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METHODOLOGY FOR IDENTIFYING THE ECOLOGICAL CORRIDORS. CASE STUDY: PLANNING FOR THE BROWN BEAR CORRIDORS IN THE ROMANIAN CARPATHIANS

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ABSTRACT

Achieving an ecological connectivity of the existing protected areas can contribute both to avoiding landscape fragmentation and, consequently, preserving the environment, including the animal species which are most affected by human impacts, such as the brown bear. Provided that these large carnivores can move over long distances, it is very important to identify their migration corridors using specific methodologies. In the last decade, the habitat and ecosystems fragmentation has been noticeably increasing in the Carpathian ecological region. As a result, several attempts were made to develop appropriate approaches for identifying the ecological corridors of the brown bears, in order to include them in the spatial plans along with the appropriate zoning-based restrictions. This article aims at proposing a novel method, focused on identifying the ecological corridors used by the brown bear in the Romanian Carpathian. The study is very important because it implements the connectivity concept into the spatial planning practice, increasing its sustainability. The approach relies on developing a model based on specific parameters and using ArcGIS in conjunction with the CorridorDesign and Linkage Mapper applications. The crucial advantage of the method is that it addresses a very important spatial planning issue and is able to support the decision making processes in relationship to preserving biodiversity and ensuring the maintenance of ecosystems and their services. Its flexibility allows for adapting it to the particular restrictions of different planning systems. At the same time, the cross-cutting

approach used for establishing the exact geographical location of ecological corridors is actually making connectivity an operational concept that can be used for drafting the spatial plans and, therefore, addressing jointly the perspectives of spatial planners and environmental conservationists, and eventually reconciling them. Last but not least, the integrated approach addresses the inter-dependency and interrelatedness of the natural and human systems. Further research is needed to improve the method, by translating it from the national scale to the local one, taking into consideration the existing specific terrain conditions and barriers, in order to obtain a more effective long-term protection.

Keywords: Natura 2000 sites, ecological network, GIS, least-cost modeling, habitat suitability, connectivity model

RESUMO

METODOLOGIA PARA IDENTIFICAÇÃO DOS CORREDORES ECOLÓGICOS. ESTUDO DE CASO: PLANEJAMENTO PARA OS CORREDORES DO URSO PARDO NOS CÁRPATOS ROMANOS

Alcançar uma conectividade ecológica das áreas protegidas existentes pode contribuir tanto para evitar a fragmentação da paisagem e, consequentemente, preservar o meio ambiente, incluindo as espécies animais mais afetadas pelos impactos humanos, como o urso pardo. Desde que esses grandes carnívoros possam se deslocar por longas distâncias, é muito importante identificar seus corredores de migração usando metodologias específicas. Na última década, a fragmentação de habitats e ecossistemas tem aumentado visivelmente na região ecológica dos Cárpatos. Como resultado, várias tentativas foram feitas para desenvolver abordagens apropriadas para identificar os corredores ecológicos dos ursos pardos, a fim de incluí-los nos planos espaciais juntamente com as restrições baseadas em zoneamento apropriadas. Este artigo tem como objetivo propor um novo método, focado na identificação dos corredores ecológicos utilizados pelo urso pardo nos Cárpatos da Romênia. O estudo é muito importante porque implementa o conceito de conectividade na prática do ordenamento do território, aumentando a sua sustentabilidade. A abordagem baseia-se no desenvolvimento de um modelo fundamentado em parâmetros específicos e usando ArcGIS em conjunto com os aplicativos CorridorDesign e Linkage Mapper. A vantagem crucial do método é que ele aborda uma questão de planejamento espacial muito importante e é capaz de apoiar os processos de tomada de decisão em relação à preservação da biodiversidade e garantia da manutenção dos ecossistemas e seus serviços. Sua flexibilidade permite adaptá-lo às restrições particulares de diferentes sistemas de planejamento. Ao mesmo tempo, a abordagem transversal utilizada para estabelecer a localização geográfica exata dos corredores ecológicos está, na verdade, tornando a conectividade um conceito operacional que pode ser utilizado para a elaboração dos planos espaciais e, portanto, abordando conjuntamente as perspectivas dos planejadores espaciais e conservacionistas ambientais , e eventualmente reconciliando-os. Por último, mas não menos importante, a abordagem integrada aborda a interdependência e inter-relação dos sistemas naturais e humanos. Mais pesquisas são necessárias para aprimorar o método, traduzindo-o da escala nacional para a local, levando em consideração as condições e barreiras específicas do terreno existentes, a fim de obter uma proteção mais eficaz a longo prazo.

Palavras-chave: Sítios Natura 2000, rede ecológica, SIG, modelação de menor custo, adequação de habitat, modelo de conectividade

1 Introduction

Background

The extension of human activities within the natural areas has severely increased the habitat loss[1], contributing significantly to the extinction of species[2]. Habitat loss and fragmentation have large negative impacts on biodiversity[3], which is why there is currently a great interest in the conservation of species and ecosystems. The preservation of animal species requires identifying which species from a given region are the most vulnerable to habitat loss[4] and estimating the minimum size of the habitat required by them.

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1 Thomas D. Sisk, Alan E. Launer, Kathy R. Switky, and Paul R. Ehrlich, "Identifying extinction threats: global analyses of the distribution of biodiversity and the expansion of the human enterprise", in *Ecosystem management*, eds. Fred B. Samson, and Fritz L. Knopf (New York: Springer, 1994), 53–68, https://doi.org/10.1007/978-1-4612-4018-1_8.

2 Lenore Fahrig, "How much habitat is enough?", *Biological conservation* 100 (July 2001): 65–74, https://doi.org/10.1016/S0006-3207(00)00208-1.

3 Lenore Fahrig, "Effects of habitat fragmentation on biodiversity", *Annual Review of Ecology, Evolution and Systematics* 34 (November 2003): 487–515, https://doi.org/10.1146/annurev.ecolsys.34.011802.132419.

4 Kimberly A. With, and Anthony W. King, "Extinction thresholds for species in fractal landscapes", *Conservation Biology* 13 (April 1999): 314–26, https://doi.org/10.1046/j.1523-1739.1999.013002314.x.

Urban expansion increases land fragmentation and decreases connectivity[5] and, consequently, affects the functions of green spaces and biodiversity. Assessing the connectivity and identifying the potential ecological corridors requires appropriate methodologies and analyses, considering specific parameters[6] that can be used by spatial planners and in the management of protected areas. The mountain regions, with their fragile ecosystems, harsh climate, remoteness and vulnerability to environmental threats have drawn a special interest in the last decade[7]. For this reason, the fast increasing of habitat and ecosystem fragmentation requires, especially in the mountain areas, considering the ecological connectivity – respectively between Natura 2000 sites and all the other categories of natural protected areas. Landscape connectivity refers both to the landscape structure and the ability of species to move across the landscape patches[8].

The fragmentation has a negative impact on the landscape functions, altering the species ability to safely pass through territories (the landscape permeability). This happens especially in the case of species with a migratory movement and that depend on a well-preserved natural environment, such as the brown bear (*Ursus arctos*). The spatial dynamics of the brown bear involves very large areas, even thousands of hectares[9]. Landscape fragmentation limits and disturbs its habits, especially in terms of migration, and the habitat fragmentation isolates the brown bear populations, with serious demographic and genetic impacts[10]. If the ecological networks are not identified, the fragmentation of landscape will intensify, limiting the dispersion and

[5] Alexandru-Ionuţ Petrişor, Ion C. Andronache, Liliana Elza Petrişor, Ana Maria Ciobotaru, and Daniel Peptenatu, "*Assessing the fragmentation of the green infrastructure in Romanian cities using fractal models and numerical taxonomy*", Procedia Environmental Sciences 32(2016): 110–23, https://doi.org/10.1016/j.proenv.2016.03.016.

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[7] Oana-Cătălina Popescu, and Alexandru-Ionuţ Petrişor, "*GIS analysis of an area representative for the Romanian hardly accessible mountain regions with a complex and high-valued touristic potential*", Carpathian Journal of Earth and Environmental Sciences 5 (2010a): 203–10; Oana-Cătălina Popescu, and Alexandru-Ionuţ Petrişor, "*GIS analysis of Romanian hardly accessible mountain regions with a complex and high-valued touristic potential*", Romanian Journal of Regional Science 4 (December 2010b): 78–94.

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[9] Szabo Szilard, Jozsef Both, Mihai Pop, Silviu Chiriac, and Radu Mihai Sandu, eds., "Practical guide for preventing the degradation and fragmentation of the brown bear habitat and assuring the connectivity of Natura 2000 sites in Romania (in Romanian)", Brasov: Green Steps, 2013.

[10] Nusha Keyghobadi, "The genetic implications of habitat fragmentation for animals", *Canadian Journal of Zoology* 85 (November 2007): 1049–64, https://doi.org/10.1139/Z07-095.

genetic exchange of wild animal species[11]. In fact, the loss and fragmentation of natural and semi-natural habitats as a cumulated result of infrastructure networks, intensification of agriculture and urbanization have been suggested as main reasons for the current biodiversity crisis[12].

Status of the brown bear in the Carpathian area

Almost 8,000 brown bears live in the Carpathian Mountains, spanning in Slovakia, Poland, Ukraine and Romania. They are protected and listed as one of the most important and endangered species by the international and national conventions, such as the 1992 Habitats Directive of the European Council, the 1979 European Council Bern Convention, the IUCN Red list of threatened species[13]; and the CITES Appendices I, II and III of CITES[14] as species protected against over-exploitation through international trade. Romania has the largest population of bears in the Carpathian and Danube area, which has greatly increased recently as their natural habitat became more and more fragmented. The brown bear in Romania is protected by law.

Theoretical approach

The term "habitat" has a particular meaning in ecology. According to Spellberg[15], the habitat can be defined as "the locality or area used by a population of organisms and the place where they live", and most

[11] Filippo Favilli, Christian Hoffmann, Marianna Elmi, Elisa Ravazzoli, and Thomas Streifeneder, "The BioREGIO Carpathians project: aims, methodology and results from the "Continuity and Connectivity" analysis", *Nature Conservation* 11 (July 2015): 95–111, https://doi.org/10.3897/natureconservation.11.4424.

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[13] "Ursus arctos (amended version of 2017 assessment). The IUCN Red List of Threatened Species 2017", Bruce N. McLellan, Michael F. Proctor, Djuro Huber, and Stefan Michel, accessed June 5, 2020, https://www.iucnredlist.org/species/41688/121229971, https://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T41688A121229971.en

[14] "*Convention on International Trade in Endangered Species of Wikd Fauna and Flora – Appendices I, II and III, updated in 2019*", CITES, accessed June 5, 2020, https://cites.org/eng/app/appendices.php

[15] Ian F. Spellberg, ed. "*Evaluation and Assessment for Conservation: Ecological Guidelines for Determining Priorities for Nature Conservation*", Netherlands: Springer Science & Business Media vol. 4, 1994.

ecologists assume that habitats contain everything that animals need for food and reproduction[16]. Habitat loss caused by human intervention is a major threat to biodiversity, often linked to the continuous habitat fragmentation and isolation[17]. The habitat fragmentation occurs when a large, continuous habitat transforms into small patches[18].

Ecological networks can be a solution to the landscape fragmentation issues, and studies confirm that they can help threatened natural population of species and habitats surviving[19]. An ecological network is a system composed by the elements of the natural and semi-natural landscape, which aims to preserve biodiversity against landscape fragmentation and reduce environmental depletion[20]. This coherent system is configured and managed with the aim of maintaining or restoring its ecological functions as a way to conserve biodiversity while also providing appropriate opportunities for the sustainable use of natural resources[21].

In other words, an ecological corridor is a landscape element with a more or less linear shape, which differs in structure and functions from the surrounding area and facilitates the movement of target species through areas with less favorable habitat types[22]. These linear elements “connect core areas and serve as migration and dispersal routes”[23]. Ecological networks consist of core areas, link corridors, link areas and buffer zones, all with an explicit spatial allocation[24].

Ecological corridors of wildlife can maintain functional ecological networks, supporting the movement of animals, securing the conservation of connectivity, migration and dispersal of species and eventually the

[16] Paul Beier, Dan Majka, and Jeff Jenness, eds. *Conceptual steps for designing wildlife corridors*, Arizona, USA: Corridor Design, 2007.

[17] Fahrig, “Effects,” 487–515.

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[22] Szilard et al., “Practical”.

[23] Jörg E. Tillmann, “Habitat Fragmentation and Ecological Networks in Europe”, *GAIA – Ecological Perspectives for Science and Society* 14 (June 2005): 119–23, https://doi.org/10.14512/gaia.14.2.11.

[24] Gurrutxaga et al., “GIS-based,” 318–26.

conservation of their populations and biodiversity[25]. The design of wildlife connectors depends on scale and species and on the "natural and man-made conditions in the landscape"[26]. The design of ecological corridors integrated in regional plans often evaluates a territory through the mobility requirements of certain species with a wide range of mobility, acting as umbrella species[27].

Previous work on identifying ecological networks

At a large scale, such as the transnational or regional one, the ecological networks can be ideal to maintain the structural connectivity, but are unrealistic from a biological viewpoint. For example, pan-ecological networks have been identified by assessing the "least-cost path analysis"[28]. However, at a sub-national level, the approach based on functional connectivity, using the focal species approach (i.e., species in most need of connectivity) can be more relevant[29]. The approach of focal species uses a model of "landscape permeability" for a particular species, measured by the "ecological cost" of movement. The model tries to minimize the cost of movement through the landscape. Previous studies have demonstrated that, in order to make the model more

[25] Czochański and Wiśniewski, "River," 77–87.

[26] Josefine Jonsson, "*Spatial Modeling of Wildlife Crossing: GIS-based Approach for Identifying High-priority Locations of Defragmentation across Transport Corridors*" (Bachelor degree thesis, University of Stockholm, 2017).

[27] Luciano Bani, Marco Baietto, Luciana Bottoni, and Renato Massa, "The use of focal species in designing a habitat network for a lowland area of Lombardy, Italy", *Conservation Biology* 16 (June 2002): 826–31, https://doi.org/10.1046/j.1523-1739.2002.01082.x; Paul Beier, and Steve Loe, "In my experience: A checklist for evaluating impacts to wildlife movement corridors", *Wildlife Society Bulletin (1973-2006)*, 20 (Winter 1992): 434–40; Geert Groot Bruinderink, Theo Van Der Sluis, Dennis Lammertsma, Paul Opdam, and Rogier Pouwels, "Designing a coherent ecological network for large mammals in northwestern Europe", *Conservation Biology* 17 (April 2003): 549–57, https://doi.org/10.1046/j.1523-1739.2003.01137.x; Carlos Carroll, "Linking connectivity to viability: insights from spatial explicit population models of large carnivores" in *Connectivity Conservation*, eds. Kevin R. Crooks, M. Sanjayan (Cambridge, UK: Cambridge University Press, 2006), 369–89, DOI: https://doi.org/10.1017/CBO9780511754821.

[28] Frank Adriaensen, J. Paul Chardon, Geert De Blust, Else Swinnen, S. Villalba, Hubert Gulinck, and Erik Matthysen, "The application of 'least-cost' modelling as a functional landscape model", *Landscape and urban planning* 64 (August 2003): 233–47, https://doi.org/10.1016/S0169-2046(02)00242-6; Andrew G. Bunn, Dean L. Urban, and Tim H. Keitt, "Landscape connectivity: a conservation application of graph theory", *Journal of Environmental Management* 59 (August 2000): 265-78, https://doi.org/10.1006/jema.2000.0373, Roger D. J. Catchpole, "Connectivity, Networks, Cores and Corridors", in *Mapping Wilderness*, eds. Stephen J. Carver, and Steffen Fritz (Dordrecht: Springer, 2016), 35–54, https://doi.org/10.1007/978-94-017-7399-7_3; Kevin Watts, Amy E. Eycott, Phillip Handley, Duncan Ray, Jonathan W. Humphrey, and Christopher P. Quine, "Targeting and evaluating biodiversity conservation action within fragmented landscapes: an approach based on generic focal species and least-cost networks", *Landscape Ecology* 25 (November 2010): 1305–18, https://doi.org/10.1007/s10980-010-9507-9.

[29] Watts et al., "Targeting," 1305–18; Catchpole, "Connectivity," 35–54; Jonathan W. Humphrey, Kevin Watts, Elisa Fuentes-Montemayor, Nicholas A. Macgregor, Andrew J. Peace, and Kirsty J. Park, "What can studies of woodland fragmentation and creation tell us about ecological networks? A literature review and synthesis", *Landscape Ecology* 30 (January 2015): 21–50, https://doi.org/10.1007/s10980-014-0107-y.

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reliable, the opinions of experts also improve the technical procedure, by combining the modeling of habitat and species with field studies[30].

Need for research

Identifying a suitable methodology for the Romanian Carpathians dealing with large carnivores (particularly the brown bear) is very important due to the fact that ecological corridors can provide species a real protection even outside of the protected areas[31]. Most studies use basically the same technical idea, but have limitations in terms of the species analyzed and algorithms used; all have in common the use of GIS and a cost-distance model for analyzing the ecological connectivity (Table 1).

Table 1. Analysis of the previous methodologies used to identify ecological corridors.

Authors	Aim	Scale	What is it assessing?	Model used	Tools	Diagnosis	Base	Practical advantage	Pilot area	Results	Further use
Marulli and Mallarach, 2005[32]	Assess landscape and ecological connectivity	Regional (a metropolitan area)	The impact of regional and urban plans on ecological connectivity	A cost-distance model including the barrier effect.	GIS and mathematical language used to make a topological analysis of a land use map	Connectivity of terrestrial landscape ecosystems by using indices for ecological connectivity and barrier effect	Previously defined set of ecological functional areas	Identify vulnerable spots for ecological connectivity. Allows a cost-effective assessment of the current situation	Barcelona Metropolitan Area	Assessment of impacts on infrastructure planning vs landscape and ecological connectivity	Can easily be extrapolated to other regions
Ferretti and Pomarico, 2013[33]	Obtain an input to land-use planning	Regional	Suitability of land to behave as an ecological corridor	Spatial multicriteria evaluations (SMCE)	GIS and multicriteria analysis (MCA)	Assessment of the ecological value of land	Integration of the GIS with a specific MCA technique (Analytic Network Process)	Can be used in spatial planning and policy-making, for strategic assessments	Piedmont Region (Northern Italy)	Maps to be used as decision variables in planning	Used as effective tool for decision-makers in spatial planning

[30] Humphrey et al., "What can," 21–50.
[31] Szilard et al., "Practical".
[32] Joan Marulli, and Josep M. Mallarach, "A GIS methodology for assessing ecological connectivity: application to the Barcelona Metropolitan Area", *Landscape and Urban Planning* 71 (March 2005): 243–62, https://doi.org/10.1016/j.landurbplan.2004.03.007.
[33] Valentina Ferretti, and Silvia Pomarico, "An integrated approach for studying the land suitability for ecological corridors through spatial multicriteria evaluations", *Environment, development and sustainability* 15 (October 2013), 859–85, https://doi.org/10.1007/s10668-012-9400-6.

Deodatus *et al.*, 2013[34]	Create and consolidate ecological corridors for the Carpathians	Trans-Regional (the Carpathians)	Location of the most suitable corridor areas for 4 wild species	A landscape ecological modeling.	Model of the institutional and regulatory framework related to ecological network development	Identify interconnected land management units with minimum obstacles for wildlife and conflicts with land use, making the shortest connection	Using the habitat requirements for 4 species	Develop corridors and their management plans in consultation with the users and owners of the land	Ukraine, Romania and Poland	Proposals of ecological corridor for the Carpathians	Used for the approval and inclusion of the corridors in the spatial planning system
Walker and Craighead, 1997[35]	Identify priority areas for wildlife management	Regional (mountain ecosystems)	Best landscape routes for wildlife moving across 3 large protected areas	A least-cost-path analysis to locate potential corridor routes	ARC/GRID and Montana Gap Analysis data	Probable movement routes, critical barriers and bottlenecks	Combines the model with road density information to create km-scale cost surface of movement	Easy computation and interpretation	Northern Rockies, USA	Habitat suitability models for three umbrella species	Used to improve connectivity between protected ecosystems
Chang *et al.*, 2012[36]	Provide a green infrastructure planning approach guiding sustainable land use decisions	Local (suburban area)	Vital ecological areas and linkages prior to the development of suburban areas	The patch corridor-matrix model	A GIS-based ecological connectivity assessment	Assesses the ecological value of land	Planned green infrastructure	Land protection by green infrastructure planning	Longgang District of Shenzhen (China)	A planning approach	Land resource units can be developed / protected in the future

[34] Floris Deodatus, Ivan Kruhlov, Leonid Protsenko, Andriy-Taras Bashta, Vitalyi Korzhyk, Stefan Mykola Bilokon, Mykhailo Shkitah, Iaroslav Movchan, Sebastian Catanoiu, Razvan Deju, and Kajetan Perzanowski, "Creation of ecological corridors in the Ukrainian Carpathians", in *The Carpathians: Integrating Nature and Society Towards Sustainability*, eds. Jacek Kozak, Katarzyna Ostapowicz, Andrzej Bytnerowicz and Bartłomiej Wyżga (Berlin: Springer, 2013), 701–17, https://doi.org/10.1007/978-3-642-12725-0_49.

[35] Richard Walker, and Lance Craighead, "Analyzing wildlife movement corridors in Montana using GIS", in *Proceedings of the 1997 ESRI user conference* (Redlands, CA: ESRI, 1997).

[36] Quing Chang, Xue Li, Xiulan Huang, and Jiansheng Wu, "A GIS-based green infrastructure planning for sustainable urban land use and spatial development", *Procedia Environmental Sciences* 12(2012): 491–98, https://doi.org/10.1016/j.proenv.2012.01.308.

Fiduccia *et al.*, 2017[37]	Model the ecological connectivity in problematic mapping conditions (e.g., road bridges and riverbanks)	Regional	Compute Potential Ecological Networks at regional level	The Least - Cost Path (LCP) algorithm	GIS and Natural Protected Areas and Land Use Map GIS datasets	Links 2 Ecological Network approaches (Species-Specific and Land Units)	Transform input datasets in rasters	A unified model of Ecological Networks obtained in the perspective of Ecological Land Planning	Veneto Region, Italy	Useful tool for ecological land planning.	More detailed results can be obtained using traditional ecological planning techniques based on feedback and needs of communities, stakeholders, and experts
Bruinderink *et al.*, 2003[38]	Design effective corridors in order to increase spatial connectivity	Trans-regional (regions of 3 countries)	Structure of the ecological network for red deer and spatial connectivity of the landscape	The LARCH landscape ecology model	Tool for visualizing the viability of meta-populations in a fragmented environment	Presents the areas and habitat areas that could support viable and persistent populations	Gaps and barriers that prevent connectivity	Policy decisions on nature conservation and spatial planning	Netherlands, Belgium, and adjacent parts of France and Germany	Maps	Applicable to other regions and species
Adriaensen *et al.*, 2003[39]	To develop a functional landscape model	Local (and virtual)	The "effective distance"	Least cost modeling	GIS system	Assess the biological usefulness of least-cost paths	Relation between landscape and mobility of organisms	A flexible tool to model functional connectivity	Virtual landscape and small scaled agricultural system	Can be applied in an iterative way	Tool for scenario making and project evaluation in wildlife protection
Favilli *et al.*, 2015[40]	Identify the most influential barriers to ecological connectivity throughout the Carpathians for 7 wild animal species	Trans-Regional (Carpathians)	Physical, legal and socioeconomic barriers	The least-cost modeling	2 ArcGIS 10.0 tools: Corridor Design and Linkage Mapper	Identify core areas and energy spent by each species moving from one core area to another	On site visits of with local experts and stakeholders in order to adapt the GIS results	Powerful tool to detect and prevent future threats to the ecological network due to human infrastructures	Carpathians, case study: Serbia-Romania	Suitability maps for whole Carpathian region	Identify the most important corridors and develop recommendations for overcoming the barriers

This is the reason why the present study is very important and specific to the present moment. The proposed methodology for improving ecological connectivity is necessary because it can provide scientific evidence to stakeholders and policy makers involved in the spatial development and protection of nature for

[37] Fiduccia et al., "A GIS-Based," 600–12.
[38] Bruinderink et al., "Designing," 549–57.
[39] Adriaensen et al., "The application," 233–47.
[40] Favilli et al., "The BioREGIO," 95–111.

making decisions at different levels and harmonizing their apparently opposite interests. The identified ecological corridors can be used in spatial planning to support the necessary measures for improving the ecological connectivity in the Romanian Carpathian Mountains. The methodology and results can be used in raising the awareness of public and professionals on the importance of landscape fragmentation and ecological connectivity.

The aims and importance of the study

The purpose of this work is to propose a new methodology that can be used to reduce the effects of habitat fragmentation by identifying ecological corridors for the migration of wild animals in a specific region, i.e., the Romanian Carpathians, focusing mainly on Natura 2000 sites, where the brown bear is encountered. A GIS-based model is proposed for mapping the ecological connectivity, GIS is widely used for designing ecological corridors. The model requires also a series of information and data on ecological, environmental and spatial factors. Also, the present study considers that the least-cost modeling is the most appropriate.

The novelty of our approach is that, unlike other studies, the methodology assumes that the permeability of the landscape for the brown bear depends on the behavioral characteristics of the species in the four periods of the year. Thus, four spatial models are developed to identify the permeability of the landscape, according to these characteristics. The present spatial modeling that sets migration corridors at the national level is not a substitute for field assessments. The GIS-based identification of ecological corridors provides a major support for identifying the national ecological networks and implementing it in future spatial plans.

2 Methods

The study area

The present study is carried out in the Romanian Carpathians. This study area was chosen for obtaining more precise results due to a better resolution of data in comparison with the other similar studies, and therefore showing the advantages of the methodology. The study area is displayed in Fig. 1, showing also the regional context: the Carpathian Ecological Region and the area covered by the Carpathian Convention.

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Fig. 1. Position of the study area in a regional context. Source of data: ESRI, Ecoregions 2017, Romanian Ministry of the Environment.

The data

The datasets used as input data to assess the habitat suitability for brown bears is the joint result of a bibliographic research on similar approaches (Table 1) and the availability of data, most characteristic to urban and spatial planning. Two types of data were used in this study: environmental data (Table 2) and occurrence data.

Data on the occurrence of the brown bear, representing relevant observations of its presence in certain regions, was derived from a map of the presence of the brown bear in the Romanian Carpathians, developed and processed by the specialists in nature protection and conservation. Other data was obtained from the map of the distribution of the brown bear, based on hunting reports, for the Alpine biogeographical region (the Carpathian Mountains), resulted from the project "*Monitoring the conservation status of species and habitats in Romania based on art. 17 of the Habitats Directive"*, co-financed by the European Regional Development Fund through the Sectoral Operational Program Environment (SOP Environment)[41], and the Technical Report

[41] Ovidiu Ionescu, Georgeta Ionescu, Ramon Jurj, Constantin Cazacu, Mihai Adamescu, Ancuţa Cotovelea,Claudiu Paşca, Marius Popa, Ion Mirea, George Sîrbu, Silviu Chiriac, Mihai Pop, Şandor Attilla, and Răzvan Deju, eds. *Synthetic monitoring guide for mammals of community interest in Romania (in Romanian)*, Bucharest, Romania: Silvica Press, 2013.

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of the project LIFEURSUS: *Best practices and demonstrative actions for conservation of the Ursus arctos species in the Eastern Carpathians* (2010-2014), producing a necessary parameterization of habitat factors[42].

Table 2. Data used to assess the habitat suitability for the brown bear in Romania (habitat factors).

Input data	Data source
Land cover and use data	CORINE database (2018), COPERNICUS site (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018
Network of national roads and railways	The URBANPROIECT database, developed and owned by NIRD URBAN-INCERC, updated
Traffic on the national roads (2015)	Website of the Romanian Ministry of Transport and the website https://www.wizard-media.ro/Panouri-Publicitare/Harta_celor_mai_circulate_drumuri_nationale_si_autostrazi/
Built up areas of each settlement (2014)	The URBANPROIECT database, developed and owned by NIRD URBAN-INCERC
The Digital Terrain Model (DTM) made on the basis of the contour lines (10 meters)	Contour lines from the URBANPROIECT database
Slopes derived from the DTM and differentiated according to the Corridor Design tool (to create topographic position raster).	Computed in GIS according to the DTM

The method

This article proposes a solution based on which ecological corridors for the brown bear can be identified in the Romanian Carpathians using a specific ecological model. The methodology presented in this article was developed based on the models developed by two projects funded by the European Union: Connect GREEN and BioREGIO. The proposed method is based on lowest costs modeling, starting with the proposal of a habitat suitability model using GIS, a widely used tool for identifying core areas and ecological networks for biodiversity protection. Among the available GIS habitat suitability models, the present study developed a joint GIS approach, using ArcGIS 10.x in conjunction with the Corridor Design and Linkage Mapper tools, which are free and relatively easy to use. Two models were used to define the habitat of the brown bear in Romanian Carpathians: the habitat suitability model (suitable areas / patches for permanent occurrence of the brown bear) and the connectivity model (linking particular patches resulted in the habitat suitability model).

[42] "Technical report on the study of the degradation and fragmentation of the brown bear habitat (in Romanian)", Szabo Szilard, Jozsef Both, Mihai Pop, Silviu Chiriac, and Radu Mihai Sandu, accessed June 5, 2020, https://issuu.com/carnivoremari/docs/ -si-fragmentare-a-habitatelor-lifeursus2

The steps of this proposed methodology are: (1) development of a national habitat suitability model for the brown bear, (2) modeling the connectivity and development of resistance surfaces, and (3) designing the ecological network.

Provided that the brown bear uses different habitats during the four seasons of the year, four habitat suitability models have been computed for all these four periods: the winter sleep (preference for higher altitude areas, old forests and quiet areas), period of hypophagy and reproduction - spring (less selective), period of berry foraging - summer (preference for areas with berries, regenerations, plantations) and period of hyperphagia - fall (preference for old deciduous forests in the area of hills and orchards). For each characteristic period of the brown bear a parameterization of habitat factors was done. Each habitat quality assessment map for the brown bear was divided into four suitability classes[43], according to the results obtained before: (1) 75–100% - optimal habitat, (2) 50–75% - sub-optimal habitat, (3) 25–50% - occasional habitat (4) 10-25% - avoided habitat/barrier. The most compact habitats are the Natura 2000 sites. For this reason, the analysis of ecological corridors was restricted only to the Natura 2000 sites, where the brown bear has most likely its habitat. Therefore, by using the selection tool of ARCGIS 10.x, the Natura 2000 sites corresponding to the brown bear habitat were selected based on location.

In the following steps, the surface of resistance and ecological corridors were obtained by using the Least-Cost paths analysis, respectively the ARCGIS10.x Linkage Mapper. Linkage Mapper is an ArcGIS toolbox, written in the programming language Python, and uses mostly ArcGIS tools to create least cost paths and least cost corridors, the latter consisting of multiple least cost paths[44]. In order to comply with the Linkage Mapper tool requirements, it was considered that Natura 2000 sites, as basic areas, are sufficiently large in surface and make the most suitable habitat for the brown bear species (core areas, see Fig. 3). The second requirement of the Linkage Mapper tool is the surface of resistance, representing the resistance of different landscape segments that influence more or less the movement of animals in the landscape. “Permeability” and “resistance” are complementary, such that “permeability” + “resistance” = 100. Thus, a perfectly permeable landscape has zero resistance. This raster was determined using the Map Algebra tool from the Spatial Analyst module of ARCGIS 10.x and the general permeability raster of the brown bear species for Romania, identified

[43] Favilli et al., “The BioREGIO,” 95–111.

[44] Elsa Nordén (2016), „Comparison between three landscape analysis tools to aid conservation efforts” (Master degree thesis, University of Lund, 2016).

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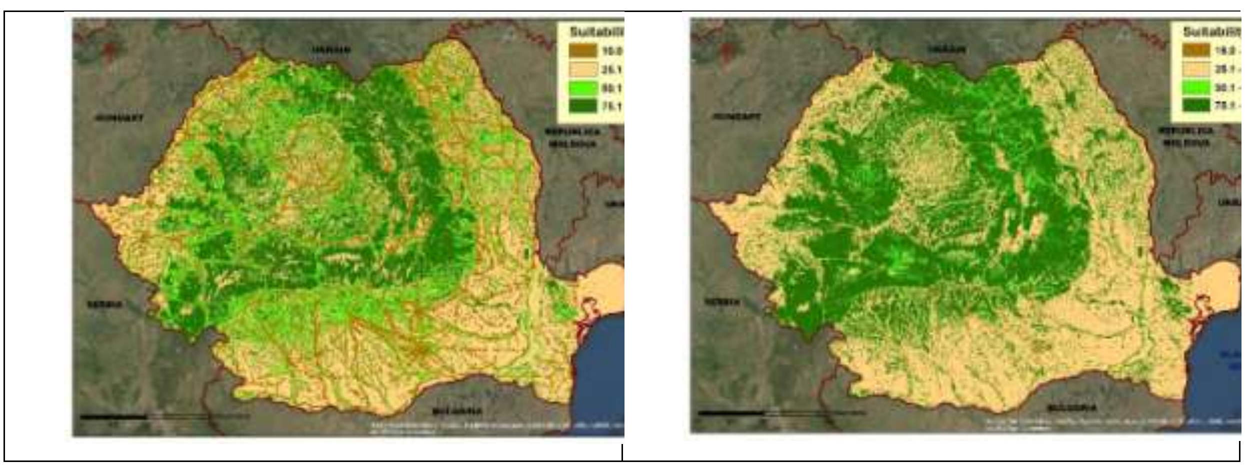
with the Corridor Design tool. The result was a map of the resistance of movement for the brown bear species in Romania.

Using the “Build Network” and “Map Linkages” commands of Linkage Mapper, the selected Natura 2000 sites and the resistance surface raster, the theoretical ecological corridors of the brown bear in Romanian Carpathian Mountains were determined. The expertise of specialists and field studies are required to validate these ecological corridors in the future.

3 Results and Discussion

By applying the methodology proposed by this study, the following results were obtained: (1) four habitat suitability maps of the brown bear for each period of the year (Fig. 2), (2) the final map of national habitat suitability (Fig. 3), (3) the map of NATURA 2000 sites where the brown bear species has its habitat (Fig. 6), resulted from overlaying the map of Romanian natural protected areas (Fig. 4) and the map of the occurrence of the brown bear in Romania (Fig. 5), (4) the map of the resistance of movement for the brown bear in the Romanian Carpathians (Fig. 7), (5) the final map of ecological corridors at different scales (Fig. 8), (6) the theoretical ecological corridors of the brown bear in Romanian Carpathian Mountains (Fig. 9).



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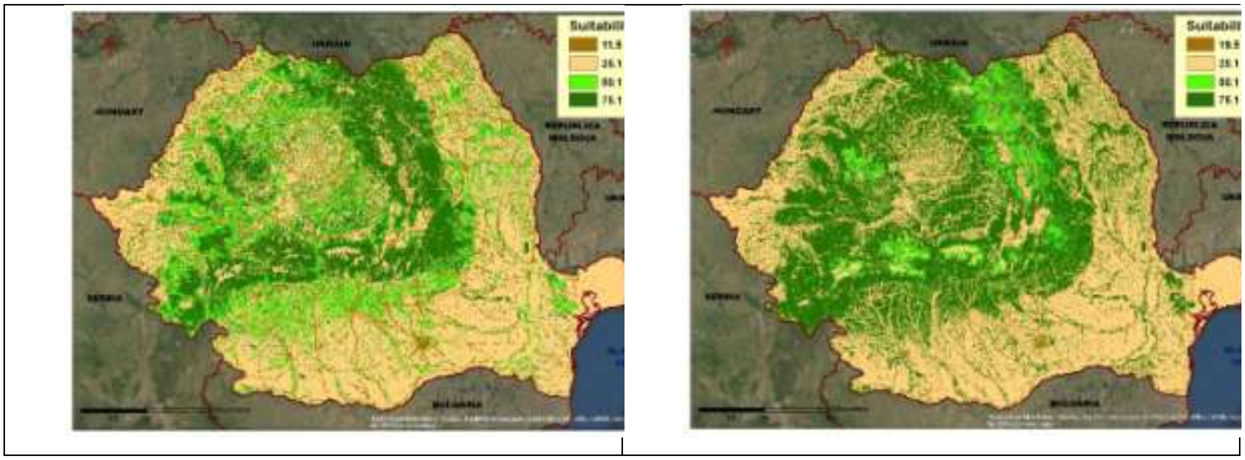

Fig. 2. Suitable habitats for the brown bear in Romania for all periods with a characteristic behavior: winter sleep, of hypophagy and reproduction, of berry foraging and hyperphagy. Source of data: ESRI, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN and the GIS user community.

The resulting GIS model needed different input data to create the probabilistic map of the ecological connectivity for the brown bear species in Romanian Carpathians, at NUTS 0 level (national level). For consistency with the reality, the factors that influence the habitat of the brown bear species, the classifications and weights have been chosen from national documents based on certified field studies[45]. The resulted connectivity model provides a coherent network of corridors, in which migration corridors for the brown bear connect patches of suitable habitat.

The novelty of this methodology consists of the fact that the suitability map is based on an algorithm that combines four different habitat suitability maps for the four periods of the year when the brown bear has different behaviors. Another novel element is the fact that in Romania the core areas of ecological corridors were identified with the Natura 2000 sites in which the occurrence of the brown bear was documented. There are no official or public results presenting the ecological / migration corridors for the brown bear in the Romanian Carpathians obtained using different methodologies sufficient to be compared with our results, even if different national or international projects had similar aims. Our study is the first study carried out at the

[45] Szilard, "Technical".

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national level presenting a theoretical easy method to determine the ecological corridors of the brown bear in Romanian Carpathians.

Fig. 3. Final map of the habitat suitability for the brown bear in Romania. Source of data: ESRI, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN and the GIS user community.

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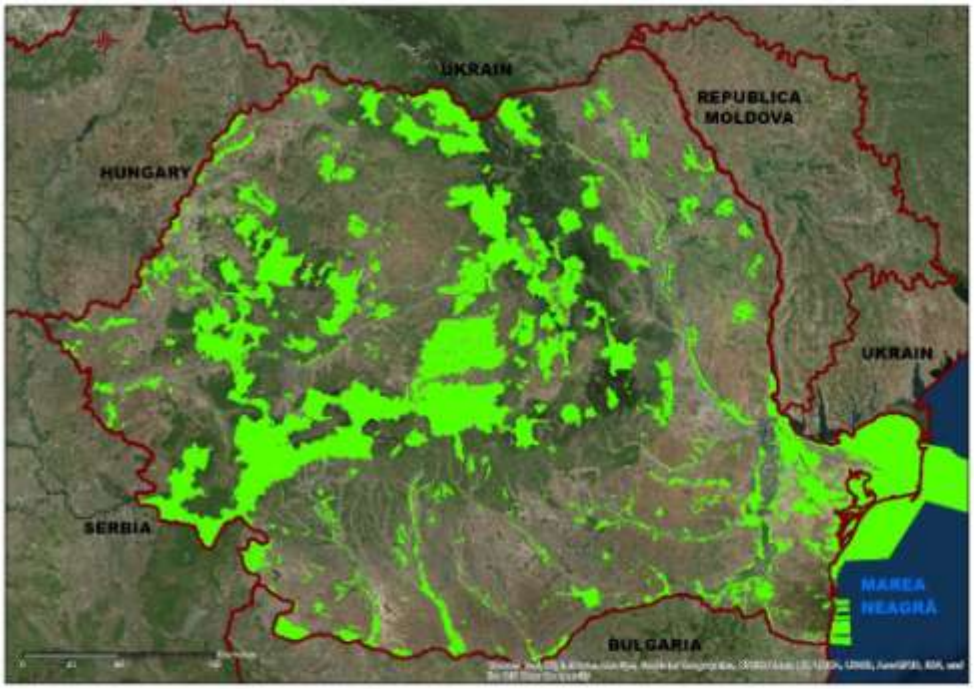

Fig. 4. Map of Romanian Natura 2000 sites. Source of the map: the Romanian Ministry of Enviornment, 2017; source of data: ESRI, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN and the GIS user community.

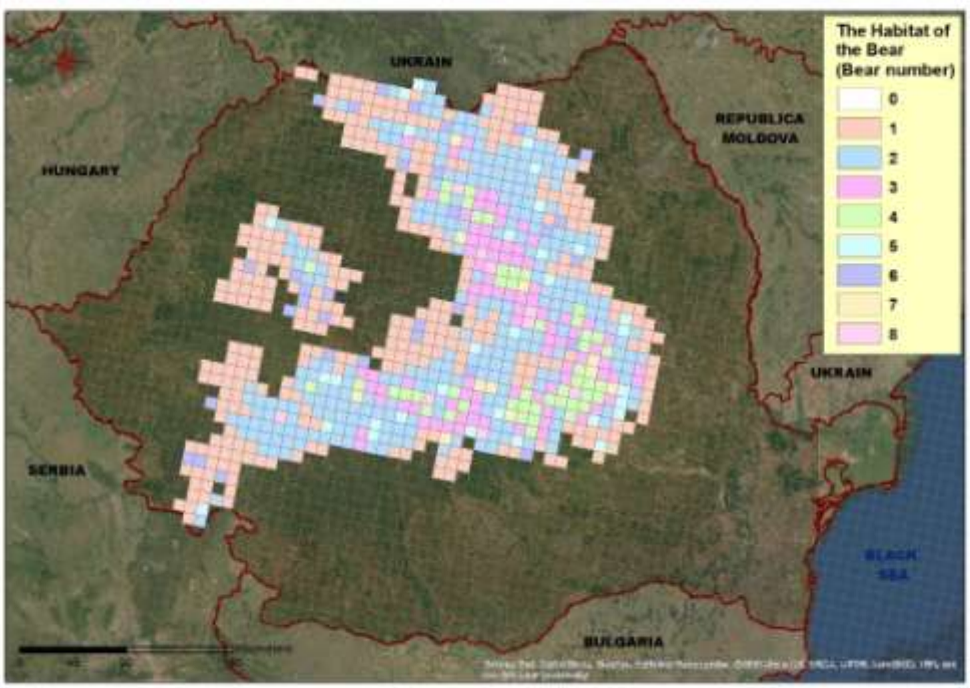

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Fig. 5. Map of the brown bear habitat occurrence in Romania. Map processed by URBANPROIECT using data from: ESRI, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN and the GIS user community.

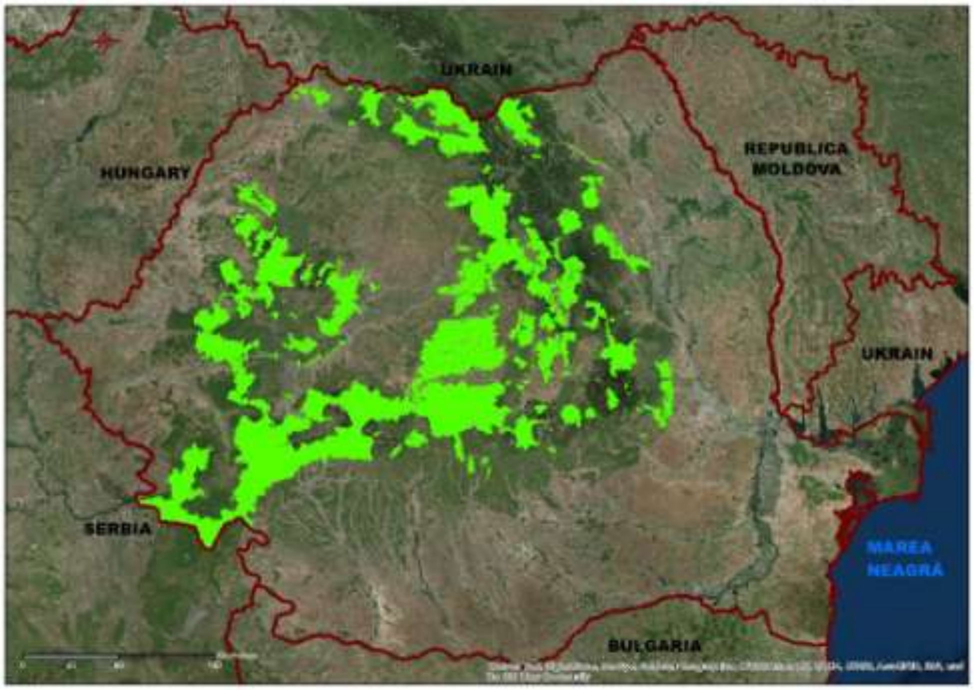

Fig. 6. Romanian NATURA 2000 sites where the brown bear species has its habitat. Source of data: ESRI, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN and the GIS user community.

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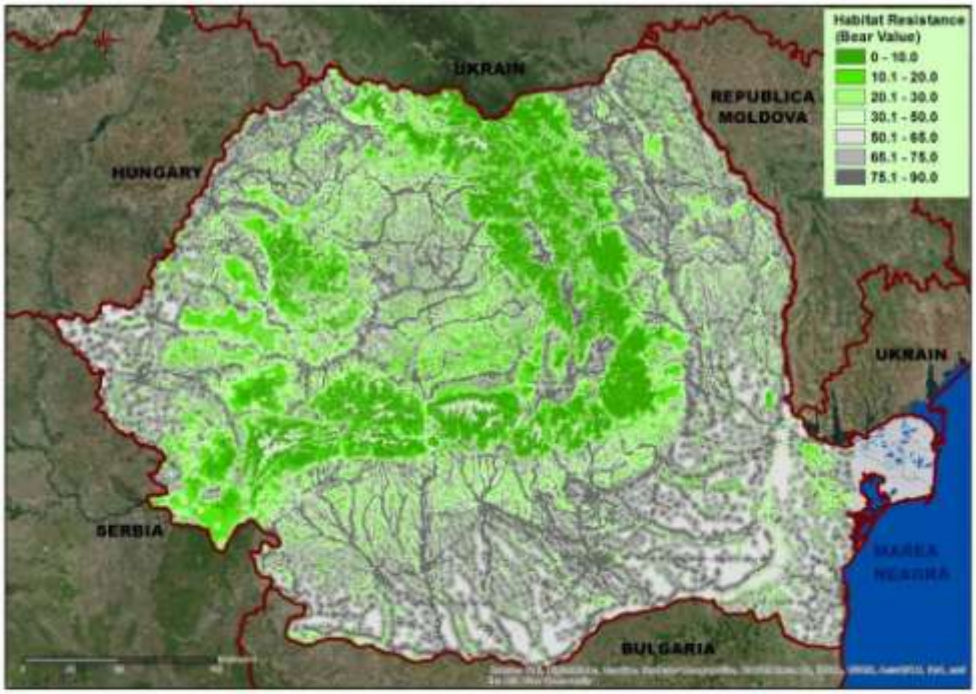

Fig. 7. Map of the resistance of movement for the brown bear in Romania. Source of data: ESRI, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN and the GIS user community.

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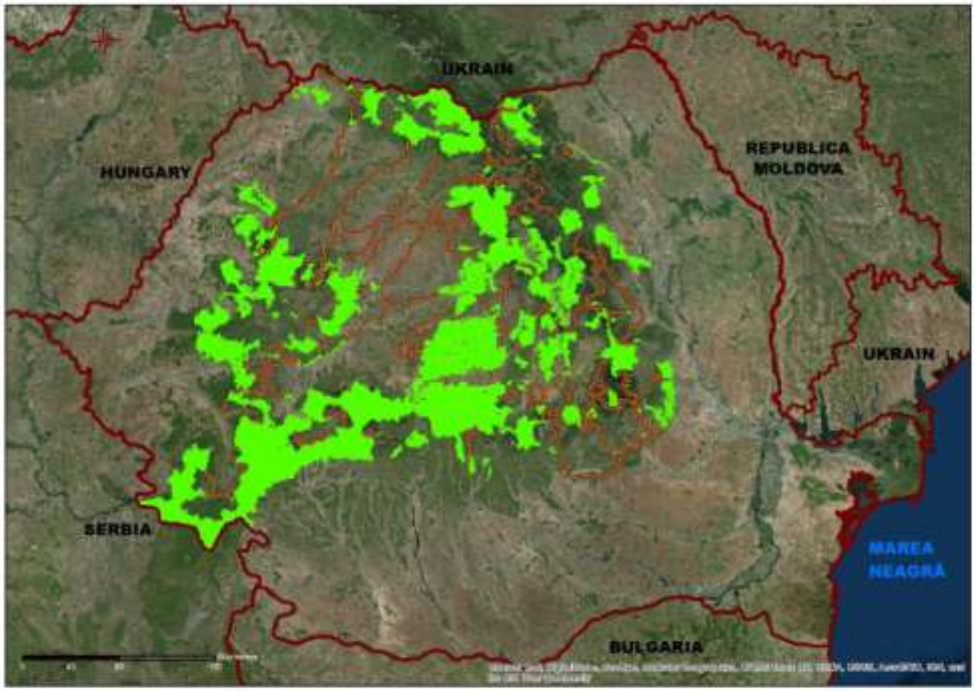

Fig. 8. Map of the ecological corridors. Source of data: ESRI, DiitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN and the GIS user community.

Fig. 9. Final ecological corridors identified by applying the methodology proposed by the study. Source of data: ESRI, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN and the GIS user community.

The limitations of this study include: (1) the resolution of the raster data was 30 meters, unlike the values of the resolution recommended in the literature (i.e., below 30 meters); (2) the CORINE data used for land use, although relatively recent (2018), does not always offer the best coverage of land when processed for such analyses at the European level; in this case, adequate satellite imagery would have yielded more accurate results; (3) only the highways, European and national roads and railways were considered (in a single raster), since they have a greater traffic and can influence the movement of brown bears. In addition, the daily traffic values of transport routes used in the study were not recent (2015).

This methodology is only the starting point for future developments. Based on the results, there is still work to be done. First, experts must verify all resulted layers, taking into consideration all existent data (built-up or non-forested areas, occurrence of the brown bear, land cover, ortophotomaps etc.). The next step is to identify the critical zones, if the proposed corridors intersect different kind of barriers (impermeable landscape structures). Experts must verify them in order to adjust the connectivity model.

Once these theoretical results are obtained, the ecological corridors identified at the national level must be verified and validated by involving the central authorities of environment and territorial planning, NGOs with environmental concerns, local authorities, different central and local organizations (e.g., the General Romanian Association for Game and Fishing, County Associations for Game and Fishing, National Forest Administration, National Environmental Guard etc.).

The methodology can be applied by nature conservation managers and spatial planners for translating the connectivity approach into the spatial plans, and their practical enforcement.

4 Conclusions

The fragmentation of landscape represents one of the major threats for the conservation of biodiversity, particularly in the Carpathian Mountains. This problem occurs also in Romania, where urban development and infrastructure limit the connection of habitats, transforming them into isolated patches. This can lead to land fragmentation and even the loss of wildlife habitats and animals life, limiting the movement of species, including the brown bear.

This study proposes a methodology enabling the identification of migration corridors used by the brown bear in the Romanian Carpathians. The migration corridors connect core areas (i.e., large areas, mainly forests, with permanent occurrence of brown bear population) by the ecological corridors. The methodology can be improved by research carried out in local, pilot areas to determine the structures acting as barriers.

What is very important is that the methodology, resulting in data and maps of the ecological/migration corridors, provides the scientific background to decision making processes at all levels. That means that spatial planners and managers of protected areas must harmonize their interests, which is a crucial need for the protection of nature. In the case of a large carnivore such as the brown bear, ensuring the connectivity by identifying the areas that create bottlenecks for the animal movement is a pressing task not only for conservationists, but also for spatial planners. They must integrate, adapt and accept these areas as part of the spatial plans and policies. At the same time, a real and strong dialogue and cooperation of international, national, regional and local stakeholders can harmonize their different interests.

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