corridors.

- Implementation of ecological corridors in urban planning documents

In Romania, the urban planning documents transpose the provisions of spatial planning plans at the level of urban and rural settlements. They establish rules that apply directly to settlements up to cadastral parcel level, and are the basis for issuing the certificate of urbanism, and subsequent building permits for new developments. At the settlement level, the ecological corridors identified by the proposed methodology can either be taken from the spatial planning documents at national or county level, or obtained by applying the methodology at the local level. These corridors must be included in the urban

planning documentation which, unlike the case of the spatial planning documentation, includes by law the operational regulations at the level of administrative-territorial unit, mandatory for all people and organizations.

In addition, according to the law, if a special protection regime is established for the areas that contain ecological corridors, the General Urban Plan establishes regulations that cannot be modified by the urban plans detailing them (i.e., lower spatial level), and no derogations can be granted. The regulations are clearly phrased in the General Urban Planning Regulations, which represent “the system of technical, legal and economic rules underlying the development of urban planning plans, as well as local urban planning regulations” according to the Law 350/2001 on spatial planning and urbanism [64], which is the main law governing the drafting of spatial and urban planning documentation, in the provisions related to the general urban plan at the settlement level. In other words, once included in the urban planning documents, the ecological corridors will determine areas to which a certain degree of protection are to be designated, through the specific General Urban Planning Regulation of each settlement, which imposes/prohibits certain human activities in that area.

5. Conclusions

Green infrastructure is recognized today as a way of conserving biodiversity in the long run [66]. Spatial planning tools are crucial for planning the connectivity of the areas of ecological interest.

There is currently no one-size-fits-all approach to environmental connectivity in the European Union, but such an approach is not necessarily needed at the country level either, although many regional or local initiatives refer to green networks. There are differences between the countries of the European Union in terms of planning ecological networks and their scales, but also the legal obligation to take them into account in the planning. From a technical point of view, even though over time many models have been proposed to assess connectivity and ecological corridors, each country is developing models tailored to its historical, geographical, political, legal and institutional specificity. There is also no universal model for identifying ecological corridors on a large scale.

Along with biodiversity conservation, more and more worldwide official documents refer to the need of integrating ecological networks into spatial planning along with other elements of the green infrastructure, and maintaining ecological connectivity on a territorial and urban scale for ensuring sustainable spatial planning. Spatial planning has a major responsibility for biodiversity, in particular because it involves a comprehensive approach and allows for the consideration of ecological networks, at least on a national or regional scale, along with other land-use issues. Each spatial plan should consider the requirements for ecological networks and include appropriate measures for ecological connectivity, and the spatial development policies should aim at interconnecting ecological networks.

In the Carpathian region in particular, spatial planning policies and programs must take into account the specific conditions through sustainable spatial planning and allow for the updating and modifying of all the relevant policies and laws on ecological corridors. Especially in countries with large carnivorous populations, the scientific identification of ecological corridors involves creating maps of ecological networks which are a very useful tool in spatial planning, as it helps in limiting development in the area of ecological corridors and in avoiding their fragmentation.

In Romania, biodiversity needs to be included in planning activities to a greater extent. Moreover, we consider that it is not only necessary to identify the ecological corridors and implement them in spatial and urban planning documents, but also to take all of the measures for their effective protection. This can be completed by including explicit legal provisions on the protection of ecological corridors in environmental and spatial planning documentation, and by environmental studies documenting, detailing and justifying the routes used by wildlife and their possible changes due to climate change.

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