COSTS OF MAINTAINING ECOLOGICAL CORRIDORS FOR WILDLIFE AFFECTED BY A LARGE INFRASTRUCTURE PROJECT: CASE STUDY ON THE CRAIOVA – TÂRGU JIU MOTORWAY

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Abstract
One of the main types of impacts generated by transport infrastructure is the fragmentation of habitats and ecological corridors. This impact can be addressed through the proposal of certain impact mitigation measures, for improving the proposed projects. This paper examines the costs associated with maintaining ecological corridors for wildlife affected by a large infrastructure project, specifically the Craiova – Târgu Jiu motorway in Romania. The analysis comprises a case study on the permeability characteristics of the proposed motorway, considering specific parameters. The findings highlight the sectors of the project where permeability criteria are not met, and where wildlife is unlikely to be able to pass freely from one side of the motorway to the other. The paper proposes several types of potential impact mitigation measures, aimed at addressing this impact, and provides a financial estimation for the implementation of these measures. The study emphasizes the significance of integrating environmental measures into infrastructure development to minimize the impact on wildlife and ensure the long-term viability of ecosystems.

Keywords: *ecological corridors, infrastructure, permeability, road ecology, fragmentation, environmental cost*
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Introduction

According to Taylor et al. (1993), ecological connectivity is a vital characteristic of a landscape that determines the extent to which wildlife can move and engage in essential biological activities such as feeding and mating.

Ensuring the preservation or restoration of ecological corridors and the conservation of ecological connectivity is crucial for the long-term protection of biodiversity, particularly in the face of climate change and its associated challenges (Hilty et al. 2020).

One of the most important leading causes of global biodiversity loss is habitat fragmentation (Hilty et al. 2020). This is also one of the main types of impacts generated by the construction of new transport infrastructure, such as motorways and railways.

In the past, conservation efforts primarily focused on creating and safeguarding designated natural areas such as "National Parks" and "Nature Reserves." However, it has been observed over the years that even within these protected areas, there is a risk of extinction due to isolation and limited genetic exchange among populations (Hilty et al., 2020). This realization has underscored the importance of establishing and maintaining movement corridors, known as ecological corridors, to facilitate genetic exchange and ensure the long-term viability of metapopulations.

At the European level, there is a strong emphasis on identifying key areas for ecological connectivity to preserve and restore green infrastructure (a system of planning which aims at maximizing ecosystem services and at enhancing biodiversity) amidst the development of built infrastructure. The integration of ecological corridors within the Natura 2000 network

by the end of 2023 is a requirement outlined in the EU Biodiversity Strategy for 2030, with the aim of connecting separate protected areas into a unified network (European Commission, 2020).
The expansion of linear infrastructure remains a significant concern, particularly in Eastern Europe, where countries have a lower amount of motorway infrastructure compared to Western Europe. Countries such as Montenegro, Albania, Kosovo, Bosnia and Herzegovina, Cyprus, and North Macedonia have the lowest levels of motorway infrastructure development. Romania is slightly higher in the ranking for motorway length, but it is still in the lower half of the list, with 931 km of motorways. In comparison, countries such as the Netherlands, for a much smaller surface, has 2,790 km of motorways, while countries such as France or Germany, of comparable size to Romania, have more than 10,000 km of motorways (EUROSTAT, 2023).
The development of transport infrastructure is one of the key investment targets of Romania, as planned in the General Transport Master Plan, issued in 2016. The need for safe and rapid transport is evident, in the context of national economic growth, as it allows for faster and better exchanges of goods and services (Romanian Government, 2023).
However, one of the challenges of infrastructure development in Romania, apart from the technical issues related to the difficulty of the terrain in mountainous areas, is that Romania still houses many areas with high natural values, especially in the mountains, as well as continuous natural landscapes, that allow for the free range of wildlife, especially large mammals.
In the context of the need for infrastructure development and of the requirements for nature protection, there is a need for identifying impact avoidance and mitigation measures that can allow for this development, while having the lowest possible impact on biodiversity.
This paper analyses the permeability of a proposed motorway in the context of the necessary requirements for different types of wildlife and provides an estimation of the costs required for mitigation measures, in order to ensure that the project contributes to the maintenance of ecological connectivity in Romania.

1. Literature review

The topic of infrastructure permeability is not a very old or a very well-studied one. The available resources such as the Web of Science database indicate only 45 results related to *infrastructure permeability wildlife,* 12 results for *motorway permeability wildlife,* 74 results related to *highway permeability wildlife* and 169 results for the more general search of *road permeability wildlife.*
A bibliometric analysis was done using the Web of Science database. In order to ensure more data, and as the terms mentioned above are generally similar and usually used interchangeably, the analysis was done on aggregated results for all of these phrasing combinations.
The analysis indicates that the main key terms in relation to infrastructure permeability for wildlife are related to conservation, and in particular to mammals. A view of the results as mapped for the period 2012-2018 indicates that in more recent years, there was a shift in preoccupations, from a more focused approach (such as a focus on *roads, crossing structures, habitats, populations*) to a more integrated, landscape level approach (such as *movement ecology, landscape permeability, habitat selection, behaviour, movement* or *flow*).

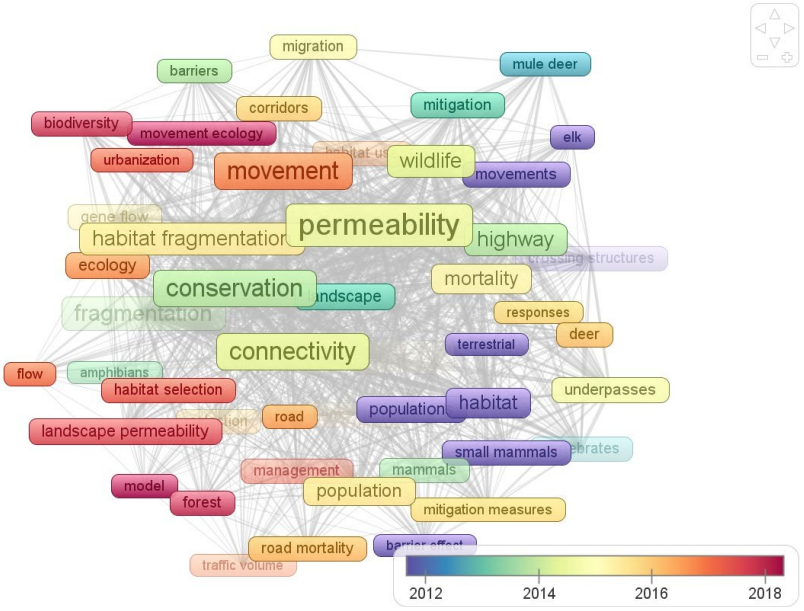

Figure 1. Clusters of the main keywords related to the available literature
Source: VoS Viewer, Web of Science

An analysis of the types of animals studied in the available resources indicates that the research is dominated by mammals, especially large mammals, both herbivores and carnivores. A small attention is given to amphibians and, in one case, to *Pipistrellus pipistrellus*, a species of bat.

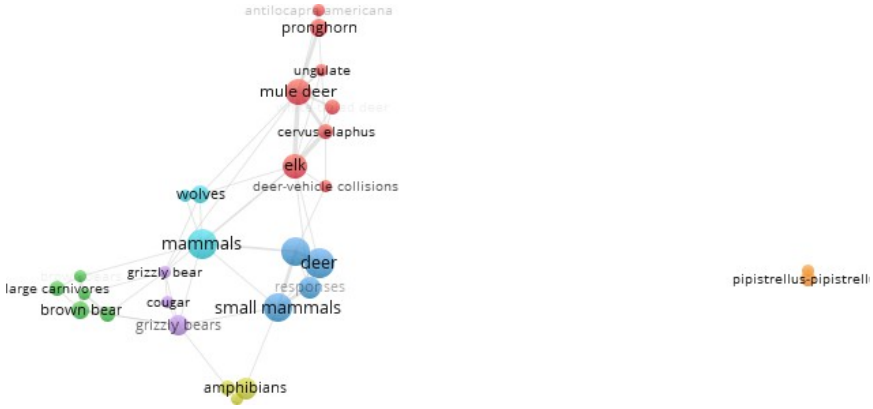

Figure 2. The types of fauna mainly studied in the available literature
Source: VoS Viewer, Web of Science

In relation to the countries and authors for these resources, most of the resources are from the USA and Canada, with smaller amount of research in Europe.

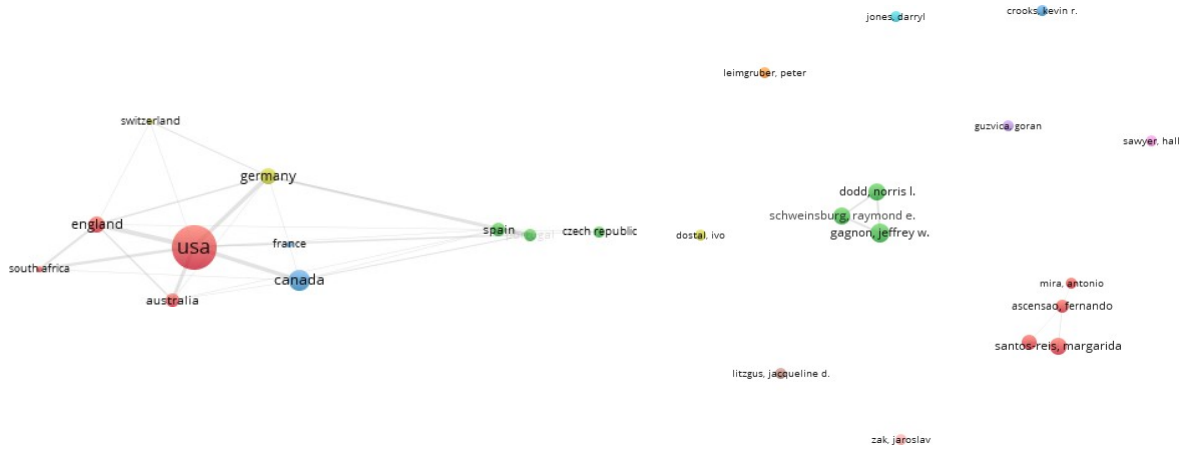

Figure 3. The main countries and authors for the available bibliographic resources
Source: VoS Viewer, Web of Science

Other important resources related to infrastructure permeability, with a focus on Europe, are represented by documents issued by the European Commission or by results of various projects implemented in the Carpathian region. These usually provide aggregated information on these topics, most of the time with quantifiable information. The most important resources from this category are represented by the COST 341 Handbook, issued by the European Commission (Iuell et al., 2003), the Wildlife and Traffic in the Carpathians Guideline (Hlavac et al., 2019), and the Thresholds for the dimension and for maximum distances of fauna passages or ecoducts and strong barriers, from 2023 (Reck et al., 2023). These resources in particular provide information relevant to the Central and Eastern European region, as well as practical information, which can be used for the fauna specific to Romania as well.

2. Methodology

The analysis of the motorway permeability was done by taking into consideration two main parameters: the openness index and the frequency of functional underpasses.

The openness index is a measure that describes the characteristics of underpasses in linear infrastructure (Hlavac et al., 2019). It can be calculated by the following formula: width X height / length, as calculated for each underpass. Utilizing this index offers several benefits: it is a well-researched attribute that can be applied to various wildlife species, and it is universally applicable to infrastructure projects regardless of their specific location. A ***Minimal*** functionality is considered for OI of over 0.1 for small mammals, over 0.7 for medium mammals and over 2 for large mammals (Hlavac et al., 2019).

Regarding the frequency of functional underpasses, the minimal distance between functional underpasses varies for different types of fauna, based on different land types and the presence of different types of pressures. The patterns of movement are not the same and they vary with the heterogeneity of the habitat. Therefore, in more sensitive areas, where fauna can move more freely, it is reasonable to require a higher frequency for permeable underpasses. So, in accordance with the information provided by Hlavac et al., 2019 and Reck et al. 2023, several classes of sensitivity were established, as shown in Table 1.

Table 1. Maximum distances between two adjacent permeable underpasses for the segment to be considered as permeable, based on different fauna categories

	Sensitivity classes				
	Very low	**Low**	**Moderate**	**High**	**Very high**
Large mammals	30 km	20 km	12 km	7 km	4 km
Medium mammals	20 km	5 km	4 km	3 km	2 km
Small mammals	2 km	1.75 km	1.5 km	1 km	1 km
Amphibians and reptiles	1 km	1 km	1 km	1 km	1 km

Source: (developed after Hlavac et al., 2019 & Reck et al., 2023)

The sensitivity classes for each analysed underpass were established based on different landscape features. Details are provided in Table 2.

Table 2. Sensitivity categories associated with each landscape feature

Sensitivity	**Landscape features**
Very low	Settlements, urbanised areas
Low	Agricultural lands, orchards, any cultivation patterns
Moderate	Meadows, pastures, abandoned agricultural lands
High	Forested areas, riparian areas, other natural ecosystems
Very high	Ecological corridors, area with high value for connectivity

The underpasses proposed for the project (bridges, viaducts and culvers) were listed in order, from the beginning of the motorway to the end. For each underpass it was determined what sensitivity corresponds to the area in which it was proposed, the Openness index was calculated and the distance to the next underpass with a ***Minimal*** level of functionality was calculated. This was done using Microsoft Excel, as well as the technical data specific to the project. The technical data consisted of: underpass start and end (as expressed in motorway kilometre), average height (in meters) and width of the motorway (in meters). The length of each underpass was calculated based on its beginning and end.
The calculation of the necessary costs for implementing permeability improvement measures was done taking into consideration other articles' estimations as well as other case studies related to these measures. Based on average costs for these measures, the information was computed and applied to the specific situation of the analysed case study.

3. Results – case study on the Craiova – Târgu Jiu proposed motorway
The results of the assessment indicate an overall good level of permeability for the motorway, with a few intervals where the conditions are not met:

- For large mammals, there is an interval between km 99+600 and 111+000, where there is no functional underpass;
- For medium sized mammals, there are four intervals without adequate underpasses, between km 5+000 – km 7+200, km 13+000 – km 19+000, km 77+000 – km 82+000 and km 98+000 – km 104+000;
- For small mammals, the motorway is impermeable in three locations: km 5+470, km 14+795 and km 101+000.

The following figure (Figure 4) shows these intervals for large mammals, medium mammals and small mammals. These areas were the target for proposed measures of defragmentation, in the form of an ecoduct and several underpasses for fauna.

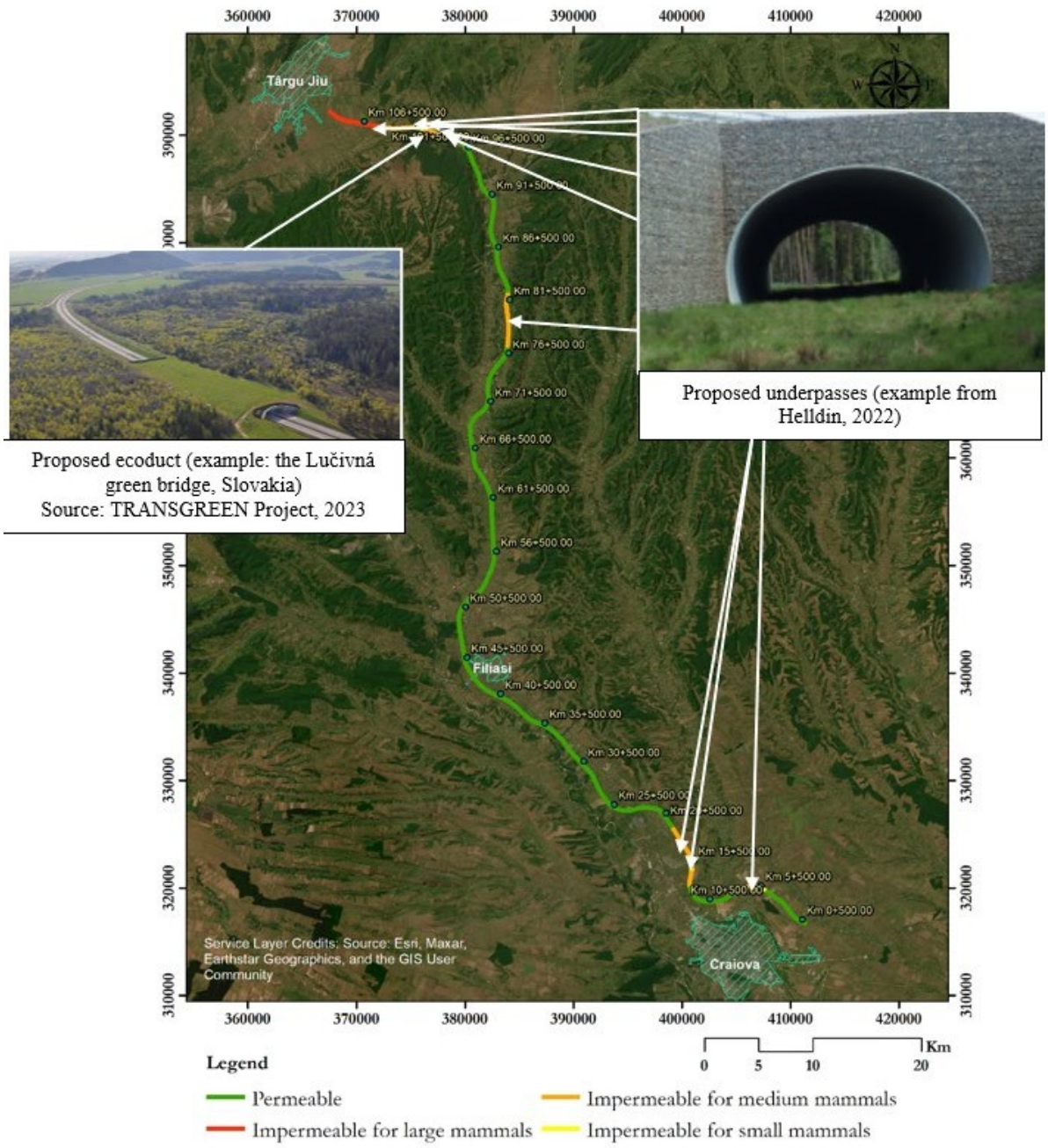

Figure 4. Permeability of the Craiova – Târgu Jiu motorway for different types of fauna

These findings impose the need for proposal of additional underpasses or overpasses, in order to allow for an improvement in the permeability of this project. Thus, to address these areas, it is proposed to implement:

- An ecoduct at km 100+000, for addressing the issue related to large mammals and to reduce the length of the interval where the motorway is not permeable;
- Underpasses of at least 40 meters in length at the following kilometres: km 5+780, km 14+754, km 15+500, km 78+150, km 100+700, km 101+500, km 102+800 and km 106+500.

For estimating the costs of these proposed measures, existing information, from other case studies was used. Thus, it was estimated that the proposed ecoduct is expected to cost around €5,000,000, based on the estimation of ecoduct costs provided by Sitjtsma et al (2020), and on the experience of building an ecoduct in Groenendaal, Belgium (Sonianforest.be, 2023). For the proposed underpasses, a cost of around €1,000,000 per underpass was estimated, based on estimation provided by Helldin (2022). In total, the proposed permeability improvement measures for this specific project are expected to total around € 13,000,000.

Conclusions

This paper intended to analyse the permeability of a proposed linear infrastructure project in Romania, the Craiova – Târgu Jiu motorway. This analysis requires specific information about the project interventions as well as information on the surrounding habitat where the project is proposed, but it is not a difficult or costly analysis. Based on several well-studied and documented parameters, such as the Openness Index and the distance between permeable underpasses, an analysis can be done to identify the sectors of the infrastructure which do not meet the required permeability criteria.

In the case of the Craiova – Târgu Jiu motorway, a particularly important area was identified in its Northern sector, where the proposed project will intersect ecological corridor areas and where, in its original configuration, the permeability requirements are not met.

Several potential connectivity improvement measures are proposed in the sectors identified as impermeable for different types of fauna. The estimated costs of these measures, based on previous experience, is around € 13,000,000.

It should be noted that the total estimated value of the project is around 1.13 million €. The measures proposed for maintaining the permeability of the motorway total around 1% of the total cost of the project. This indicates that the necessary environmental measures generally have a low cost, and do not increase unjustifiably the costs of the project, while also being able to provide extraordinary benefits for the protection of the wildlife of the area.

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