



# IDENTIFICATION OF ECOLOGICAL CORRIDORS FOR THE LARGE CARNIVORES AS AN IMPORTANT INPUT FOR INFRASTRUCTURE PLANNING IN SERBIA – CASE STUDY OF NATIONAL PARK ĐERDAP

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**Abstract.** Inadequate planning of transport and spatial infrastructure significantly contributes to biodiversity loss through increased habitat fragmentation and wildlife mortality. In alignment with the EU Biodiversity Strategy for 2030, Serbia must harmonize infrastructure development with nature conservation principles. This paper presents a refined methodological approach for identifying and integrating ecological corridors into spatial and infrastructure planning, developed within the ConnectGREEN project. Using the case study of Đerdap National Park, the paper outlines steps taken to define, protect, and manage ecological corridors for large carnivores in Serbia. The results provide strategic recommendations and participatory planning insights that could inform sustainable development policies across the region.

**Keywords:** ecological corridors, large carnivores, transport planning, Serbia, Đerdap National Park.

## Introduction

The planning and management of ecological corridors, as key components of green infrastructure, play a crucial role in maintaining ecological connectivity – the degree to which the landscape facilitates movement of species and the flow of ecological processes. While green infrastructure represents a broader network of natural and semi-natural features (including forests, wetlands, rivers, and green urban spaces) (EC, 2013a), ecological corridors specifically refer to spatially connected linear features that enable the movement of species between core habitats, ensuring their survival and maintaining genetic exchange (Jongman et al., 2004; Bennet & Mulongoy, 2006; CBD, 2006; Hilty et al., 2006; COE, 2010, EC & Trinomics, 2016).

Ecological connectivity relies on the preservation or restoration of natural corridors, which facilitate species migration, adaptation to climate change, and the maintenance of ecosystem services such as pollination, soil preservation, and regulation of water streams and water bodies (Hilty et al., 2020).

Over time, uncoordinated spatial development and increasing pressure from urbanization, industrialization, and transportation infrastructure have led to substantial habitat fragmentation, which specifically refers to the process of breaking large and continuous habitats into smaller, iso-

lated patches. This differs from landscape fragmentation, a broader concept that reflects the disintegration of ecological, visual, and functional unity of the landscape (EEA & FOEN, 2011). Both forms of fragmentation severely impact biodiversity and ecosystem resilience.

To mitigate the adverse consequences of habitat fragmentation, nature conservation experts emphasize enhancing ecological connectivity (Debinski & Holt, 2000; Hilty & Jodi, 2006; Hilty et al., 2020). Ecological corridors support species migration, adaptation to climate change, and maintenance of key ecosystem services such as pollination, water regulation, and soil conservation. Wildlife corridors, in particular, are defined as 'landscape elements that connect historically connected habitats' (Bennett, 2003), and are essential not only for animal populations but also for ensuring the functional coherence of protected area networks.

The expansion and modernization of transportation networks, particularly roads and railways, have intensified the fragmentation of ecosystems and natural landscapes in Europe and Serbia (Brooks, 2003; Linnell et al., 2007; Hlavač et al., 2019; Spanowicz & Jaeger, 2019). These newly constructed linear barriers hinder wildlife mobility, increase the risk of collisions with vehicles, and reduce habitat quality and viability for numerous species.

Increased human activities, such as the construction of roads, railways, settlements, and industrial zones, have broken up continuous ecosystems into smaller, isolated patches, negatively impacting biodiversity. Habitat fragmentation leads to the reduction in the size and quality of habitats, disables species movement and migration, reduces genetic diversity, and increases the risk of extinction for many threatened species.

In recent decades, anthropogenic changes and rapid landscape modifications have had substantial cumulative impacts, often disregarding the characteristics and values of these landscapes. Decision-making in spatial, urban, and infrastructure planning has frequently neglected the importance of biodiversity and landscape character. The expansion and modernization of transportation networks across Europe have particularly intensify landscape fragmentation, limiting the movement and genetic exchange of wildlife species (Debinski & Holt, 2000). These newly constructed barriers along traditional wildlife corridors also increase the risk of vehicle collisions, further complicating the conservation of species (Brooks, 2003; Hlavač et al., 2019).

European countries have responded to these threats through integrated planning and legislative instruments. The EU Biodiversity Strategy for 2030 aims to expand the EU's network of protected areas and create a Trans-European Nature Network, reinforcing ecological connectivity through the development and restoration of green infrastructure and ecological corridors (EC, 2020). For example, countries like Germany (Juell et al 2003; BfN, 2018), Austria (Kohler & Plassmann, 2006), and the Netherlands (Jongman & Pungetti, 2004) have long experience in integration of ecological corridors into their spatial planning systems, using national ecological networks to reconnect habitats fragmented by transport infrastructure.

Despite these progressive examples, many countries in Southeast Europe, including Serbia, are still in the process of integrating such approaches. Serbia's commitment is formalized through its ratification of the Carpathian Convention, particularly Article 4, which emphasizes the integration of biodiversity and landscape protection into sectoral policies (Carpathian Convention, 2003). However, inadequate spatial and transport planning remains a key driver of habitat fragmentation and species decline.

Non adequate planning of transport infrastructure is the main cause of the drastic decrease in the number of species due to fatal outcomes on the Serbian, and European roads in general.

The lack of ecological considerations in infrastructure planning, especially in areas of high biodiversity, such as Serbia's Đerdap National Park (located in the Eastern Serbia), continues to disrupt

wildlife migration routes and contribute to roadkill mortality. These challenges necessitate urgent integration of ecological corridor planning into formal planning instruments.

Recent conservation efforts, particularly through the INTERREG DTP 2 ConnectGREEN project “Restoring and managing ecological corridors in mountains as the green infrastructure in the Danube basin”, have provided a structured methodology for the identification and management of ecological corridors in Serbia and other Carpathian countries. One of the project’s pilot area – Đerdap National Park – demonstrates how science-based tools and participatory processes can be used to harmonize infrastructure development with biodiversity goals. Together with the WWF Romania as a leading partner, and 12 other institutions in the field of nature protection and spatial planning from 5 countries (Austria, Czechia, Hungary, Slovakia and Serbia), Institute has developed the methodology for the identification of migratory corridors of large mammals (wolf, lynx and bear) in Đerdap National Park, established a geodatabase and defined the Strategy on the Identification, Preservation, and Management of Ecological Corridors.

This paper presents the outcomes of the ConnectGREEN project, with emphasis on the application of the newly developed methodology in Serbia. It aims to clarify the conceptual distinction between green infrastructure and ecological corridors, and to offer planning recommendations that can enhance ecological connectivity, mitigate habitat fragmentation, and support sustainable spatial development across the region.

Application of the proposed methodological approach along with the set of measures (including reducing habitat fragmentation and constructing green overpasses/bridges that facilitate the safe movement of animals) will provide new insight into existing practice in infrastructure planning. These efforts will contribute to sustainable development while supporting biodiversity conservation.

This paper will present results of the project and give strategical guidance for future steps in infrastructure planning towards better protection of endangered species in Serbia.

## **Theoretical and strategical background**

The strategic importance of integrating ecological connectivity into spatial and infrastructure planning has been increasingly recognized across Europe in response to growing habitat and landscape fragmentation. The European Union’s policy framework strongly emphasizes the need to preserve, restore, and enhance functional ecological networks, especially through the protection and planning of ecological corridors. While the EU Green Infrastructure Strategy ([EC, 2013a](#)) provides a general framework for embedding nature-based solutions into land use systems, the implementation of ecological corridors remains a challenge, particularly in areas undergoing rapid infrastructure development.

One of the primary goals of the strategy is to create a cohesive ecological network that supports biodiversity across Europe. This includes expanding the Natura 2000 network of protected areas ([EC, 2013b](#)), as well as developing new, innovative approaches to land use that prioritize the protection and restoration of natural ecosystems. Ecological corridors, such as wildlife overpasses, underpasses, and green bridges, are crucial elements of this vision. These corridors allow species to safely traverse fragmented landscapes, reducing the risk of mortality due to road traffic, while also promoting gene flow between isolated populations.

The European Commission's Green Infrastructure Strategy (EC, 2013a) promotes cross-sectoral integration, encouraging Member States to adopt green infrastructure solutions across various sectors.

Incorporating green infrastructure into transportation networks, for example, can help to reduce habitat fragmentation caused by roads and railways. Creating green corridors alongside transport routes, or building wildlife passages such as tunnels or bridges, can help wildlife safely navigate through otherwise inhospitable landscapes.

This strategy aims to make the protection, restoration, creation, and enhancement of green infrastructure an integral part of spatial planning and territorial development. Its primary objective is to 'preserve, restore, and enhance green infrastructure to halt biodiversity loss and ensure ecosystems continue to provide essential services to humans.' The Green Infrastructure Strategy serves as a framework for the development of the Trans-European Network for Green Infrastructure (TEN-G) (EC, 2016).

The Natura 2000 network (EC, 2013b) forms the cornerstone of the EU's green infrastructure, aiming to ensure the long-term survival of Europe's most valuable and endangered species and habitats, as outlined in the Birds Directive (EC, 2009) and the Habitats Directive (EC, 1992). This network plays a vital role in maintaining Europe's biodiversity by linking protected areas across the continent.

Looking towards the future, one of the primary long-term goals outlined in the first draft of the Global Biodiversity Framework post-2020 (EC, 2021; UNEP, 2022) is to increase the area, connectivity, and integrity of natural ecosystems and habitats by 2050. Specific targets for 2030 include expanding the land area covered by spatial plans, preserving existing intact areas and wilderness, and revitalizing degraded ecosystems to improve their connectivity. The framework envisions that by 2030, at least 30% of the Earth's surface will be protected through a well-connected and effective system of protected areas and conservation measures.

Practical experiences from countries such as Germany, Austria, and the Netherlands have demonstrated how ecological networks and corridors can be systematically integrated into spatial planning systems. Germany has established a national biotope network supported by legal obligations for wildlife crossings; Austria has operationalized connectivity objectives through regional land use plans under the Alpine Convention; the Netherlands' *Ecologische Hoofdstructuur (EHS)* is a pioneering example of embedding ecological connectivity into national policy frameworks (Jongman & Pungetti, 2004; BfN, 2018).

All of presented strategies and policies on the EU level have common goals which are: integration and promotion of green infrastructure in various sectoral policies, such as land-use planning, planning of transport infrastructure, territorial development, agriculture, forestry, water management, and urban development. Integrating green infrastructure into these frameworks can help mitigate the impacts of urbanization and industrialization by providing natural solutions to environmental challenges, such as reducing the urban heat island effect, improving air quality, and increasing the resilience of cities to climate change, all while promoting biodiversity. Active management efforts provided within these documents will be necessary to facilitate wildlife recovery, protect species, and reduce conflicts between citizens and wildlife.

In Europe, most of these strategies are adequately implemented, although the level of implementation is not the same.

In contrast, countries in the Carpathian region face heterogeneous implementation levels. The ConnectGREEN project has documented both institutional strengths and gaps across five participating countries: Czechia, Slovakia, Hungary, Romania, and Serbia. While some have legally

(through regulations and laws) recognized ecological corridors as spatial planning elements, others rely more on ad hoc or project-based approaches (Okanikova et al., 2021).

Czechia has long-standing practice of recording ecological corridors along and adequate strategic and legislative framework as well as defined a national network of wildlife ecological corridors. That is the reason why Czechia has long tradition in building green bridges for different animal species as the part of a good practice. Hungary has also long tradition of designing green bridges for wildlife crossings and EU harmonized strategic and legislative framework, as well as national ecological network and Natura 2000 (EC, 2013b) are integrated into spatial planning systems. Slovakia on the other hand has significant conflicts between construction and nature protection, while Romania has adopted the practice of building green bridges for wildlife crossing and EU harmonized strategic and legislative framework (Okanikova et al., 2020). In Serbia, efforts to establish a national ecological network have been formalized through the Regulation on the Ecological Network (RS, 2010a), but the operationalization of ecological corridors remains limited. Sectoral fragmentation, lack of coherent spatial data, and weak intersectoral cooperation continue to hamper progress. Furthermore, while planning documents often reference green infrastructure, the concept of ecological corridors is either poorly defined or insufficiently integrated into planning instruments.

It can be observed that countries in the Carpathian region have similar challenges in managing ecological corridors and addressing habitat fragmentation for wildlife as Serbia. Each of these countries uses indicator systems to identify ecological networks and corridors, based on methodologies developed for the Natura 2000 sites and the Pan-European Ecological Network. However, there is significant variation in the indicators used across these countries, as well as in their respective levels of importance. This inconsistency is largely due to differences in national data systems and legislative frameworks, which hinder the effective systematization of data at a broader, transnational level. This disparity in data and regulatory structures presents a challenge for coordinating efforts across countries and for addressing ecological connectivity in a holistic manner (Simonović Alfrević et al., 2024). Also, an adequate strategic and legislative framework, as well as the national ecological network and Natura 2000 (EC, 2013b), should be better integrated into spatial planning systems.

## **Ecological connectivity and habitat fragmentation in Serbia: challenges and solutions for biodiversity conservation**

In Serbia, ecological connectivity is a critical but under-addressed aspect of biodiversity conservation and spatial planning. Despite the country's rich natural heritage and diversity of protected areas, habitat fragmentation continues to intensify, primarily due to unchecked urban expansion, infrastructure development, agriculture, and forestry. This type of fragmentation in Serbia refers to the process in which formerly continuous habitats are divided into isolated patches, reducing the ability of species to move, reproduce, and maintain viable populations, especially in the part of Carpathian region in Eastern Serbia. In contrast, landscape fragmentation reflects the broader disintegration of the landscape's visual, ecological, and structural cohesion (EEA & FOEN, 2011).

Key biodiversity areas in Serbia, including national parks and nature reserves, are increasingly threatened by intersecting roads, railways, and expanding settlements. Species with large territorial ranges – such as large carnivores - brown bears, wolves, and lynxes – are particularly vulnerable,

as their habitats are being reduced in size, degraded, or severed. Roadkill mortality and loss of genetic exchange between isolated populations are growing concerns. Smaller, fragmented habitats often cannot sustain viable wildlife populations, leading to local extinction.

Efforts to counteract this trend include the establishment of ecological corridors that connect fragmented habitats and support species movement. These corridors – whether riparian zones, forest strips, or engineered wildlife crossings – are essential for maintaining ecological integrity and increasing landscape permeability. The goal is to create a network of connected habitats that allows species to move freely across the landscape, improving their chances of survival and reproduction.

Moreover, Serbia is working to integrate ecological connectivity into its broader environmental and spatial planning policies. This includes efforts to link protected areas, such as national parks and nature reserves, through ecological corridors, and to promote sustainable land-use practices that reduce habitat fragmentation. The Natura 2000 network (EC, 2013b) aims to protect the most valuable natural habitats and species across Europe, including in Serbia, which has committed to aligning its conservation efforts with EU standards.

Despite these efforts, challenges remain in achieving effective habitat defragmentation. One of the major obstacles is the lack of comprehensive data on the distribution of wildlife and habitats on the whole territory of Serbia, as well as the insufficient coordination between environmental, urban, and transportation planning authorities. Furthermore, there is a need for greater public awareness and engagement in conservation efforts, as well as increased funding for habitat restoration projects.

Also, the management of ecological corridors has not been comprehensively integrated into spatial planning methodologies, nor is it adequately addressed within infrastructure corridor planning. Achieving a balance between socioeconomic growth, particularly in infrastructure development, and environmental conservation demands a coordinated approach. This approach should be based on the analysis of various data sources, including scientific research, analytical documentation, and data-driven methods, combined with responsible spatial planning that accounts for the long-term environmental impacts on a larger scale.

At the national level, Serbia lacks a systematic identification of ecological corridor networks. The Emerald (COE, 2022) and Natura 2000 networks (EC, 2013b) are recognized as isolated areas rather than as interconnected corridor systems. The framework for establishing an ecological network in Serbia is defined by the Regulation on the Ecological Network (RS, 2010a).

Between 2009 and 2012, an ecological network was developed and mapped across the territory of Autonomous Province Vojvodina (northern part of Serbia), and this information is available on the website of the Provincial Institute for Nature Protection. This mapping allowed for the identification of key elements of the network in Vojvodina and facilitated its integration into spatial plans at both the regional and local levels. This integration aids in the formulation of spatial development goals that balance the protection of natural resources with the growth of settlements and infrastructure.

However, these efforts have not been extended to the rest of the country. While some progress has been made in identifying ecological corridors, detailed mapping and comprehensive identification of these networks have not been completed. The absence of clear obligations to define and protect ecological corridors contributes to the further degradation of existing corridors, which raises the costs of future restoration efforts. This, in turn, leads to irreversible genetic and landscape changes, making it difficult to restore these corridors for future generations.

Current legal frameworks remain partially operational, with unresolved legal ambiguities. Furthermore, supporting strategic documents such as action plans and strategies remain insufficiently implemented. The lack of effective law enforcement is further intensified by conflicts arising from activities in other sectors like forestry, agriculture, and water management, all of which have significant impacts on landscape structure. To address these issues, Serbia needs to align sectoral legislation with international agreements, such as the Bern Convention (COE, 2021) and the EU's Habitats Directive (EC, 1992).

Despite adopting several laws and regulations in line with the Carpathian Convention, Serbia has not fully embraced its recommendations. A significant gap is the failure to properly identify, assess, and protect ecological networks at the national level, a process which should be incorporated into national policies and strategies for nature and biodiversity conservation. Only two national strategies reference ecological networks: the Biodiversity Strategy of the Republic of Serbia (2011-2018-outdated) and the National Strategy for Sustainable Use of Natural Resources (2012-outdated), alongside the Nature Protection Program (2021-2023-outdated). However, none of these documents offer detailed guidance on integrating ecological networks into other sectors, beyond nature conservation. Also, another key constraint is in the lack of consistent data and monitoring especially outside major protected areas. Although some monitoring exists for flagship species such as large carnivores, it is fragmented and not systematically linked to planning tools. Additionally, financial resources and technical expertise remain limited.

In Serbia, the identification of ecological networks is based on the identification of critical animal habitats (especially for species like bears, lynxes and wolves) and the recognition of human-altered landscape features (such as shelters, canals, and embankments) that function as habitats or ecological corridors. The presence of human-made barriers, including infrastructure corridors, as well as settlements, fences, etc. is also taken into account. The quality of ecological networks is primarily measured by the diversity and structural variety of habitats and corridors, the presence of protected species, and the temporal and spatial permanence of the network elements in the landscape.

The main obstacles to properly identifying ecological corridors are a lack of comprehensive data on wildlife populations, including habitat maps and sectoral plans, insufficient financial support, a shortage of expert personnel, and a failure to implement previously outlined measures from legislative and strategic frameworks. Since ecological corridors are not well-defined, they are often overlooked as constraints in development planning documents.

While there is some monitoring of animal habitats (especially for species like brown bears, wolves, and Eurasian lynx), this monitoring is not continuous or conducted nationwide. Given these gaps in scientific research and practical approaches to defining ecological corridors, it is essential to establish a methodology for identifying wildlife corridors, which would contribute to the conservation of species and reduce wildlife mortality rates caused by poorly designed transportation infrastructure. The reduction of wildlife populations often results from habitat fragmentation due to infrastructure projects that do not take ecological corridors into account.

To move forward, Serbia must establish a coherent, nationwide ecological network, supported by huge databases with spatial data and other statistical data, cross-sectoral cooperation, and legal enforcement. The integration of ecological connectivity into planning instruments must become a binding criterion for infrastructure development and decisions in spatial and planning of transport infrastructure. In this regard, the ConnectGREEN project has provided a valuable framework for identifying corridors, assessing barriers, and proposing realistic mitigation measures based on ecological modeling and participatory validation. These efforts now need to be pushed into national and regional planning practice.



## Inovative methodology in planning infrastructure corridors

In the context of Serbia, ensuring the continuity and integrity of ecological corridors is key to addressing the pressing issue of habitat fragmentation (Simonović Alfrević et al., 2024). As urbanization and infrastructure development accelerate, especially in terms of construction new highways, many natural habitats are divided, severely compromising the biodiversity of the region. The implementation of ecological corridors as part of new methodology in spatial planning is one effective strategy to mitigate these issues, connecting fragmented habitats and reducing barriers to wildlife movement. These corridors are essential for safeguarding ecological integrity and for ensuring the long-term sustainability of natural resources, which benefit both wildlife and human populations alike.

However, the successful implementation of these ambitious goals in faces numerous challenges. Habitat fragmentation continues to increase, intensifying the decline in biodiversity, and reducing the effectiveness of existing protected areas.

The situation is particularly urgent in regions like the Serbian part of Carpathian Mountains, where the construction of infrastructure corridors within nature protected areas has led to the isolation of wildlife populations.

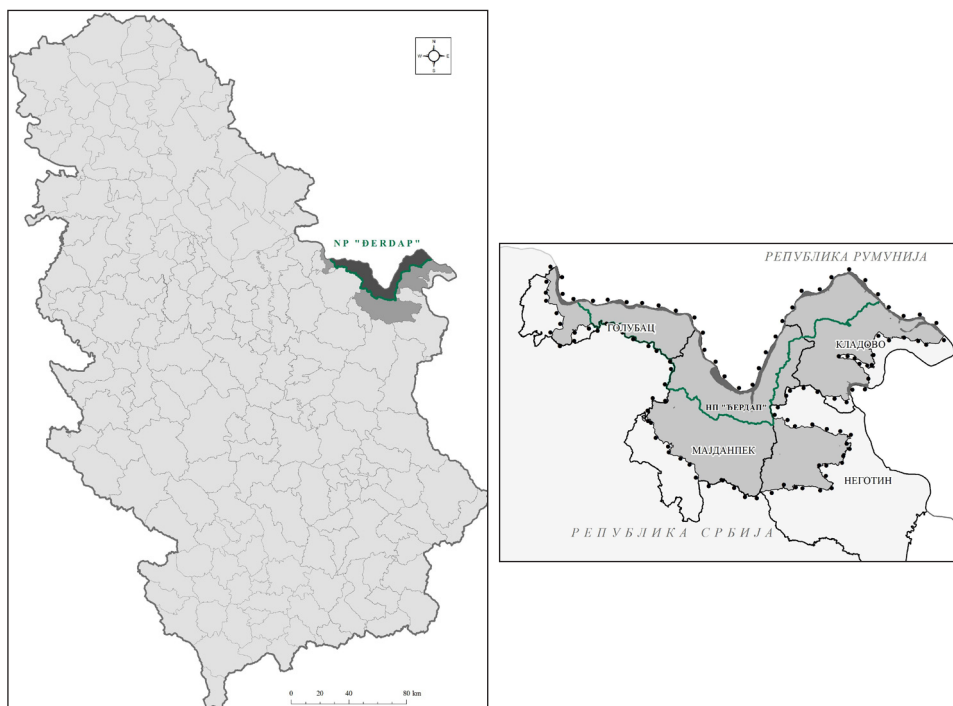
One significant initiative addressing these issues is the INTERREG DTP2 ConnectGREEN project, a collaborative effort involving countries from the Carpathian region, including Serbia, Romania, Slovakia, Hungary, and Czechia. The project focuses on restoring and managing ecological corridors in mountain areas of the Danube Basin. The project developed a Methodology for identifying ecological corridors in the Carpathian countries by using large carnivores such as the Eurasian lynx, grey wolf, and brown bear as umbrella species (with possibility of extension on red deer in future elaboration) (Okankova et al., 2021; Vlkova et al., 2023). These species are highly sensitive to habitat fragmentation, making them ideal for measuring the effectiveness of ecological corridors. Beside newly proposed methodology, the project also introduced practical Guidelines on how to use spatial planning tools in Integrative Management of Ecological corridors and Recommendations developed together with spatial planners to avoid/minimize fragmentation of ecological corridors caused by the new infrastructure pathways in protected areas and created the CCIBIS database – Carpathian Countries Integrated Biodiversity Information System (CCIBIS, 2025), an information system for biodiversity in the Carpathian region.

The work carried out under the ConnectGREEN project emphasizes the importance of cross-border cooperation in addressing ecological fragmentation.

In Serbia, the project involved the Institute for Architecture and Urban&Spatial Planning of Serbia and Đerdap national park (Fig. 1), which developed a methodology for identifying and mapping ecological corridors in Serbian part of Carpathian region. Institute of Architecture and Urban&Spatial Planning of Serbia was in charge for defining existing and planned infrastructure corridors within the area of the Đerdap national park that can cause serious habitat defragmentation and also breaking of the existing ecological corridors.

This methodology helped to identify wildlife migration corridors and recognize migration barriers, such as roads and other infrastructure. It also provides recommendations for mitigating these barriers, including the construction of wildlife crossings like eco-ducts or green bridges, measures to prevent animals from entering transportation corridors, and strategies to alert drivers of animal movement.





**Figure 1.** Position of National Park Đerdap in Serbia

Source: authors and the Spatial Plan for the Special Purpose Area of Đerdap National Park (RS, 2022).

The methodology also defines a series of measures to reduce barriers and wildlife mortality: measures for safe infrastructure crossings (eco-ducts/green bridges) in Serbia, measures to prevent animals from entering infrastructure corridors, measures to warn animals of transport infrastructure, and measures to alert drivers to the approach of animals or risky sectors. Increased fragmentation is caused by the growing number of migration barriers. Migration barriers are one of the main topics when determining wildlife corridors and migratory routes. The large number of barrier types and their diverse impacts on ecological connectivity often hinder the consideration of all possible variations in the field and prevent the identification of simple solutions with general application methods.

The methodology was developed in multiple phases, which involved including various stakeholders and interest groups in the decision-making process. To collect the base data for the green corridors issue in Serbia, three national workshops were organized through the project, with the active participation of over 50 participants – representatives from ministries, local governments, public enterprises, institutes, scientific institutions, interest groups, and non-governmental organizations. The workshops aimed to facilitate expert exchanges of views in the fields of nature protection, infrastructure planning, and spatial planning through a participatory planning process. These conclusions were intended to serve as input for the draft Carpathian methodology for identifying key areas and ecological corridors in Serbia used by large carnivores.

Based on the inputs provided, a document titled ‘Strategy for the Identification, Conservation, and Management of Ecological Corridors in the Carpathian Countries’ was created, along with ‘Guidelines for the Use of Planning Tools in Integrative Management of Ecological Corridors’ and Decision-Support Tools (DST). Additionally, several different documents were developed: Database and Maps of Significant Areas and Ecological Corridors of Large Carnivores of Transnational Importance in the Carpathian Ecoregion - Carpathian Countries Integrated Biodiversity Information System (CCIBIS, 2025) and an International Action Plan on conservation of large carnivores and ensuring ecological connectivity in Carpathians (and in Đerdap National Park). All these documents, which resulted from participatory planning, have been published as publications or distributed online.

The results of the analysis served as the basis for defining the content of the methodology and modeling ecological connectivity. The methodology was implemented through several phases of ecological connectivity modeling (Fig. 2).

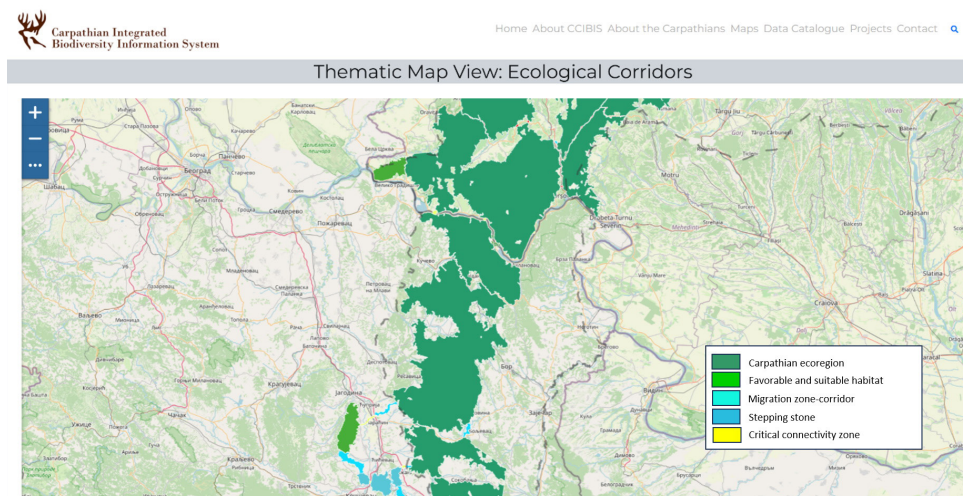
A. CARPATHIAN LEVEL	
1. HABITAT SUITABILITY MODELING	
1.	Data collection and preparation for input
2.	Development of the habitat suitability model
3.	Definition of favorable habitats attached to primary habitats and other favorable habitats
4.	Expert discussion/check of the favorable habitat layer by national and local experts and finalization of the model
2. CONNECTIVITY MODELING	
1.	Preparation of resistance surface model, including barriers
2.	Modeling connectivity – corridor network (and connecting zones, stepping stones)
3.	Expert discussion/check/completion of the connectivity model (by national and local experts) and finalization of the model
3. CRITICAL ZONES	
1.	Identification of barriers and critical zones
2.	Expert discussion/check of critical zones, adoption, and integration of verified critical zones into the model
4. DEFINITION OF ECOLOGICAL NETWORK FOR LARGE CARNIVORES	
3.	Synthesis of separate results – proposal for the ecological network map for large carnivores
4.	Expert discussion/check of the proposed ecological network map for large carnivores – national and local experts
5.	Finalization of the ecological network map for large carnivores in the Carpathians
B. PILOT AREA LEVEL	
6.	Desktop (laboratory) verification of corridors and critical zones
7.	Field verification
8.	Finalization of the ecological network model for the pilot areas

**Figure 2.** Phases of ecological connectivity modeling  
Source: authors own elaboration.

International experiences served as a basis for comparing the results of the research conducted in the Republic of Serbia and enabled direct application at the pilot area level of the Đerdap National Park. All the mentioned phases were followed by expert discussions and reviews, in which has participated large number of experts from the fields of spatial and infrastructure planning and nature conservation, both from the country and abroad.

After the synthesis of the results was completed, work began on creating the ecological network map for large carnivores in the Đerdap National Park area, based on detailed field research. The mapped areas of large mammal habitats, as well as ecological corridors, were also integrated

into the CCIBIS portal . Also CCIBIS maps have taken into account the existing and planned roads and other infrastructure barriers that needs to be overcome on the Serbian part of Carpathian region (Fig. 3).



**Figure 3.** Modelled ecological corridors and critical zones in Đerdap National Park, based on habitat suitability, resistance, and connectivity analysis within the ConnectGREEN project  
Source: CCIBIS (2025).

Figure 3 presents the final result of the corridor identification and modeling process conducted within the Đerdap National Park. The map reflects the cumulative outcome of the multi-step methodology applied in the ConnectGREEN project, including:

1. habitat suitability analysis,
2. resistance surface modeling based on anthropogenic and natural barriers, and
3. connectivity modeling verified through expert discussion and fieldwork.

The visualized ecological corridors and critical zones were derived from the integration of spatial data and expert knowledge collected during the three national workshops in Serbia. In particular, the map highlights the spatial conflicts between ecological corridors and existing/planned infrastructure (e.g. state road IV category, tourist development zones), and served as a basis for proposing mitigation measures such as wildlife crossings and buffer zones. As such, the figure is not merely illustrative but instrumental in demonstrating how the methodology was translated into planning decisions and regulatory provisions adopted in the Spatial Plan for the Special Purpose Area of Đerdap National Park (RS, 2022).

The maps were created based on the availability of occurrence data, ecological variable data, data collection on the occurrence of individuals, barrier inventory (railways, roads, fences, watercourses, deforested areas, and built-up areas) in corridors and critical zones (which were conducted through field research in the Đerdap National Park during 2020, 2021, and 2022). Based on these databases, critical zones were assessed, and corridors and actual migratory paths used by animals were defined.

This research served as the basis for defining guidelines and measures to ensure connectivity and reduce the barrier effect, which include:

- A. Measures that enable and facilitate safe passage across infrastructure (wildlife crossings).
  - B. Measures to prevent animal mortality and human casualties:
1. Measures that prevent animals from entering infrastructure,
  2. Measures that alert animals to transport infrastructure or approaching vehicles,
  3. Measures that warn drivers of approaching animals or of sections with a collision risk (warning signs, speed limits, animal detection warning systems).

The implementation of all these measures can drastically reduce the mortality rate of animal species in a given area.

All of these measures were implemented not only in the final version of the Spatial plan of the special purpose area of Đerdap National Park (RS, 2022), but also in the different documents on the local and regional level in Serbia (detailed regulation plans, general regulation plans, general urbanistic plans, and other documents that have the occurrence of possible habitat fragmentation due to construction of the road infrastructure).

The methodology was tested in Serbia on the Đerdap National Park area but can also be applied to protected areas all over Serbia (Favilli et al., 2013). The methodology may require adjustments due to the occurrence of different species with specific characteristics, but the guidelines for modeling ecological connectivity can be adapted. Thus, this methodological approach can be applied not only to other areas with the dispersion of observed species (wolf, lynx, bear) but also in cases of other animal species.

After the methodology was developed, experts defined guidelines for its application in planning documents in Serbia.

Based on the analyzed issues, the application of the Methodology for Identifying Ecological Corridors for Large Mammals in the Carpathian Countries and the results of its application in the pilot area of the Đerdap National Park, it was possible to identify preserved and endangered existing ecological corridors and their spatial conflicts with existing construction areas of tourist complexes and settlements. In the next methodological step, planners have proposed alternative solutions for the preservation and reconstruction of existing corridors and the creation of new ecological corridors in relation to other uses in the protected area. All proposed alternative solutions involved the same locations for the animal crossings over the state road.

A participatory approach was necessary in order to achieve coordination and address existing and potential conflicts, which involved key stakeholders in nature protection, tourism, and spatial planning at both national and local management levels. After several iterations, planners selected a compromise solution to reconcile the planned development with the preservation of existing ecological corridors and the formation of several new ones, while limiting the expansion of construction areas for tourist complexes and settlements in relation to the designated corridors. The chosen planning solution enabled the adequate protection and improvement of ecological corridors and strengthened their role in connecting Đerdap National Park with protected areas of natural values in the surrounding area – the Homolje Mountains in Serbia and the Portile de Fier Nature Park in Romania.

In addition to this planning document, the methodology was applied in the form of conditions defined through the Rules for Planning and Construction for Public Areas and integrated into Spatial Plans for Special Purpose Areas (SPSPA) and Detailed Regulation Plans (DRP), four of which have been adopted, in accordance with the Regulation on Special Technical and Technological Solutions that allow for the unhindered and safe communication of wildlife (RS, 2010b).

Considering the fact that Serbia has this regulation that enable unhindered and safe communication of wildlife whose application is currently insufficient and inadequate, the proposed methodological approach could serve as input for updating this document.

This would significantly improve planning practices regarding transportation infrastructure planning in line with nature protection requirements.

## Conclusion

Based on the Methodology for Identifying Ecological Corridors for Large Mammals in the Carpathian Countries, and its implementation in the pilot area of Đerdap National Park, it was possible to identify preserved and endangered ecological corridors within the Spatial Plan for Special Purpose of Đerdap National Park (RS, 2022). This included conflicts with existing construction areas for tourist complexes and settlements, as well as with the Category IV state road that runs longitudinally through the entire protected area.

Despite the progress made in this project, there remains a need for comprehensive national strategies to ensure the continued development of ecological corridors in Serbia and across the countries of Carpathian region. Effective management and monitoring systems must be put in place to track the health of these corridors and to ensure that they function as intended. This includes further integrating ecological considerations into spatial and infrastructure planning and aligning national legislation with international environmental agreements, such as the Bern Convention and the EU Habitats Directive.

In conclusion, ecological corridors represent a critical tool in the fight against habitat fragmentation. Through effective planning, cross-border cooperation, and the implementation of nature-based solutions, it is possible to enhance ecological connectivity, protect biodiversity, and support the sustainable development of both human and wildlife populations. However, this requires ongoing commitment and action at the national and international levels, ensuring that ecological corridors are not just preserved but actively integrated into the landscape for the benefit of all species.

Ecological connectivity and habitat de-fragmentation are vital for ensuring the long-term survival of Serbia's biodiversity. Continued efforts are needed to strengthen ecological corridors, improve habitat restoration initiatives, and integrate conservation priorities into national policies and planning frameworks. By addressing habitat fragmentation, Serbia can safeguard its natural heritage and contribute to broader efforts to protect biodiversity in Europe.

That is the reason why Institute of Architecture and Urban&Spatial Planning of Serbia, along with several different infrastructure planning institutions are trying to define guidelines and measures for overcoming problems in potential habitat defragmentation caused by the construction of new infrastructure corridors – main and regional roads, highways and railways in Serbia. This approach to integrating new planning practices into established design methodologies may promote broader and more impactful implementation, while also facilitating the expedited adoption of strategic frameworks that institutionalize such practices as standard requirements.

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## References

- Bennet, A. (2003). Linkages in landscape – The role of corridors and connectivity in wildlife conservation. Conserving Forest Ecosystems Series, 1. IUCN Forest Conservation Programme.
- Bennett, G., & Mulongoy, K. J. (2006). Review of experience with ecological networks, corridors and buffer zones. Technical Series, 23. CBD Secretariat.
- BfN. (2018). Green Infrastructure in Germany: Planning and Implementation. Bonn: Bundesamt für Naturschutz. Retrieved from <https://www.bfn.de/en/publications/green-infrastructure-germany>
- Brooks, C. (2003). A scalar analysis of landscape connectivity. University of North Carolina at Chapel Hill.
- Carpathian Convention (2003). Framework Convention on the Protection and Sustainable Development of the Carpathians. Retrieved from [http://www.carpathianconvention.org/tl\\_files/carpathiancon/Downloads/01%20The%20Convention/1.1.1.1\\_CarpathianConvention.pdf](http://www.carpathianconvention.org/tl_files/carpathiancon/Downloads/01%20The%20Convention/1.1.1.1_CarpathianConvention.pdf)
- CBD (2006). Review of experience with ecological networks, corridors and buffer zones. Secretariat of the Convention on Biological Diversity. Retrieved from <https://www.cbd.int/doc/publications/cbd-ts-23.pdf>
- CCIBIS (2025). Thematic map view: Ecological corridors. Carpathian Integrated Biodiversity Information System. Retrieved from <https://ccibis.org/thematic-map-01-2-3/>
- COE (2010). Guidelines for the development of the Pan-European Ecological Network. Strasbourg: Council of Europe.
- COE (2021). Vision for the Bern Convention for the period to 2030. Convention on the Conservation of European Wildlife and Natural Habitats. Standing Committee, Council of Europe. Retrieved from <https://rm.coe.int/tpvs14e-2021-vision-final/1680ada0f0>
- COE (2022). The Emerald Network – A Pan-European ecological network for nature conservation. Council of Europe. Retrieved from <https://www.coe.int/en/web/bern-convention/emerald-network>
- Debinski, D. M., & Holt, R. D. (2000). A survey and overview of habitat fragmentation experiments. *Conservation Biology*, 14(2), 342–355. <https://doi.org/10.1046/j.1523-1739.2000.98081.x>
- EC & Trinomics (2016). Supporting the implementation of green infrastructure – Final report. European Commission: Directorate-General for Environment and Trinomics B.V. <https://data.europa.eu/doi/10.2779/781371>
- EC (1992). EU Habitats Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora. European Commission. Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TX/?uri=CELEX%3A01992L0043-20130701>
- EC (2009). EU Birds Directive 2009/147/EC on the conservation of wild birds. European Commission. Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009L0147>
- EC (2013a). Green Infrastructure — Enhancing Europe's Natural Capital. European Commission. Retrieved from [https://environment.ec.europa.eu/topics/nature-and-biodiversity/green-infrastructure\\_en](https://environment.ec.europa.eu/topics/nature-and-biodiversity/green-infrastructure_en)
- EC (2013b). Natura 2000 – Managing sites and networks for nature conservation in Europe. European Commission. Retrieved from [https://environment.ec.europa.eu/topics/nature-and-biodiversity/natura-2000\\_en](https://environment.ec.europa.eu/topics/nature-and-biodiversity/natura-2000_en)



- EC (2020). EU Biodiversity Strategy for 2030. European Commission. Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/DOC/?uri=CELEX:52020DC0380>
- EC (2021). The First draft of the Global Biodiversity Framework post-2020. European Commission. Retrieved from [https://knowledge4policy.ec.europa.eu/publication/first-draft-post-2020-global-biodiversity-framework\\_en](https://knowledge4policy.ec.europa.eu/publication/first-draft-post-2020-global-biodiversity-framework_en)
- EEA & FOEN (2011). Landscape fragmentation in Europe. EEA Report, 2/2011. Copenhagen: European Environment Agency & Swiss Federal Office for the Environment.
- Favilli, F., Hoffmann, C., Ravazzoli, E., & Streifeneder, T. (2013). *Advanced tools and methodologies adopted GIS Model Design for deriving ecological corridors*. Bolzano: European Academy of Bolzano.
- Hilty, A., & Jodi, L. W. (2006). *Corridor ecology: The science and practice of linking landscapes for biodiversity conservation*. Berkeley: Island Press.
- Hilty, J. A., Lidicker, W. Z., & Merenlender, A. M. (2006). *Corridor ecology: The science and practice of linking landscapes for biodiversity conservation*. Washington, DC: Island Press.
- Hilty, J., Worboys, G. L., Keeley, A., Woodley, S., Lausche, B., Locke, H., Carr, M., Pulsford, I., Pittcock, J., White, J. W., Theobald, D. M., Levine, J., Reuling, M., Watson, J. E. M., Ament, R., & Tabor, G. M. (2020). Guidelines for conserving connectivity through ecological networks and corridors. Best Practice Protected Area Guidelines Series, 30. Gland: IUCN.
- Hlaváč, V., Anděl, P., Matoušová, J., Dostál, I., Strnad, M., Immerová, B., Kadlečík, J., Meyer, H., Moť, R., Pavelko, A., Hahn, E., & Georgiadis, L. (2019). Wildlife and traffic in the Carpathians: Guidelines how to minimize impact of transport infrastructure development on nature in the Carpathian countries. Danube Transnational Programme TRANSGREEN Project. The State Nature Conservancy of the Slovak Republic.
- Jongman, R. H. G., & Pungetti, G. (2004). *Ecological networks and greenways: Concept, design, implementation*. Cambridge: Cambridge University Press.
- Jongman, R. H. G., Külvik, M., & Kristiansen, I. (2004). European ecological networks and greenways. *Landscape and Urban Planning*, 68(2–3), 305–319. [https://doi.org/10.1016/S0169-2046\(03\)00163-4](https://doi.org/10.1016/S0169-2046(03)00163-4)
- Iuell, B., Bekker, G.J., Cuperus, R., Dufek, J., Fry, G., Hick, C., Hlaváč, V., Keller, V., Rosell, C., Sangwine, T., Torslov, N., & Wandall, B. (2003). *Wildlife and Traffic. A European Handbook for Identifying Conflicts and Designing Solutions*. KNNV Publishers.
- Kohler, Y., & Plassmann, G. (2006). Alpine ecological network: A common vision. CIPRA & WWF.
- Linnell, J. D. C., Salvatori, V., & Boitani, L. (2007). Guidelines for population level management plans for large carnivores. LCIE and Istituto Ecologia Applicata.
- Okanikova, Z., Romportl, D., Kluchova, A., Hlaváč, V., Strnad, M., Vlkova, K., Janak, M., Kadlecik, J., Zyka, V., Remus-Papp, C., & Nenkovic Riznic, M. (2021). Methodology for identification of ecological corridors in the Carpathian countries by using large carnivores as umbrella species. ConnectGREEN Project – Danube Transnational Programme.
- RS (2010a). The Regulation on the Ecological Network. Government of the Republic of Serbia, Official Gazette of RS, 102/2010. Retrieved from [http://demo.paragraf.rs/demo/combined/Old/t/t2011\\_01/t01\\_0149.htm](http://demo.paragraf.rs/demo/combined/Old/t/t2011_01/t01_0149.htm)
- RS (2010b). Regulation on Special Technical and Technological Solutions that allow for the unhindered and safe communication of wildlife. Government of the Republic of Serbia, Official Gazette of RS, 72/10. Retrieved from [http://demo.paragraf.rs/demo/combined/Old/t/t2010\\_10/t10\\_0092.htm](http://demo.paragraf.rs/demo/combined/Old/t/t2010_10/t10_0092.htm)
- RS (2022). Decree on establishing the Spatial plan for the special purpose area of the “Đerdap” National Park. Government of the Republic of Serbia, Official Gazette of the Republic of Serbia, 117/2022. Retrieved from [http://demo.paragraf.rs/demo/combined/Old/t/t2022\\_10/SG\\_117\\_2022\\_001.htm](http://demo.paragraf.rs/demo/combined/Old/t/t2022_10/SG_117_2022_001.htm)
- Simonović Alfrević, S., Nenkovic Riznić, M., Brankov, B., & Stojković, M. (2024). ConnectGREEN Project and the future of planning infrastructure corridors. IRASA International Scientific Conference SETI VI 2024. Conference proceedings (pp. 87–99).
- Spanowicz, G. A., & Jaeger, J. A. G. (2019). Measuring landscape connectivity: On the importance of within-patch connectivity. *Landscape Ecology*, 34(5). <https://doi.org/10.1007/s10980-019-00881-0>



UNEP (2022). Post-2020 Global Biodiversity Framework. United Nations Environment Programme. Retrieved from <https://www.cbd.int/doc/c/409e/19ae/369752b245f05e88f760aeb3/wg2020-05-l-02-en.pdf>

Vlkova, K., Zyka, V., Remus-Papp, C., & Romportl, D. (2023). An ecological network for large carnivores as a key tool for protecting landscape connectivity in the Carpathians. *Journal of Maps*, 20(1), 2290858. <https://doi.org/10.1080/17445647.2023.2290858>

