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Article

County-level method for identifying Romanian ecological corridors: environmental and spatial planning issues

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Abstract. A solution for the habitat fragmentation, decline of biodiversity, loss of ecosystems and ecosystem services can be to increase the number of protected areas and the connectivity between them, by creating ecological corridors. Since this conservation practice is becoming more relevant considering the climate change, the concept of ecological connectivity must be integrated in most political frameworks, especially in relation with the spatial development, requiring appropriate legislation. The article aims at proposing a new technique of ecological connectivity modeling, demonstrated by a specific methodology aiming to identify the ecological corridors used the brown bear (Ursus arctos) within the Natura 2000 sites in the Romanian Carpathian Mountains covered by the Buzau County. The processed GIS layers together with the ArcGIS.x Corridor Design Tool were used to map the permeability in the studied area and thus to identify the ecological corridors. The obtained results are useful tools for spatial planners that must integrate, adapt and accept these corridors in their plans. It is the first study published at national level, a novel one, in which ecological corridors for the brown bear are identified based on a County Land Use Plan, embedding the ecological dimension in the concept of spatial planning.

Keywords: biodiversity, fragmentation, ecological connectivity, GIS assessment tools, Corridor Design, permeability maps, spatial plans

Abstract. La croissance numérique des aires naturelles protégées et des connections entre eux peut-être une solution contre la fragmentation des habitats, la réduction de la biodiversité et des services des écosystèmes. Donne la relevance agrandie de la conservation dans le contexte des changements climatiques, le concept de connectivite écologique faut être intégré dans la plupart des cadres politiques, surtout en relation avec le développement spatial, demandant une législation spécifique. Cet article a l'objectif de proposer une nouvelle technique pour modeler la connectivité écologique, démontrée par une méthodologie spécifique pour identifier les

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corridors écologiques utilisés par l'ours brun (Ursus arctos) dans les sites Natura 2000 situées dans les Carpates roumains, département de Buzau. Les strates SIG transformés avec l'outil ArcGIS.x Corridor Design Tool ont été utilisées pour construire une carte de perméabilité de l'aire d'étude et identifier les corridors écologiques. Les résultats obtenus sont des instruments utiles pour les planificateurs, qui peuvent intégrer, adapter, et accepter les corridors dans les plans spatiaux. C'est la première étude nationale, et cependant nouvelle, dont l'identification de corridors de l'ours brun est faite au niveau d'un plan départemental de l'occupation du sol, incluant le volet écologique dans le concept de planification spatiale.

Mots-clés : biodiversité, fragmentation, connectivité écologique, SIG outils d'évaluation, Corridor Design, carte de perméabilité, documents de planification spatiale

1. Introduction

1.1. Overall view

Natural systems experience the consequences of development over the last 50 years, human activities altering 75% of the terrestrial environment and threatening 25% of plant and animal species. Anthropogenic pressures lead to habitat loss and fragmentation (Kindlman and Burel, 2008; Crooks and Sanjayan 2006; Worboys et al., 2010), causing the isolation of species and their resistance to human-induced or climate changes (Bennett, 1990; Fahrig and Marriam, 1994; Watson, 1998).

Globally, ecosystems have declined by 47%, according to the New Nature Economy Report (World Economic Forum and PwC, 2020). The loss of ecosystems caused by habitat fragmentation unfortunately reflects on the decline of biodiversity and ecosystem services, a topic that has recently been included on the agenda of many European strategies dealing with ecosystems and biodiversity restoration, such as: the EU biodiversity Strategy to 2020 (European Commission 2011); the EU Green Infrastructure Strategy (European Commission 2013 a); EU Strategy on adaptation to climate change (European Commission 2013 b); EU Biodiversity Strategy for 2030 (European Commission 2020); the new EU Strategy on Adaptation to Climate Change (European Commission 2021). A solid conclusion was that the designation of new protected areas and the integration of ecological corridors into such areas can be a solution.

The integration of biodiversity in planning activities – one of the Aichi Targets (CBD, 2010) - had not been fully achieved until 2019, being considered that only moderate progress has been made until now (IPBES, 2019). This is also reflected at the urban level, where incorrect planning led to urban sprawl and to social, environmental and health challenges, according to the 2020 Global Risk Report (World Economic Forum, 2020), with a risk as high as that of biodiversity loss or natural disasters.

One of the most common recommendations for protecting biodiversity is to increase connectivity by creating ecological networks that connect natural habitats

(Heller and Zavaletta, 2009), a conservation practice that is becoming even more relevant considering imminent climate change (Carroll et al., 2009; Spring et al., 2010). Ecological corridors, complementary to protected areas, aim to maintain ecological connectivity. The concept of ecological connectivity has been given attention for 20 years ago, initially referring to the connectivity of the landscape in mountainous areas or at the level of protected natural areas but the interest grew and the concept began to be approached in relation to the preservation of connectivity and governance (Lausche et al., 2013). Connectivity is needed because of the risk of species extinction, the spread of anthropogenic activity and climate change (IUCN, 2020). Ecological corridors must be identified, established, planned and implemented in areas that require connectivity, in order to maintain or restore it, where it has been lost.

The concept of connectivity and its implementation has been addressed by international instruments and bodies, in particular programs and conventions related to biodiversity, climate change, protection of cultural and natural heritage - for example Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) (Council of Europe, 1979), to which Romania acceded in 1993.

The concept of ecological connectivity must be also addressed in spatial planning, by approaches for integrating it in its political framework. In Romania, ecological corridors must be first identified and subsequently officially designated by appropriate environmental legislation. Spatial plans should also incorporate this dimension of ecological sustainability, taking into account aspects such as identifying key areas of biological diversity, species relationships with ecosystems and habitats, land use requirements, and public participation. It is essential that ecological corridors are identified and included in development plans at any level - local / county / regional - in order to avoid the negative impact of development. Effective conservation of biodiversity can be achieved only through an adequate spatial planning, since nature conservation must be a priority for any type of development. The ecological dimension must be incorporated into the concept of spatial planning, and spatial planners must take into account considerations related to biodiversity, ecosystems and habitats.

The mountain regions and particularly the Carpathian Mountains have been largely studied, due to their special characteristics – such as the inclusion of fragile ecosystems – though not in relation with the ecological connectivity, which is a more recent concern, but always in connection with specific methodologies using GIS tools. In Romania GIS tools were used, for example, to identify remote mountain areas with high touristic potential in order to protect their vulnerability (Popescu and Petrişor, 2010). Likewise, spatial data was often used in correlation when studying the effects of global changes within Romanian protected areas (Petrişor, 2016).

The Romanian Carpathians shelter approximatively 40% of the total number of brown bears in Europe, with 6,500 specimens in 2016 and about 7,200 in 2019, according to the Romanian Ministry of Environment. In Romania the brown bear population covers an area of approximatively 69,000 km^2, which represents 30% of the total country area, with highest densities in the central part of Romanian Carpathians, in counties like Harghita, Covasna, Brașov, Buzău or Mureș.

In Romania, the brown bear (*Ursus arctos)* is a species of community interest that requires strict protection, according to the Habitats Directive (Council of the European Communities, 1992) and GEO 57/2007 (Government of Romania, 2007). It is considered a vulnerable species for which hunting is prohibited according to the Hunting Law (Romanian Parliament 2006). The brown bear habitats in the Romanian Carpathians consists mainly of large unfragmented forests and their daily movement, larger than other European brown bear population, is determined by their seasonality and occurs within a large altitude range (Pop et al, 2018). Most of them live in mountains and travel on long daily distances, even 150 km a day.

Ecological networks and corridors for the brown bear must be considered in development plans at all levels, but the first step is to find a method for their identification based on solid scientific information.

1.2. Literature review

The EU Biodiversity Strategy for 2030 (European Commission, 2020) points out that the loss of ecosystems is one of the problems which humanity will face in the next decade. Therefore, the Strategy envisages that by 2050 all the world's ecosystems to be restored and protected, and by 2030 Europe's biodiversity to be restored. For this reason, as the current network of protected areas is not large enough to protect biodiversity and is proposed that 30% of the EU's land area to be protected, compared to 26% in 2018 (of which 18% belong to Natura 2000 network). The integration of ecological corridors and the legal designation of new protected areas must be demonstrated by member countries by 2023. At urban level, the Commission calls on European cities with at least 20,000 inhabitants to draw up urban greening plans by the end of 2021, to help improve connections between green spaces.

Connectivity is an important property that results from the interaction between animal movement behavior and landscape structure (Olden *et al.*, 2004). Conserving connectivity is a topical issue, especially in the context of climate change and its consequences on biodiversity. Terms such as *ecological connectivity, ecological corridor* or *ecological network for conservation* are the basis of planning ecological corridors and their inclusion in spatial management plans. Ecological connectivity is defined as "the unimpeded movement of species and the flow of natural processes that sustain life on Earth" (UN Environment and CMS, 2020). On the other hand, the ecological corridor is "a clearly defined geographically space that is governed and managed over the long term to maintain or restore effective ecological connectivity" (IUCN, 2020). Thus, an ecological network for conservation is "a system of core habitats (protected areas, OECMs 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" (IUCN, 2020). When planning ecological corridors and networks it is necessary to have information on ecological structure and processes in the landscape as well as on the species behavior. Ecologists have proposed various solutions for planning ecological corridors (Unnasch *et al*., 2008). In the construction of the ecological network, it becomes necessary to correlate the intersectoral and interdisciplinary activities involved in spatial planning, in areas such as management of protected natural areas, land use planning and urban development, biodiversity protection, agriculture and forestry, transport and tourism. Regarding the integration of biodiversity and connectivity in spatial planning plans, there are some key challenges, such as lack of public awareness and poor stakeholder inclusion, the need to integrate analyzes carried out during previous programs and projects, the high degree of complexity of data and IT solutions, rapid development of technology and, very importantly, regulatory limitations (Daly and Klemens, 2005). An ecological corridor must be clearly set out according to ecological connection needs, and its limits must be accepted by the entities responsible for governance, as the definition of conservation objectives is closely linked to institutional capacity and efficiency, technical soundness, financial costs and political support (Gökmen and Gülersoy, 2018). At the same time, the conservation of connectivity also depends on the people involved in each stage of the planning process (Lockwood, 2010) and on the social, cultural and economic factors that can affect connectivity (Worboys *et al.*, 2010).

To preserve connectivity in large landscapes, coarse-grained **connectivity maps** are needed for decision support, and fine-grained maps for site-specific interventions (Beier *et al.*, 2011). In order to develop these connectivity maps, it is essential to delimit and prioritize the connectivity areas. These maps are useful to make assessments on connectivity. Most contemporary **connectivity assessments** are primarily aimed at (a) protecting specific migratory routes or movement corridors for a species or suite of species, (b) protecting or enhancing the biodiversity of a landscape or region, (c) improving species' resistance to disturbance, such as climate change, (d) maintaining natural evolutionary processes; or (e) mitigating the impact of human activities, such as transport, construction, and extractive industries.

Computer tools that can shape connectivity (**connectivity modeling**) began to be developed in the 1990s. Ecologists together with specialists in geographic information systems have managed to develop such tools with which they have obtained **connectivity models**, easy to use by those who are familiar with GIS systems. Approaches for assessing connectivity depend on the complexity of the data required. Studies have shown that modeling corridors connectivity between habitats is all the more accurate the more precisely the characteristics of the landscape and the behavior of specific organisms are integrated (Adriaensen *et al.*, 2003). Another defining attribute for a correct assessment of ecological connectivity is the spatial scale (Hilty *et al.*, 2006), determined by the scale at which territorial planning and management is performed.

Table 1. Comparison between different methods used to assess connectivity and ecological corridors

Method	Use	Benefits	Disadvantage
LCP – Least Cost Path	Identifies a potential route that minimizes the cost of moving an animal species. It can be used to find connectivity on a coarser scale.	It does not require much data; it integrates environmental influences and animal behavior.	Subjective interpretation of the topography, sometimes the effectiveness of the corridors is not confirmed.
Graph theory	Can be used to rank corridors based on their contribution to landscape connectivity.	It requires little data, has a simple shape, can be used on different scales.	It does not contain matrix effects; no real map is obtained.
Landscape networks	It can be used to classify corridors based on their contribution to landscape connectivity.	It includes matrix effects, allows the examination at landscape level of the configuration of areas or connections.	Subjective interpretation of the topography, sometimes the effectiveness of the corridors is not confirmed.
Circuit theory	It can be used to predict dispersion rates based on simple environmental/landscape data and for dispersion-dependent modeling processes; it is ideal for identifying/prioritizing high-risk areas and for comparing alternatives	The generated values are process-based, it is easy to parameterize from the raster type grids; it is robust to scale changes.	Cannot be used for unidirectional movements; identified areas of constrained movement are not the same as corridors or connections
Models based on individual movement	Detects movement details, for example based on telemetry can detect migration rates in an area. Represents the functional/potential connectivity	It is the most direct estimation of existing connectivity	Data is usually limited to small areas; there is no need for data such as travel speed, energy costs, mortality risk in each habitat.
Network flow/dispersal chains	It is an emerging and growing approach, helping to identify Climate Change Corridors	It does not depend on the resistance map	Very large amounts of data and hypothesis are needed

Source: created by the authors based on literature review

Ecological models involve techniques that simulate ecological systems and processes (Vogiatzakis, 2003), such that ecological modeling combines mathematical modeling and computer techniques with ecology and the management of the environment and natural resources (Zhang *et al.*, 2003). In the case of ecological corridors, several methods of assessing connectivity have been used (Aune *et al.*, 2011), each with its own advantages and disadvantages (Table 1).

An analysis of previous methodologies used to identify ecological corridors (Popescu and Petrişor, 2020) shows that they were developed in order to identify priority areas for wildlife management (Walker and Craighead, 1997), to increase spatial connectivity (Bruinderink *et al.*, 2003) and to create functional landscape models (Adriaensen *et al.*, 2003), to assess landscape and ecological connectivity (Marulli and Mallarach, 2005), to develop a green infrastructure planning approach (Chang *et al.*, 2012), to create and consolidate ecological corridors (Deodatus *et al.*, 2013) or to identify the most important barriers for ecological connectivity in the Carpathian Mountains. These methodologies models were mainly GIS-based assessments, using mathematical languages and multicriteria analysis, and were developed and applied in different pilot areas, including parts of the Romanian Carpathians. The results (such as habitat suitability models and maps) represent useful tools in spatial planning approaches.

1.3. Research goals, novelty, and importance

The goal of the present article is to present an original methodology of identifying the ecological corridors used by the brown bear (*Ursus arctos*) as migration corridors in the Carpathian area covered by Buzău County. Unlike other methodologies proposed by the same authors in previous articles, this new methodology makes the transition from the national to the County level.

The study presented in the paper has two objectives: to present an innovative methodology for identifying ecological corridors in a County in Romania (NUTS level 3) and to provide a tool for including ecological corridors in urban planning and spatial planning documentation. Through this dual approach - technical and practical - it is possible to achieve the integration of biodiversity issues, such as the interconnection of protected areas, in spatial planning activities, which will reduce fragmentation and will protect ecosystems that serve people.

Another reason why such a study on ecological corridors in Romania is necessary is that, in addition to being useful - it helps to conserve natural ecosystems, habitats, species of flora and fauna - ecological corridors can minimize the potential impact of plans that may affect large areas of a territory. Maps of ecological networks, even without a legal or official support, represent a first step in inserting ecological networks in territorial plans. This makes the present study useful not only to ecologists, but also to urban and spatial planning specialists.

2. Methods and data

This methodology is based on the selection of a focal species (umbrella species) as a conservation target. The concept of umbrella effect considers that the requirements of the focal species cover the needs of other species, and a conservation plan built around a well-selected focal species will satisfactorily cover the requirements of all other species (Soulé *et al.*, 2003; Unnasch *et al.*, 2008).

The present study presents a method of identifying the ecological corridors for the brown bear species within the Natura 2000 sites in the Carpathian Mountains located on the territory of a County in Romania (Buzău County).

Buzău County is located in the southeastern part of Romania, in the southeast of the Eastern Carpathians (Figure 1). Mountains cover 25% of Buzău County, in its Northern part. On the territory of the County there are 15 Natura 2000 sites (11 SCIs and 4 SPAs), natural protected areas of national importance (15 nature reserves) and others of County importance (9 nature reserves and the Ținutul Buzăului Geopark). In most Natura 2000 sites economic activities are kept, with a particular focus on the conservation of the species and habitat for which they have been declared.

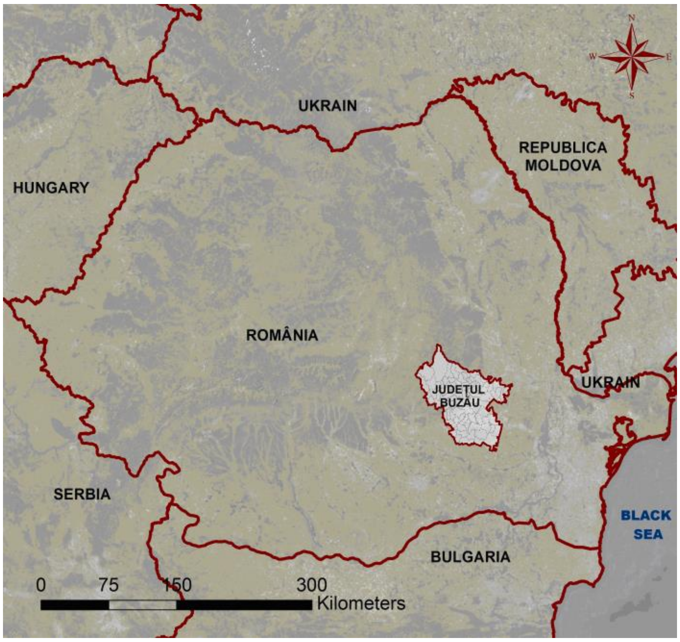

Figure 1. Geographical location of Buzău County
Source: the authors

The study area - Buzău County - has one of the highest densities of the brown bear population in Romania and was chosen due to the numerous existing studies in the field of urbanism and spatial planning, including the Buzău County Spatial Planning Plan (PATJ Buzău). For the proposed methodology, the detailed knowledge of the territory of Buzău County is an important asset in defining the weights for each habitat factor considered, as well as the relative weights between the habitat factors that were used.

Unlike other studies and methodologies proposed even by the authors of this study, the proposed methodology estimates the permeability of the landscape for the brown bear at County level.

The methodology performs an assessment of the landscape permeability, which provides an estimate of the relative potential of animals to pass through the landscape. Singleton (2002) defines the permeability of the landscape as "the quality of a heterogeneous terrestrial area to ensure the passage of animals". Permeability involves the identification of potential barriers to animal movement. A successful preservation of connectivity is when one or more species can move in a given landscape on all spatial and temporal scales, which means that the landscape is permeable.

Among the models based on geographic information systems (GIS), which are widely used tools for identifying ecological corridors (see Table 1), the Least Cost Path model stands out due to the good results of its application, allowing parameterization and testing through empirical studies. This model was used and applied in the present study, resulting in maps of the cumulative cost, which highlights the corridors with the lowest costs, more precisely the least expensive routes between the brown bear's movement sites (Nor *et al.*, 2017). The idea is that in an ideal situation, a dispersed animal should travel on the shortest, safest and least expensive path in terms of energy consumed, between the source habitat and the destination (Cazacu *et al.*, 2014).

From a series of available GIS habitat adequacy models, a combined GIS approach was selected in the present analysis, by using ArcGIS 10.x, CorridorDesign and Linkage Mapper tools. ArcGIS CorridorDesign tools are best suited for designing corridors in a heterogeneous landscape on a regional scale (e.g. between 2 and 500 km). These tools are free and relatively easy to apply.

To parameterize the habitat factors we used the results of the Technical Report carried out within the LIFE08NAT / RO / 00500 project, which had a similar purpose for the brown bear, in the Harghita-Covasna-Vrancea pilot area. At first it is necessary to identify habitat factors that influence habitat permeability (the ability of animals to pass safely through a habitat). For the assessment of potential habitats of the brown bear, the following habitat factors were considered (Tache *et al.*, 2020):

- Land cover (data taken from CORINE 2020) for Romania;
- The combined network of national roads and railways in Buzău County and the traffic on national, county and communal roads in 2018;
- Built-up areas for all the settlements belonging to Buzău County;

- The DEM (digital elevation model) of the County, based on the level curves (10 meters);
- Slopes derived from the DEM and differentiated according to the Corridor Design tool (Create topographic position raster).

All these layers have been standardized by rasterizing the input data sets in order to apply the habitat permeability assessment algorithm. The pixel size for the obtained raster was given by the raster of the Digital Elevation Model (25 x 25 meters).

This GIS method for obtaining the map of potential ecological connectivity required data on ecological factors, several modeling processes, as well as GIS tools adaptable to specific situations and was verified using the results of other scientific studies and with real field data. This model that allows the identification of ecological corridors at County level is not a substitute for field assessments, however, the identification of ecological corridors by using the GIS is a major support for establishing ecological networks and for their subsequently implementation into spatial planning documents at County level.

For habitat factors, we chose the following weights, based on the data and knowledge regarding the territory of Buzău County (Table 2):

- For the land cover raster of Buzău County: 6 land use categories (from 1 to 6) with weights from 0 to 100 (0, 40, 60, 70, 80, 100).
- For the layer containing the built-up areas of the settlements: weights between 0 and 100 (0, 25, 60 and 100) for four categories of distances: 0-200 m, 200-500 m, 500-800 m, over 1000 m.
- For the layer of roads and railways at County level: four categories of weights (30/60/80/100) for the national road DN 10 (0-100 m, 100-500 m, 500-1000 m, over 1000 m), a weight of 85% for County roads (for a distance between 0-10 m from DJ), a weight of 95% for communal roads (at a distance between 0 and 10 m) and a weight of 80% for the railway (for distances up to 50 m from the railway). The values are justified, taking into account the existing traffic on DN 10 and on the communal and County roads in the area (some County and communal roads are impracticable - such as DJ 103P from Nehoiu city until near the entrance to the village Bâsca Chiojd).
- For the DEM: four categories of weights (0/20/60/100) for four altitude ranges (0-200 m, 200-500 m, 500-800 m, over 1000 m).
- For the terrain slope, weights were applied according to the *Corridor Design / Create topographic position raster* application. Thus, the four types of weights (35/70/100/60) were chosen according to the types of slope: deep valley, gentle slope, steep slope, and ridge.

The permeability map for Buzău County was made with the Corridor Design application, that can be used to compute each ecological corridor between 2 core areas. Applying the ARCGIS.x Corridor Design tool (*Create habitat suitability* model) required a weighting of all factors used. Thus, the weights granted were:

- For CORINE land cover: 40%
- For the built-up area raster: 15%
- For the road and railway raster: 15%
- For the DEM model: 15%
- For the slope raster: 15%

The chosen algorithm was the weighted geometric mean, which more realistically reflects the real situation in the field, by combining all habitat factors.

Table 2. Weights used in modelling the habitat factors

DEM		Slope		Built-up areas		Roads, railroads		CORINE	
Altitude	**Weight**	**Slope**	**Weight**	**Distance**	**Weight**	**Distance**	**Weight**	**Landuse Category**	**Weight**
0-200 m	0	Deep valley	35	0-200 m	0	0-100 m from DN10	30	1	0
201-500 m	20	Mild slope	70	201-500 m	25	100-500 m from DN10	60	3	40
501-800 m	60	Steep slope	100	501-800 m	60	500-1000 m DN10	80	6	60
> 800 m	100	Ridge	60	> 800 m	100	> 1000 m from DN10	100	5	70
						0-10 m from County roads	85	4	80
						0-10 m from communal roads	95	2	100
						0-50 m from railroads	80		
Final weight	**15**		**15**		**15**		**15**		**40**

3. Results

3.1. Modeling the brown bear habitat favorability at County level

In order to evaluate the permeability of the territory of Buzău County, several GIS layers were processed (**by rasterization and standardization**) related to the following habitat factors: land cover, built-up areas, roads and railways, the DEM model and the digital model of land slope. The GIS layers before and after rasterization are showed in the next maps.

The map of brown bear habitat

For a correct evaluation of the ecological corridors for the brown bear species from Buzău County, the areas where the brown bear was observed were identified. Figure 2 shows the habitat area of the brown bear within the territory of Buzău

County, which needs to be further analyzed based on the statistics on the presence of the brown bear in that area. The map shows that the higher the altitude, the more brown bears are being observed (0 brown bears in plain areas and 3-8 brown bears in forests from mountains).

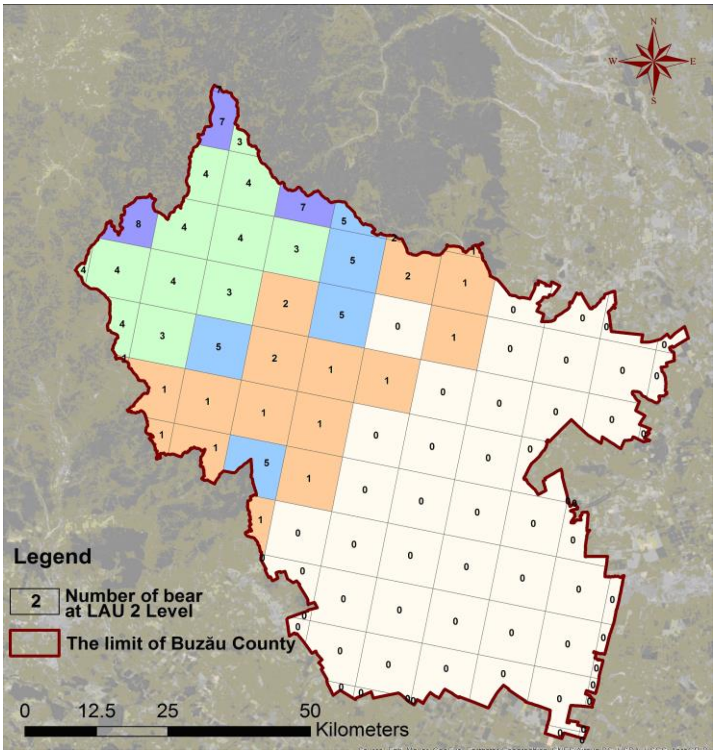

Figure 2. Map of brown bear habitat in Buzău County.

Source: https://wwf.ro/specii/ursul/wwf-romania-exista-suficiente-date-pentru-o-harta-nationala-a-zonelor-de-risc-privind-conflictele-om-urs/

The surface was divided into a square grid (10/10 km) in which each cell was assigned a number of brown bears based on data collected in the field. The surface was divided into a square grid (10/10 km) in which each cell was assigned a number of brown bears based on data collected in the field.

The map of land cover

Figures 3a and 3b show the land cover layer before and after rasterization. Figure 3a indicates the cover with forests in the mountainous area from the northern part of the County. In Figure 3b The dark brown spots are favorable areas for the brown bear habitat (core areas), while the light brown areas are favorable for its movement (for ecological corridors).

We have considered *maximum weights* related to the brown bear movement through broad-leaved forests, coniferous forests, mixed forests, transitional woodland shrub and partially on pastures, natural grasslands peat bogs and in agricultural land with significant areas of natural vegetation. We have considered *small weights* (or even zero) for industrial or commercial units, construction sites, sport and leisure facilities, non-irrigated arable land.

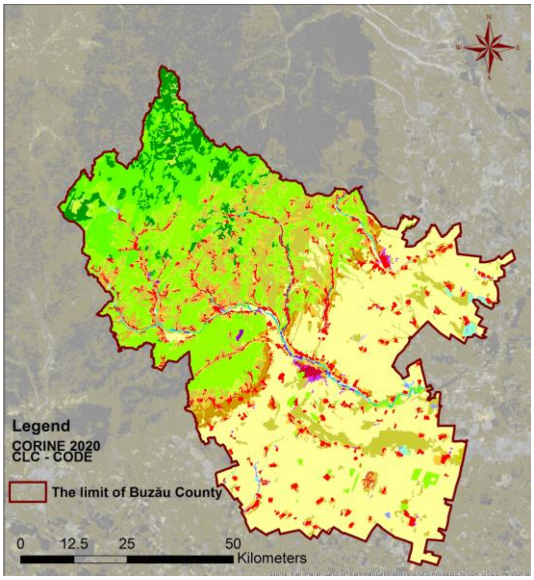

Figure 3a. Land cover (CORINE 2020) for Buzău County
Source: map created by the authors

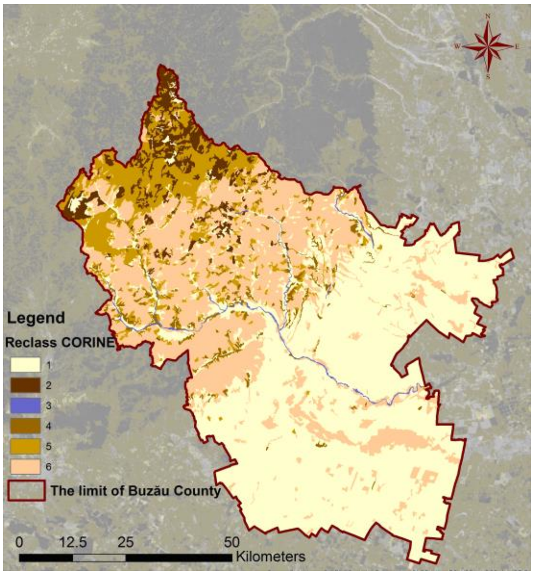

Figure 3b. Land cover (CORINE 2020) after rasterization and standardization.
Source: map created by the authors

The map of built-up areas

Figures 4a and 4b represent the layer of built-up areas, before and after rasterization and standardization. For this layer, the probability of brown bear occurrence is relatively small in the vicinity of inhabited localities, instead we have considered a much higher probability of brown bear occurrence at more than 500 m from the built-up areas. Beginning with 800 m the probability of brown bear's occurrence is 100% (the brown bear ca move in that area). In Figure 4a it is observed that in the northern part of the County, at high altitudes, there are many small settlements, close to each other. Figure 4b shows the white areas from the northern part of the County are the most favorable for the brown bear's movement, while the colored buffers show an impediment of movement due to the continuity of built-up areas.

The map of the Digital Elevation Model in the case of Buzău County

Figures 5a and 5b show the Digital Elevation Model of Buzău County, before and after standardization (reclassification). Figure 5a shows the high altitude of the County in its northern part, where the brown bear can be observed more often, and

Figure 5b clearly shows, after reclassification, that only the northern part of the County is favorable for the presence of the brown bear

The altitude has a great importance in the brown bear's occurrence, which it happens usually between 800 and 1200 m, but its presence was also reported at altitudes of 300 m and even 2000 m.

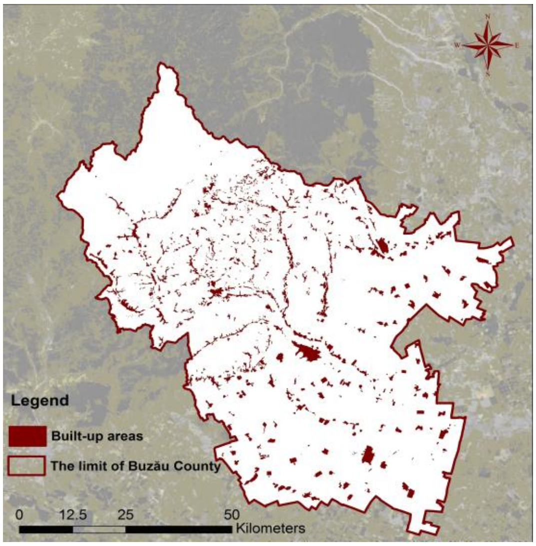

Figure 4a. The layer of built-up areas for all localities of Buzău County.
Source: map created by the authors

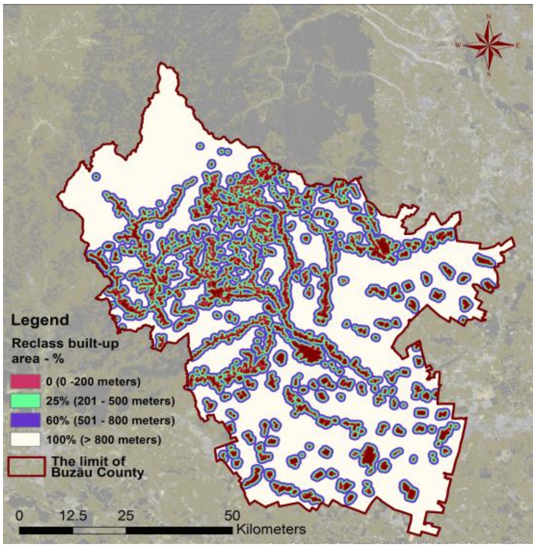

Figure 4b. Reclassification of the layer of built-up areas.
Source: map created by the authors

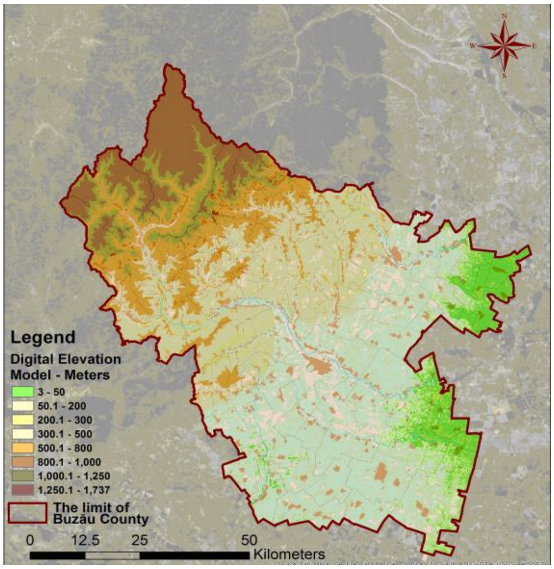

Figure 5a. Digital Elevation Model (DEM) for Buzău County. **Source**: map created by the authors

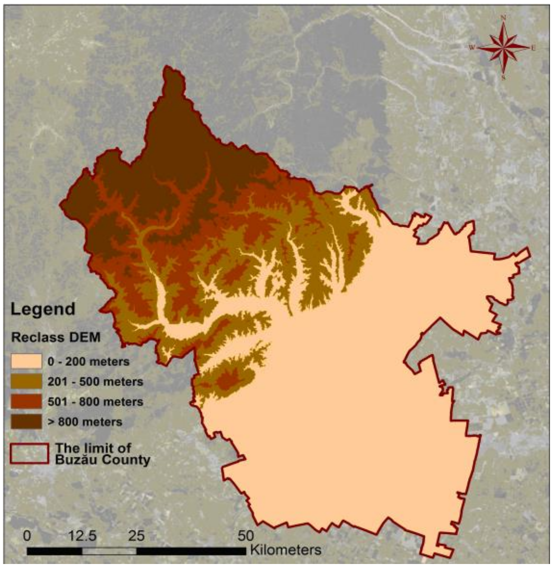

Figure 5b. Reclassification of DEM.
Source: map created by the authors

3.2. Permeability map of Buzău county

In order to obtain the map of permeability for Buzău County, the brown bear habitat factors were combined by assigning weights, according to their relative importance. The next step was the choice of an algorithm that combines all the weighted habitat factors in a permeability raster.

The results (Figure 6) show that the northern half of the County has a permeability of more than 75%, being a favorable habitat for the brown bear due to many forests, but also to the high altitude and of the lack of settlements and modernized roads. In the southern half of the territory, a permeability less than 25% have been obtained, the brown bear's presence being unlikely here. The map clearly shows that a high permeability is in forest areas of mountains, while in the southern part of the territory due to many barriers the permeability is very small and the brown bear cannot be present.

The chosen algorithm was the weighted geometric mean that more realistically reflects the actual situation in the field, by combining all habitat factors.

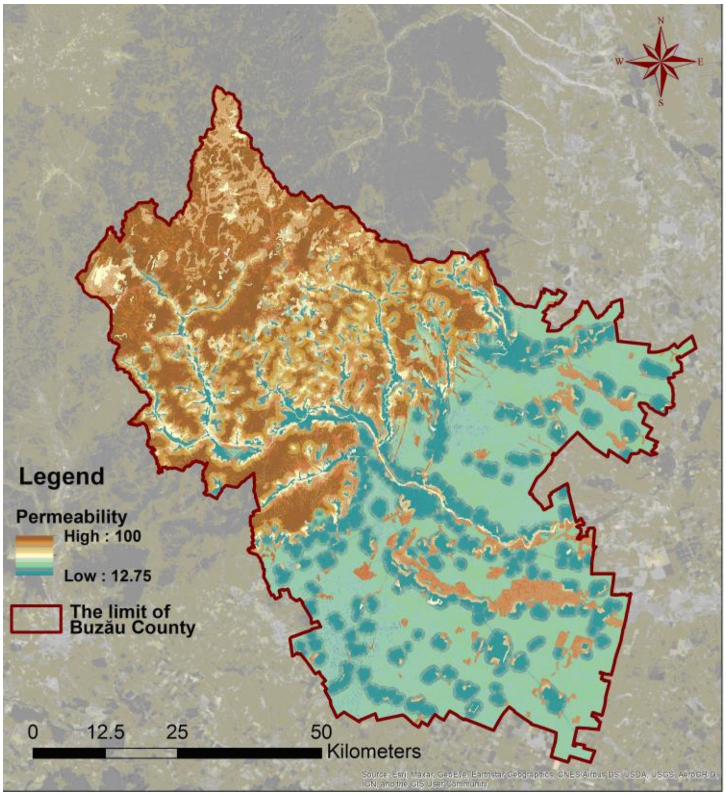

Figure 6. Permeability of the territory of Buzău County obtained by the presented methodology. (map created by the authors)

3.3. Ecological corridors

In order to identify the ecological corridors, we considered as core areas the surfaces of Natura 2000 sites legally declared in Buzău County. Using Corridor Design (*Create corridor model*) two core areas were selected and the probable ecological corridor that connects them was computed. To compute the probabilistic ecological corridors in the area where the brown bear has its habitat, pairs of 2 core areas were selected and an ecological corridor was computed for each combination of them (Figure 7). They are connecting especially the Natura 2000 sites (in dark green) and are located between 500 m and 1,737 m. The map also shows critical areas for the brown bear movement.

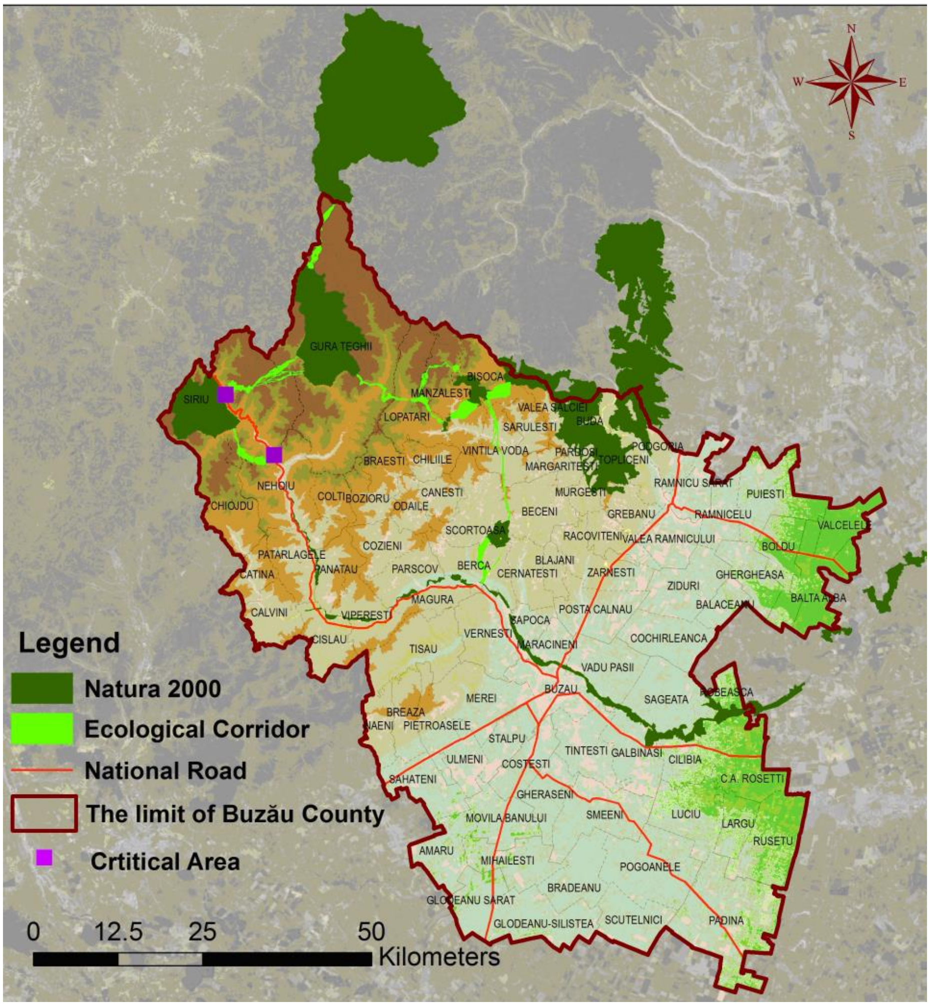

Figure 7. Ecological corridors for Buzău County (in light green) identified by applying the methodology. **Source**: map created by the authors

Our results show that the identified ecological corridors connect especially the Natura 2000 areas (core areas for the brown bear habitat). In the northern part of the County there is a high permeability, so the brown bear can move between core areas. From the planning point of view, identifying critical areas along ecological corridors is a matter of crucial importance. Compared to other Romanian counties studied by us (Harghita, Vrancea, Covasna), Buzău County has fewer critical areas because the road network is not very well-developed and its communal roads are un-modernized in the mountain area. Still, there are some problems in the case of man-bear interaction due to the settlements that are very close to each other in the northern half of the County and there is no space between built-up areas in which the brown bear can move unhindered. In the two critical areas showed on the map there were accidents such as collisions between bears and vehicles on DN10, at the border of Nehoiu town with Siriu commune and also on DN10 in Siriu commune.

4. Discussions

Applying the proposed methodology, the final map of the ecological corridors resulted, most of them located in Natura 2000 sites. Before obtaining that, other important maps were developed: raster maps - resulted on the base of 5 thematic GIS layers: land cover, built-up, roads and railways, the DEM model and the land slope model - and also the permeability map of Buzău County.

The ecological corridors used by the brown bear which have been identified in the case of Buzău County in the present study are consistent with the results obtained in the only previous study carried out at the national level (Tache *et al.,* 2020) (Figure 8). Both this and previous studies on the same topic (Tache *et al., 2020*) demonstrated that before establishing and delimiting the ecological network at any scale, an overview is needed to achieve the desired connectivity, which must take into account the conservation targets and the information and data needed to define ecological corridors. In addition to conservation, identified ecological networks can prevent and reduce fragmentation, one of the major causes of biodiversity loss at the habitat and species level. (Harris, 1984; Apps and McLellan, 2006; Hepcan *et al.*, 2009). Ensuring and maintaining ecological connectivity and ecological networks is the solution both for the conservation of biodiversity in systems that have been fragmented, and for ecological and human mobility. Once the ecological corridors have been established, priority interventions and actions to conserve, monitor and assess changes in them must be identified. And, of course, ecological corridors must be implemented in urban and spatial planning documentation, which requires a revision of the legislative framework.

The novelty – Compared to other methodology proposed (Tache *et al.,* 2020), which identified the ecological networks for the brown bear in Romanian Carpathian Mountains at national level, this new approach translated the scale to the County

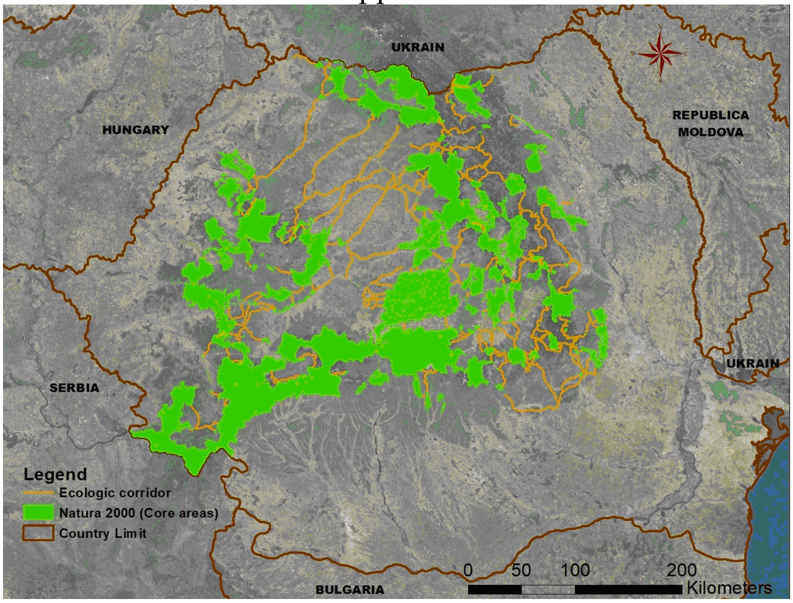

Figure 8. Map of ecological corridors at the Romanian national level – identified corridors at the level of Buzău County
Source: Tache *et al.*, 2020)

level (Buzău County), which determined the use of the Corridor Design tool, more suitable for smaller areas. Another novelty consists in the fact that is the first study which identifies such ecological corridors in the case of one specific Romanian County, using the information provided by the County Land Use Plan. This kind of spatial plan was necessary because it could offer important traffic data, such as roads viability and traffic intensity.

The advantage – The proposed method embeds very actual biodiversity concerns into the concept of spatial planning: it can be used both by ecologists and by spatial planners. The connectivity corridors resulted from the presented method can contribute to the identification of the measures of conservation of the ecological connectivity at County level by minimizing the potential impact of development plans.

Limitations – Although the authors of this study could find and use data on roads and railroads traffic, there are some limitations in terms of the input data, such as the resolution of raster data (which is higher than the recommended one), and of CORINE data (which is not as accurate as, for example, the imagery data). Nevertheless, the resulted network of ecological corridors, as a movement corridor for the brown bear can be considered a useful tool for spatial planning activity.

The methodology presented at County level is a starting point for consistent analyzes that must be performed to implement the issue of ecological corridors in urban and spatial planning documents. The ecological corridors identified for Buzău County by this methodology can be improved by local specialists, who can use other more precise data or can combine the present methodology with other methodologies regarding data collection in the field.

The quality of input data is a requirement for a correct assessment of ecological corridors, but unfortunately data on the occurrence of species are little available to the public, which limits the ability to identify habitat areas and assess the connection needs of a species (Faith *et al.*, 2013). From this point of view, the next step in improving the location of these ecological corridors is to make the model based on the individual movement of the brown bear species based on telemetry and GPS measurements in the field. In this regard, it is necessary an inventory of all possible barriers in the vicinity of ecological corridors and critical areas, based on a data sheet containing standardized forms and procedures for the inventory of barriers. Data can be recorded automatically using the ArcGIS Survey123 online application.

Planning implications – The findings suggested that ecological corridors represent an important tool for preventing the loss of biodiversity by preserving and restoring ecological connectivity. This tool can be useful for planners. Currently there are no legal requirements for implementing the ecological corridors in urban and territorial plans (Popescu and Petrişor, 2021). Although there is some pressure to change the legislation, originating from the results of several interconnected projects carried out under the Interreg framework and aimed at better interconnecting the European network of natural protected areas (e.g., ConnectGREEN and SaveGREEN – Interreg Danube, Centralparks – Interreg Central Europe, and Dinalpconnect – Interreg ADRION), further analyses are required. The reason is that the methodological limitations, particularly those due to the lack of local data, make the results questionable. If restrictions are imposed via spatial planning based on the identification of such corridors, environmental conflicts are expected to occur, as it happened in the case of natural protected areas (Iojă *et al.*, 2016).

Conclusions

Applying this method, an interesting conclusion is that, since the existing Natura 2000 sites in Buzău County have been identified as being core areas of ecological corridors for the brown bear, it is very important to increase the number and area of Natura 2000 sites in this County.

This method enables the identification of migration corridors used by the brown bear species (*Ursus arctos*) at a local level, in the Romanian Carpathian Mountains. It completes a previous methodology developed by the same authors, as a top-down vision in a pilot area. Still there is absolutely necessary to complete the present study with field research of the existent barriers. Spatial planners and managers of protected areas must integrate, adapt and accept these identified areas in spatial planning documents and policy. At the same time, a real, strong dialogue and cooperation is needed between different actors to harmonize their different interests.

A necessary task of spatial planning is to include ecological corridors in development plans, which requires identifying the barriers that cross these corridors and avoiding the creation of new barriers. Existing critical areas identified or those that may arise in the implementation of economic investments with a negative impact on biodiversity must be included in local / county / regional development plans to avoid fragmentation of ecological corridors.

Disclosure statement

No potential conflict of interest was reported by the authors.

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