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Maintaining ecological connectivity for the conservation of large carnivores in the Carpathian Mountains, in the context of linear transport infrastructure development

SUMMARY

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Content

1. Introduction

1.1. Main impacts and causes of habitat fragmentation and loss

Over a quarter of the world's mammal species face extinction risk (Butchart et al. 2010), mainly due to habitat loss and degradation (Schipper et al. 2008), which are in fact considered to be the main causes of global biodiversity decline and loss (Rands et al. 2010; Barnosky et al. 2011; Hilty et al. 2020).

The causes of fragmentation, including of habitat loss, are multiple and include in particular the development of transport infrastructure (Trocmé et al. 2003; Jaeger et al. 2005; Morales-González et al. 2020) and other types of infrastructures (Nellemann et al. 2003; Torres et al. 2016), active land use (Foley et al. 2005), including land use changes and conversion (Newbold et al. 2015; Súľovský et al. 2017), large-scale intensive agriculture (Chappell & LaValle 2009; Žarnovičan et al. 2021), urbanisation (Delaney et al. 2010), pollution (Smith et al. 1999) and climate change (Opdam & Wascher 2004). In mountain areas, recreational activities can also have a significant negative impact (Cianga & Racasan 2015; Havlíček & Dostál 2019; Dertien et al. 2021). However, the development of linear transport infrastructure (LTI), and in particular roads, motorways and medium- and high-speed railways, are the main causes of habitat fragmentation (Trocmé et al. 2003; Geneletti 2003, 2004; Rhodes et al. 2014) and can have severe consequences for wildlife movement if specific mitigation measures are not implemented.

1.2. Overall impact of linear transport infrastructure and traffic on biodiversity

Linear infrastructure in human-dominated landscapes, specifically roads (especially motorways, expressways, but also European and national roads with heavy traffick), medium- and high-speed railways and human settlements, can be identified as the main anthropogenic barriers to wildlife and ecological connectivity at the landscape level (Andersen et al. 2017; Zeller et al. 2019).

LTI construction is a prerequisite for socio-economic development, but also entails an increase in traffic. Among the most commonly reported negative effects of LTI development are habitat loss and fragmentation, increase of edge effects on natural areas, barrier, filtering and avoidance effects, isolation of wildlife populations, wildlife collisions/road mortality, spread/dispersal of invasive plants and increased human access to natural areas (Forman & Alexander 1998; Van der Ree et al. 2015; Hlaváč et al. 2019). Negative effects of LTI typically start during construction and continue thereafter throughout the entire exploitation period.

As LTI is continuously expanding globally (Van der Ree et al. 2015; Meijer et al. 2018), including in the Carpathian ecoregion, it is particularly important to prevent negative effects of

these infrastructures on large mammals, and especially large carnivores, by identifying critical ecological corridors and proposing the most appropriate measures to maintain landscape permeability (Papp et al. 2022). For the most viable measures to avoid or reduce impacts, a transdisciplinary approach and collaboration is often needed.

1.3. Ecological connectivity, ecological network and ecological corridors: the solution to the fragmentation of large carnivores' habitats

Large carnivores are much more vulnerable than other animal groups to habitat fragmentation, given their body size, lower reproductive rates and other factors (Fisher & Owens 2004; Cardillo 2005). Large carnivore species such as the brown bear (*Ursus arctos* L.), the gray wolf (*Canis lupus* L.) or Eurasian lynx (*Lynx lynx* L.), require large territories to meet their biological and survival needs and are thus sensitive to habitat fragmentation (e.g. Noss et al. 1996; Crooks 2002; Crooks et al. 2017) caused by LTI and traffick (Forman & Alexander 1998; Trocmé et al. 2003; Fahrig & Rytwinski 2009; Morales-González et al. 2020), making it difficult to conserve these species (Noss et al. 1996) and to ensure coexistance with them, especially in human-dominated/modified landscapes (Chapron et al. 2014; Hartel et al. 2019) and especially in the absence of a favourable management and policy framework (Linnell et al. 2001).

To prevent and mitigate the effects of habitat fragmentation on large carnivores, in-depth ecological connectivity studies are needed (Loro et al. 2015; Mimet et al. 2016); their results should be integrated into spatial planning processes.

Ecological connectivity is becoming an increasingly important topic, given the context of global changes (Ament et al. 2014), and has been addressed and defined in several ways in the literature (e.g. Taylor et al. 1993; Bennett 2003; Bennett 2004; Mallarach & Marull 2006; Boitani et al. 2007; Worboys 2010). The most widely used definition today is that adopted by the Convention on the Conservation of Migratory Species of Wild Animals (CMS 2020), according to which, "ecological connectivity is the unimpeded movement of species and the flow of natural processes that sustain life on Earth".

In the Carpathian ecoregion, including Romania, ecological connectivity studies are not conducted in a unified way in the absence of an officially agreed methodology for identifying ecological corridors. Thus, the results obtained from the implementation of studies or projects aimed at identifying ecological corridors are not, or cannot be harmonised. In addition, there is no method for the official designation of ecological corridors, which may lead to their loss/interruption over time.

1.4. The importance and vulnerability of the Carpathian Mountains

Mountain areas cover only about 25% of the world's total land area, but are home to more than 85% of the planet's amphibian, bird and mammal species and, in addition, fulfil a multitude of roles for Earth's biodiversity and influence adjacent areas through biotic interchanges, changes in regional climate and nutrient runoff (Rahbek et al. 2019a, 2019b).

The Carpathian Mountains, which are spread across seven countries (Czech Republic, Hungary, Poland, Romania, Serbia, Slovakia, Ukraine), still host the highest levels of biodiversity in Europe (REC 2007), hosting three of the continent's five large carnivore species, namely the brown bear, gray wolf and Eurasian lynx (CERI 2001; UNEP 2007). Chapron et al. (2014) estimated populations of 7,200 brown bears, 3,000 wolves and 2,350 lynxes for this region.

Climate change is affecting mountain ecosystems at a much faster rate than other terrestrial ecosystems (Jacobs et al. 2021). Increases in mean temperature are also predicted for the Carpathian Mountains over the next decades (EEA 2017), including changes in the water regime (Werners et al. 2014a, 2014b), which will most likely induce changes in the habitats' structure and distribution, including in the distribution of large carnivores.

The Carpathian ecoregion is also home to more than 17 million people living in both small, remote villages and large cities (UNEP 2007), which is increasing the pressure LTI development, which creates additional fragmentation of natural habitats. In addition, changes in land use and land cover, including land abandonment (Turnock 2003; Munteanu et al. 2017) and European agricultural policies favouring the expansion of cultivated areas, pose another major threat to natural habitats (Díaz et al. 2019; Pe'er et al. 2020), and consequesntly on ecological connectivity.

1.5. Benefits and challenges of large carnivore conservation

Most populations of large carnivore species around the world have declined considerably in recent decades, as a result of both habitat fragmentation and loss, as well as of other threats such as persecution (through hunting and poaching) by humans, or, the hunting, use and therefore the reduction in the numbers of prey species (Ripple et al. 2014).

The importance of large carnivores, and hence the need for their conservation, derives from their economic value, but also from the benefits they provide through ecosystem services, such as: providing natural selection and control of ungulates and other prey species; maintaining abundance of other mammals, birds, reptiles or invertebrates; carcass consumption and disease and epizootic/outbreak control, etc. (Noss et al. 1996; Ripple et al. 2014; Prugh & Sivy 2020).

At the same time, large carnivores are considered problematic/conflict species, although generally only certain habituated/nuisance individuals may pose a threat to the health and/or integrity of humans, or their property, especially domestic animals (e.g. Linell et al. 1999; Treves & Naughton-Treves 1999; Morehouse & Boyce 2017; Van Eeden et al. 2017; Bombieri et al. 2021), and can also be an important stressor (Suraci et al. 2016). There may also be other types of conflicts with these species, such as competition over the same food resource with humans (e.g. on ungulate species, berries) (Treves & Karanth 2003; Sévêque et al. 2020), or collisions (Redpath et al. 2014).

Conservation of large carnivores in human-dominated landscapes often generates controversy and intense debates (Hartel et al. 2019; Salvatori et al. 2021).

1.6. Conservation of large carnivores in Romania

Large carnivores have been a topic of interest and debate at least since the Second World War in Romania, and especially after 2007 (after the EU accession), but never has it been so important as it is today. This is mainly due to (1) the high economic value that these species, especially brown bears, can have (Penteriani et al. 2017; Gren et al. 2018); (2) conflicts between humans and carnivores and the damage these species can cause (Van Eeden et al. 2017; Carter & Linnell 2016); and (3) conflicts between stakeholders over carnivore management and conservation (Swan et al. 2017; Salvatori et al. 2021; Hartel et al. 2019), for example between hunting management units (who want hunting) and environmental organisations (who want protection), often fuelled by political decisions contested by some stakeholder groups (Treves et al. 2015; Darimont et al. 2018).

All three large carnivore species in the Carpathian ecoregion are also present in Romania, where they are estimated to have the largest populations on the continent, excluding Russia (Chapron et al. 2014). According to the latest official population size estimates (Iordache et al. 2016), there were between 6,050 - 6,640 brown bears, 2,650 - 3,030 gray wolves and 1,355 - 1,575 Eurasian lynxes in Romania.

Brown bears and wolves benefit from national conservation action plans (INCDS "Marin Drăcea" 2018; APM Vrancea 2018), officially adopted, but their actual implementation does not take place, except with small exceptions. Among the greatest threats to large carnivore species in our country are habitat fragmentation and degradation, conflicts with humans, including livestock depredation, and poaching (INCDS "Marin Drăcea" 2018; APM Vrancea 2018).

Socio-cultural aspects and studies are generally ignored in the context of coexistence with large carnivores, although they are extremely important (Erős et al. 2021). According to INCDS (2020), the number of human-bear conflicts at least, and damages caused by this species, has been

increasing at the national level since 2016. In contrast, there is no programme to prevent damages caused by large carnivores in areas at risk, and the damage compensation system is bureaucratic and discouraging. There is also no national stakeholder platform, or any 'community of practice' created, through which best measures to improve coexistence with large carnivores can be agreed (e.g. Carter et al. 2021).

The fate of large carnivores in Romania remains uncertain in the absence of integrated management and policies based on science and research that take into account and address immediate ecological and social problems and needs, on long-term (Popescu et al. 2019).

1.7. Aim and objectives of the thesis

As habitat fragmentation is one of the greatest threats to large carnivores, concerted conservation measures are needed to ensure permeable landscapes for them. In this respect, identifying and maintaining critical ecological corridors is vital to ensure the movement of large carnivores across the landscape, and thus maintaining genetic viability of these species.

The aim of the thesis is to contribute to the long-term conservation of large carnivores in Romania (and in the Carpathian ecoregion in general), by increasing knowledge and practices related to the identification of ecological corridors on the one hand, and recommending concrete measures to maintain their functionality on the other hand, especially in areas where habitat fragmentation due to the development of linear transport infrastructure is a major threat to these species.

The objectives of the research were to:

O1. Analyse the implications and effects of the development of linear transport infrastructure on ecological connectivity for large carnivores in the Carpathian Mountains (Chapter 2).

O2. Contribute to the development of a methodology for the identification of ecological corridors for large carnivores in the Carpathian Mountains in order to maintain landscape permeability for these species (Chapter 3).

O3. Improve large carnivore conservation and ecological connectivity by proposing/implementing a genuine transdisciplinary and participatory approach (Chapter 4).

O4. Contribute to the development of an international action plan and favourable policies for the conservation of large carnivores and maintenance of ecological connectivity in the Carpathian Mountains (Chapter 5).

O5. Develop specific recommendations for the long-term conservation of large carnivores, and in particular the maintenance of ecological connectivity for these species in Romania and in the Carpathian ecoregion in general (Chapter 6, but also conclusions of Chapters 2, 3, 4 and 5).

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Apologies to all those I may have missed, most likely unintentionally.

Keywords: *conservation, ecological connectivity, ecological corridors, ecological network, habitat fragmentation, large carnivores, linear transport infrastructure, transdisciplinarity.*

2. Rapid linear transport infrastructure development in the Carpathians: A major threat to the integrity of ecological connectivity for large carnivores[1]

2.1. Introduction

As previously mentioned, habitat fragmentation and loss are some of the main causes of global biodiversity decline (Rands et al. 2010; Barnosky et al. 2011; Hilty et al. 2020), and are often caused by LTI development (Geneletti 2003, 2004; Trocmé et al. 2003; Rhodes et al. 2014), with significant negative effects particularly in mountainous areas, where it affects large carnivores (Forman & Alexander 1998; Fahrig & Rytwinski 2009; Morales-González et al. 2020), not only at local but also at landscape level (Proctor et al. 2012; Bischof et al. 2017; Finďo et al. 2018).

Knowing the location of ecological corridors, especially when planning the construction of new LTI, is essential to mitigate negative effects on wildlife movement within the landscape by proposing and including the most appropriate wildlife crossing passages.

Habitat fragmentation has started to increase throughout the Carpathians, including in Romania, as an effect of the growing and legitimate need for socio-economic development (Hlaváč et al. 2019).

The aim of this chapter is to document the negative effects of LTI in particular on the ecological connectivity for large carnivores in the Carpathian ecoregion (in Romania, but also in other Carpathian countries for comparison). This approach was chosen given that measures taken in one country, could also affect large carnivores in another country, and that carnivore management should be applied (also) at the population level (Linnell et al. 2008; Boitani et al. 2015). This animal group was chosen as target species, as they are umbrella species (Rozylowicz et al. 2010; Hlaváč et al. 2019).

The chapter provides a comprehensive analysis of LTI development (as grey infrastructure), and conservation of ecological corridors (as part of green infrastructure). Specifically, the paper provides a brief overview of (1) relevant legislation governing nature conservation and LTI development; (2) the status of transport infrastructure development in the region; (3) key ecological aspects; (4) the effects of current LTI on ecological connectivity in the

[1] *This chapter is based on the article* **Papp C-R**, Dostál I, Hlaváč V, Berchi GM, Romportl D (2022) Rapid linear transport infrastructure development in the Carpathians: A major threat to the integrity of ecological connectivity for large carnivores. In: Santos S, Grilo C, Shilling F, Bhardwaj M, Papp CR (Eds) Linear Infrastructure Networks with Ecological Solutions. Nature Conservation 47: 35–63. https://doi.org/10.3897/natureconservation.47.71807

Carpathians; (5) positive and negative examples of transport infrastructure development in the Carpathians; and (6) gaps in sustainable transport infrastructure development. In addition, it also proposes a set of recommendations for maintaining ecological connectivity under the conditions of LTI development in the Carpathians.

2.2. Methods

Relevant information from studies, projects, reports and scientific literature related to LTI and ecological connectivity in the Carpathian ecoregion was collected. Datasets on transport and biodiversity were also collected. The most relevant legislation in the field of biodiversity conservation at European, Carpathian and national level was selected and analysed.

Important sources of information related to transport infrastructure and ecological connectivity in the Carpathians came from the TRANSGREEN (DTP1-187-3.1) and ConnectGREEN (DTP2-072-2.3) projects (e.g. Papp & Berchi 2019; Hlaváč et al. 2019; Okániková et al. 2021), which addressed for the first time in a systematic way the conflict between the two sectors in this region.

In order to complete the picture of LTI development and ecological connectivity at national levels, as well as to collect country-specific information on different practices, various consultation meetings of key stakeholders were organised.

2.3. Results and discussions

2.3.1. Relevant legislation on ecological connectivity in the Carpathians

Relevant legislation at international level and implications for the Carpathian countries

The most important legislative instruments and environmental policies for large carnivores at international level are the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) (CoE 2022) and the Habitats Directive (EC 1992), the EU Biodiversity Strategy 2030 (EC 2021) and the EU Green Infrastructure Strategy (EC 2013).

The Convention on Environmental Impact Assessment (EIA) in a Transboundary Context, or the ESPOO Convention, may also play an important role. At EU level, an 'EU Platform on Coexistence between Humans and Large Carnivores' has been established (EC 2014).

The European Commission's most important transport policy is the Trans-European Transport Network (TEN-T) (EC 2022).

At macro-regional level, the most important instruments are the Framework Convention on the Protection and Sustainable Development of the Carpathians (Carpathian Convention) (UNEP Vienna Programme Office 2022) and the Strategy for the Danube Region (EUSDR 2020).

Relevant legislation on ecological corridors at national level

In all Carpathian countries, there is relevant nature conservation legislation that also provides the general framework for the conservation of ecological connectivity. However, none of the countries in the region has formal methodologies for identifying and designating ecological corridors.

In Romania, the most relevant legal acts from the point of view of environmental law are GEO 57/2007 and GEO 195/2005, and from the point of view of spatial planning, these are Law 350/2001, Law 5/2000 and Order of the Ministry of Regional Development and Public Administration 233/2016 (Popescu et al. 2021). However, in practice, there are no legal obligations and restrictions imposed to ensure the functionality of ecological corridors, and there is poor harmonisation between environmental and spatial planning legislation (same in Serbia).

The Czech Republic in particular, followed by Slovakia, is the most advanced country in terms of preserving connectivity. Hungary and Poland also have regulations on ecological corridors, but their binding framework is not well established. The only Carpathian country with a law dedicated to ecological network conservation is Ukraine, but its implementation is difficult due to conflicting sectoral legislation.

SEA, EIA, AA procedures and LTI planning in the Carpathians

Strategic Environmental Assessment (SEA), Environmental Impact Assessment (EIA) and Appropriate Assessment (AA) can further contribute to a higher level of protection of biodiversity and ecological connectivity by assessing the impact of different strategies, plans, programmes or projects on them.

The main problem in implementing SEA, EIA or AA in the Carpathian countries is that the cumulative effect is not properly assessed, or not calculated at all.

2.3.2. The development of transport infrastructure in the Carpathians

Trade routes have crossed Europe since time immemorial and transport has always played a crucial role in the socio-economic development of the Carpathian region. Towards the end of the 19th century, the foundations of modern transport networks were laid in the region (Oszter 2017).

Rail transport reached its peak at the beginning of the First World War, but its privileged position began to decline in favour of road transport, which became the main transport system in the 1960s (Oszter 2017). Motorway construction in the Carpathian countries was slow. However, after 1990 the length of the motorway network quintupled and further expansion is expected in the coming years (e.g. MD ČR 2017). In Romania alone, more than 2,200 km of new motorways are to be built by 2030 and more than 3,000 km of railways are to be upgraded (Ministry of Transport and Infrastructure 2021).

2.3.3. Key ecological aspects in the Carpathian ecoregion

Ecological connectivity in the Carpathian ecoregion

Several projects and studies have focused on identifying ecological networks and corridors for large mammals in the Carpathians, but regardless of the target species selected, the identification of ecological corridors has used different methodologies.

In the ConnectGREEN project (Papp et al. 2022; Vlková et al. 2022), the most comprehensive and representative ecological network to date for large carnivores was modelled for the entire Carpathian ecoregion. The approach was based on running various models such as habitat favorability, resistance surface, fragmentation geometry, landscape permeability, etc., in GIS, and incorporating real occurrence data of large carnivores. The network has been consulted and improved with various experts at local, national and international level and is a solid tool for spatial planners and other stakeholders.

Other threats to ecological connectivity (than transport) in the Carpathian ecoregion

Residential development, including house building, as well as large commercial, industrial or logistic centres on the outskirts of towns and villages negatively influences ecological connectivity in the Carpathians.

Human disturbance (which includes off-road motorised vehicle use, mushroom or berry picking, hunting, ski slopes often built in the heart of favourable habitats, etc.) has become increasingly pronounced in the last three decades, especially around large cities and/or touristic areas. Also, intensive agriculture in many Carpathian countries, together with intensive and large-scale forestry, leads to a reduction and fragmentation of habitats. Even the large-scale use of electric fences can contribute to landscape fragmentation.

Edge effects (Haddad et al. 2015) and also climate change are serious threats as well, but more difficult to quantify.

2.3.4. Effects of current road and rail transport on ecological corridors in the Carpathians

In the Carpathians, large carnivores were widespread a few decades ago and there was no need to designate ecological corridors. The situation has changed, with the construction of new LTI in mountain valleys, which has brought with it residential development and an increase in human activities in, or near, natural habitats. The Western Carpathians on the border between the Czech Republic, Slovakia and Poland are among the most affected areas.

In Romania, due to the lack of identification, designation and official recognition of ecological corridors, the effect of road and rail transport on large carnivore corridors has not yet been adequately addressed. Similar problems exist in Hungary, Serbia and Ukraine. Only the Czech Republic has managed to officially designate a network of ecological corridors for large carnivores, but this too can be improved.

The main negative effects of LTI, apart from fragmentation, are animal mortality due to traffic and disturbance of wildlife.

2.3.5. The development of sustainable linear transport infrastructure

Measures to reduce the effects of LTI on ecological connectivity and large carnivore species

The measures relate in particular to the construction along the LTI of wildlife passages to facilitate fauna movement within the landscape. There are numerous recommendations and solutions in this respect (e.g. Clevenger & Waltho 2003; Trocmé et al. 2003; Kusak et al. 2008; Smith et al. 2015; Hlaváč et al. 2019). Wildlife passages fall into two main categories, namely overpasses (tunnels (bored or cut-and-cover), ecoducts/green bridges, classic wildlife passages and multi-purpose passages), and underpasses (viaducts/bridges, dedicated wildlife passages and multi-purpose passages), respectively.

These types of wildlife passages have also started to be built, to a greater or lesser extent, in the Carpathian countries. The choice of type and their frequency along the LTI depends on factors such as the number and importance of ecological corridors crossed, the suitability of the habitats crossed, the presence and density of target species in the area and region, the existence of other physical barriers, topography of the terrain, etc. The size and design of wildlife passages must take into account the local context.

Positive examples of transport infrastructure development in the Carpathians

The first major transport infrastructure project in Romania to incorporate measures to reduce the impact on biodiversity in general, and large carnivores in particular, by providing landscape-level

connectivity is the Lugoj-Deva motorway. This includes a complex of solutions (tunnels, viaducts, ecoducts) to allow the movement and dispersal of large carnivore species. In total, three ecoducts have been built so far (and 2 tunnels and 3 viaducts are expected to be completed under the revised environmental permit in 2013).

In the Czech Republic, Poland, Slovakia and Hungary, various passages for large mammals have been built, mainly on motorway routes crossing natural areas. In Serbia and Ukraine, there are no notable examples of good practice.

Negative examples of transport infrastructure development in the Carpathians

There are many negative examples of ILT development in the Carpathian region. For example, in Romania, due to the lack of an integrated approach, the first ecoduct ever built over a motorway (in Brănișca area, along the Lugoj-Deva motorway), ends right in a county road, instead of crossing it and leading the animals into the forest patch bordering the road.

In the Czech Republic, the construction of a few ecoducts in inappropriate locations has created a negative impression about the spending of public money on such structures. Hungary, Slovakia or Poland have relatively few wildlife passages and these are not evenly distributed with regards to the main identified ecological corridors. There are also cases where due to the poor design of the structures they are not used by animals. In Serbia and Ukraine, the development of LTI is generally done without taking into account the movement needs of animals.

2.3.6. Gaps in avoiding fragmentation caused by transport infrastructure development

Firstly, there are huge gaps in the availability of knowledge, but also expertise and experience in adequately mitigating the negative effects of LTI, especially in countries such as Romania, Serbia and Ukraine.

There are also gaps in understanding the effects and impacts of LTI on large carnivores, including a lack of dedicated studies, both in Romania and in the Carpathian ecoregion in general. There is no standard monitoring of the effectiveness of the mitigation measures implemented and of the wildlife passages already built in various contexts. In addition, databases are usually few and inconsistent, especially in Romania, Ukraine and Serbia. In the Czech Republic, accurate information on wildlife mortality on roads is collected, while for Serbia, this type of information is not available. There is no close cooperation and transparent dialogue between the various actors involved in the development of grey and green infrastructure.

2.4. Conclusions

The LTI network is not fully developed in the Carpathian ecoregion, which gives the countries of the region the opportunity to plan and implement appropriate mitigation measures in the right locations to allow large carnivores to move across the landscape. However, this requires a transdisciplinary approach from the start of the planning processes, as well as high-quality studies and robust databases.

Regarding the legislation on ecological corridors, there are notable differences between the Carpathian countries and its improvement and harmonisation with the legislation on transport and spatial planning in these countries should be ensured. The development and approval of methodologies for the official designation of ecological corridors is also essential. There is also a need to improve cross-border and transnational cooperation on ecological connectivity and large carnivore conservation for greater impact.

The effects of climate change on large carnivores and their habitats need to be properly addressed in order to define specific policy actions and responses. Ideally, ecological networks should incorporate both connectivity needs based on current and future habitat distributions, and LTI development should take this into account.

3. The identification of ecological networks and corridors for large carnivores: a key tool for reducing the effects of landscape fragmentation on these species in the Apuseni Mountains[2]

3.1. Introduction

Continued habitat fragmentation and loss leads to declines in wild species populations and even local extinctions (Crooks et al. 2017; Westekemper et al. 2021). The most common approach to address fragmentation is to identify ecological networks, including ecological corridors. This can be difficult in practice (Boitani et al. 2007; Spear et al. 2010), as landscapes are dynamic and constantly changing in time and space. It is therefore necessary to understand and anticipate landscape-level connectivity and its changes as much as possible (Hanski 1999; Zeller et al. 2020),

[2] *This chapter is based on an unsubmitted manuscript at the date when the thesis was published* (**Papp** et al. Maintaining ecological connectivity for large carnivores in the south-western part of the Carpathian Mountains) *and on a manuscript under review* (Vlková K, Zýka V, **Papp C-R**, Romportl D (2022) An ecological network of large carnivores as a key tool for protecting landscape connectivity in the Carpathians. Journal of Maps).

which is particularly important but also difficult, especially in human-dominated landscapes (Newmark 2008; Wittemyer et al. 2008; Smith et al. 2019).

Europe is one of the most fragmented continents due to intense human activities (Wade et al. 2003; Selva et al. 2011), however, the Carpathian Mountains are currently the least affected area (compared to other mountain ranges), which has also allowed the development of the most significant populations of large carnivores on the continent here (Chapron et al. 2014; Hlaváč et al. 2019). The trend, however, is towards increasing landscape fragmentation in this region (Jongman 2002). Identifying ecological networks for large carnivores, combined with appropriate conservation policies and measures, may solve the problem, and in addition provide benefits to many other species (Rozylowicz et al. 2010).

The aim of the study is to identify a coherent ecological network for large carnivores in the Apuseni Mountains (as a case study), which facilitates the movement of these species to and from this area, and which can then be integrated into spatial planning processes and documents, as well as used as an example in other areas or countries. The ecological network has a regional character and aims to maintain permeability at landscape level. It is adapted to the heterogeneity of the landscape and is designed to anticipate and respond to changes in the landscape.

3.2. Study area and target species

3.2.1. Study area

The main area of interest is represented by the Apuseni Mountains, which differ from the other mountain groups in the Carpathian Mountains mainly because of the greater geographical fragmentation and isolation, amplified by the expansion of physical barriers of anthropic origin, which has negative effects also on the large carnivore species here (Salvatori 2004).

A connectivity study targeting large carnivore species in the Apuseni Mountains makes sense if the movement possibilities of these species to other adjacent mountain areas to ensure gene flow with other metapopulations, is explored. For this reason, the Someșan Plateau (to the north) was included to explore connectivity with the Gutâiului and Tibleș Mountains and the Poiana Ruscă Mountains, respectively, as well as most of the Retezat-Godeanu mountain group in the Southern Carpathians and the Banat Mountains (to the south). The extended area has a total surface of 3,047,732 ha and is heavily fragmented by roads, motorways and railways, as well as by human settlements which together represent a significant barrier to the movement of large carnivores.

3.2.2. Target species

The target species chosen are the three representatives of the large carnivores in our country, namely the brown bear, the grey wolf and the Eurasian lynx. In the study area, they generally have lower numbers and densities compared to other areas in the Romanian Carpathians (Chapron et al. 2014).

According to the latest official estimates of the populations of the three species, in the Apuseni Mountains there were ca. 300 bears, more than 400 wolves and more than 160 lynxes (Iordache et al. 2016) (i.e. about 4.6% of bears, 14.5% of wolves and 11.3% of lynxes estimated at national level).

3.3. Methods

3.3.1. Collection of occurrence data of target species

The main methods used to detect the presence of large carnivores in the study area were the use of motion sensor cameras, snow and/or mud tracking, direct observation of animals or tracks and traces left by them (droppings, urine, hair, carcasses left behind, claw marks). Collisions with vehicles were also used.

3.3.2. Assessment of landscape permeability and of physical barriers

The assessment of landscape permeability and of physical barriers in areas relevant from the point of view of ecological connectivity, focused on roads and railways, fences, watercourses, large clear areas (not covered by forest vegetation) and built-up areas, following the methodology developed by Okániková et al. (2021). Special attention was paid to the permeability of physical barriers represented by ILT, which was assessed also taking into account the methodology developed by Moț (2010).

The results of field assessments were integrated into the GIS modelling.

3.3.3. Modelling of the corridors and the ecological network

To define the ecological network for large carnivores the following steps were followed: (1) modelling of favourable habitats for large carnivores using the Maximum Entropy (MaxEnt) method/software (Phillips et al. 2004); (2) determination of core areas and consultations with other experts; (3) modelling connectivity using the Random Walk approach; (4) modelling connectivity using the Least-Cost Path approach; (5) comparison and combination of both models; (6)

consultations with other experts and improvement of the ecological network; (7) classification/delineation of the ecological network components; and (8) statistical analysis and evaluation of the final ecological network.

All detailed analyses, modelling and statistics were performed in Esri ArcGIS 10.7 (Corridor Designer, Circuitscape, Linkage Mapper, Cell Statistics).

3.4. Results and discusions

3.4.1. Presence of large carnivores in the study area

A total of 800 individual large carnivore occurrences were recorded in the study area, of which 321 belong to bear, 381 to wolf and 98 to lynx. As a result of data collection efforts, the presence of the three species was confirmed/documented mainly in the area of the Apuseni Mountains, the Retezat-Godeanu Mountains and the Poiana Rusca Mountains, followed by the Banat Mountains. In the Someșan Plateau the presence of large carnivore species was insignificant, suggesting that the most viable/probable direction for large carnivores in the Apuseni for dispersal and gene flow is southwards. Thus, in terms of connectivity, the most relevant metapopulations for Apuseni carnivores are those in the Retezat-Godeanu Mountains, passing through the Poiana Ruscă Mountains.

3.4.2. Modelling of favourable habitats

The habitat modelling resulted in a set of consolidated habitat suitability models for the three target species using the suitability index (HSI) on a scale from 0 to 1. The result shows differences in the preferences of the large carnivore species considered for different habitats.

The next step was to merge the habitat favorability models of the three target species to obtain the combined maximum HSI values. By including fragmentation geometry (highways, primary roads and human settlements) as unfavourable habitat (HSI = 0), the impact of major physical barriers on the movement potential of large carnivores in the landscape, but also the additional threat to landscape permeability if they expand, is revealed. Thus, combined core areas for the three species with HSI ≥ 0.5 were identified, which were consulted and validated with other experts.

The surface resistance map, which expresses landscape resistance/permeability for the movement of large carnivores, was also generated. The assessment of the permeability of major LTI within the landscape contributed significantly to the development of this layer. The greatest problems are found in areas where LTI are mainly complemented by human settlements or other linear barriers. The most critical situation is in the northern, eastern and southern part of the

Apuseni Mountains, where LTI is more developed. In the south, in the area between the Apuseni Mountains and the Poiana Rusca Mountains, can be found the most cumulative barriers, which significantly restricts the movement possibilities of large carnivores between these two areas.

3.4.3. Modelling of ecological connectivity

The first result of the landscape connectivity modelling shows the so-called general connectivity, which indicates the likelihood of permeable areas for carnivore movement within the landscape.

The second connectivity modelling result shows potential particular ecological corridors connecting patches of favourable habitat (core areas) and facilitating the crossing of anthropogenic barriers by large carnivores with the lowest energy costs (Least-Cost Path). Using this model, it is possible to anticipate certain landscape-level changes (e.g., residential expansion) that could affect ecological connectivity, i.e., to design an ecological network that is functional in the long term and allows large carnivores to move across the landscape.

Occurrence data of large carnivore species were of particular importance both in validating ecological corridors and in improving the model. Without this dataset, the modelling would have been purely theoretical and unverified and validated in the field.

3.4.4. The modelling of ecological network for large carnivores

The final version of the ecological network (Fig. 1) is the product of combining the previous models, with the favourable habitat patch layer, and respectively the inclusion of large carnivore occurrence data and consultations and improvements made through meetings with other experts. The outcome of the assessment and consultations also led to the proposal of a new terminology and classification of the ecological network components (Fig. 2) suitable for the Carpathians and beyond.

Thus, the favourable and suitable habitats delimited, correspond to the greatest extent to areas with actual and potential presence of large carnivores. Continuous favourable areas (core areas) and other suitable areas currently provide favourable conditions for large carnivores, as confirmed by field surveys. These areas overlap to a large extent with large protected areas (national and nature parks) and relevant Natura 2000 sites (some of which were designated specifically for the conservation of large carnivore species) (Fig. 1).

The identified movement/dispersal areas facilitate the movement of large carnivores between favourable habitats. They are in fact the linkage areas normally found in a heterogeneous, mosaic landscape dominated by humans and their activity (comprising several stepping stones and

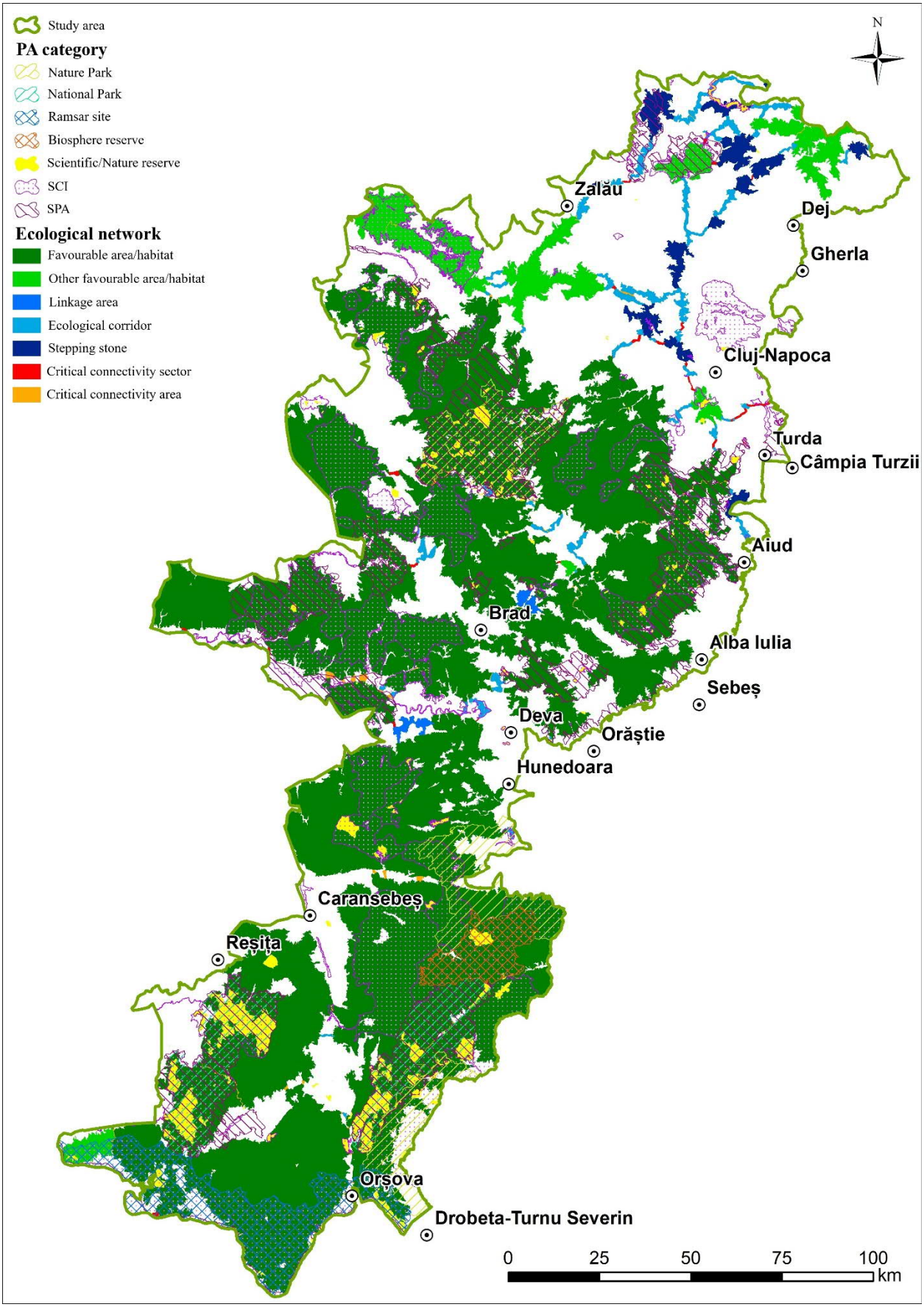

Figure 1. The ecological network for large carnivores and overlapping with protected areas of national and European interest.

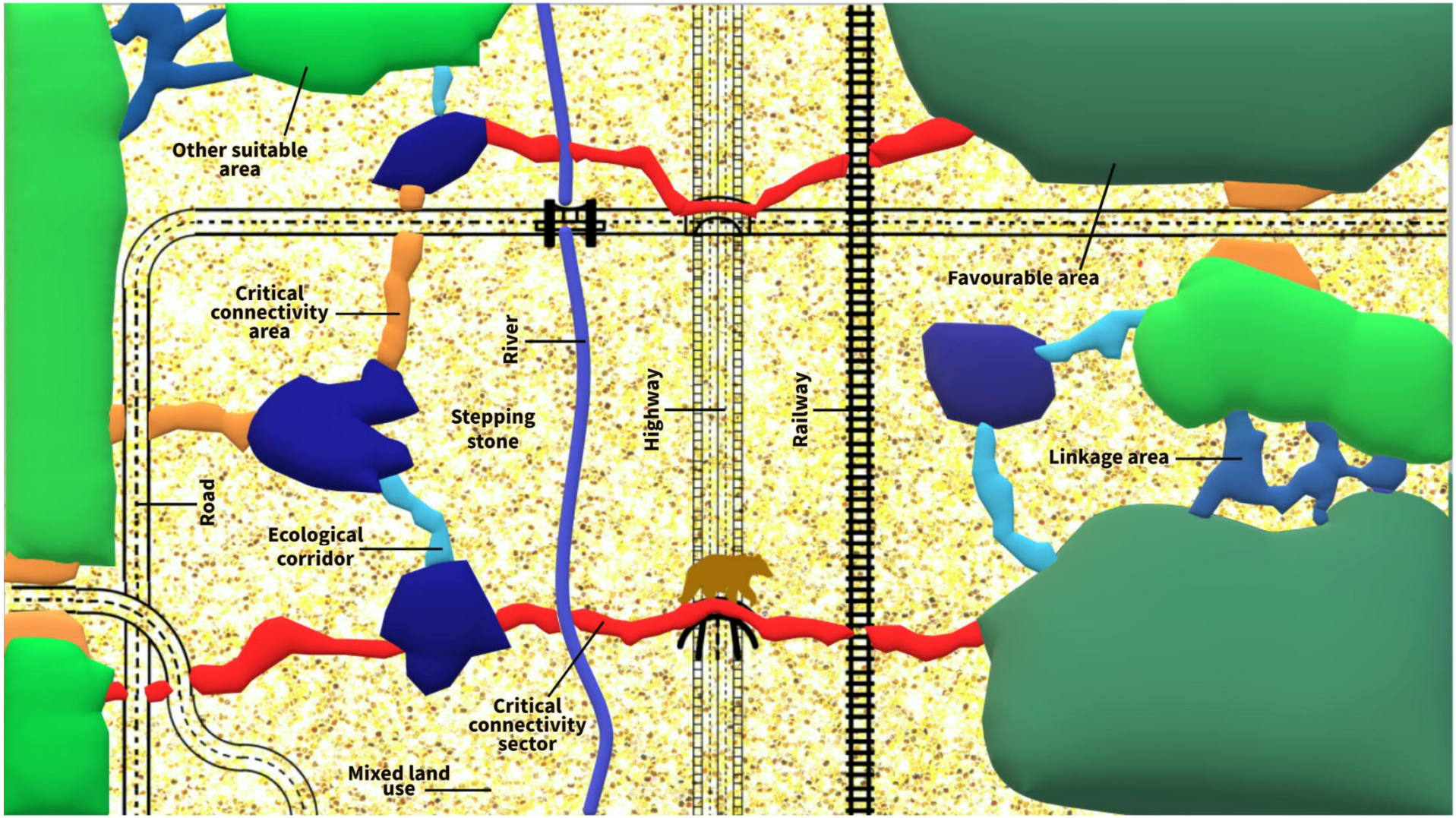

Figure 2. Graphical representation of the elements of the ecological network identified. (Note: the dimensions of the network elements are represented at a much smaller scale than the linear barriers).

corridors among various unfavourable and fragmented habitats), respectively ecological corridors in the classical sense and stepping stones.

Critical areas in terms of connectivity correspond to places where connectivity or movement opportunities are currently drastically reduced. Critical connectivity sectors indicate that there is little or no possibility of crossing one or more physical barriers, usually at a very narrow point. Critical connectivity areas imply a wider area where large carnivore species have the opportunity to cross one or more barriers. Even if these areas are relatively permeable, there is a risk that other threats may emerge that block the movement of large carnivores, or that the current barriers may be extended in the future.

These components/categories and subcategories proposed as an integral part of the ecological network (the approach is new and encourages a paradigm shift), are necessary from the point of view of increasing objectivity but also efficiency in their conservation and/or management. This approach actually proposes a prioritisation in terms of conservation of the elements of an ecological network. Once there is a formally approved corridor designation methodology, such an approach should ensure that key corridors at landscape level are maintained with priority, by designating critical connectivity sectors and areas first, followed by corridors (in the classical sense), linkage areas and stepping stones.

The results of the statistical assessments show that the ecological network identified covers an area of 18,441.75 km^2 (60.51% of the study area). It consists mainly of favourable and suitable habitats (94.91% of the total area), movement/dispersal areas (4.56%) and critical areas for connectivity (0.51%). Approximately 51.38% of the ecological network is protected through protected areas of national interest and the Natura 2000 network. 47.37% of the critical areas (with red and orange) are protected, at least on paper.

The map of the ecological network and the overall statistical results show that there are still favourable and suitable large natural habitats in the area, especially in the Apuseni Mountains, Retezat-Godeanu, and the Banat Mountains, but that there are also many bottlenecks at landscape level, where connectivity should be maintained as a priority.

3.4.5. General characterisation of the ecological connectivity by sub-area

The study area was divided into six sub-areas, namely: (1) the Apuseni Mountains sub-area; (2) the northern Apuseni Mountains and the link with the Someșan Plateau sub-area; (3) the Someșan Plateau sub-area; (4) the southern Apuseni Mountains and the link with the Poiana Ruscă Mountains sub-area; (5) the Poiana Ruscă Mountains – Retezat-Godeanu Mountains sub-area; and (6) the Retezat-Godeanu Mountains – Banat Mountains sub-area. For each of these sub-areas, the

status of ecological connectivity was analysed and characterised in detail, including the main threats to it, such as linear barriers represented by motorways, European, national and county roads, railways, human settlements, or rivers. A total of 30 critical connectivity sectors and 66 critical connectivity areas were identified within these sub-areas.

The ecological connectivity between the Apuseni Mountains and the Transylvanian Plateau (to the east) is extremely low due to the cumulative impact of several linear barriers. The potential for connecting large carnivores with other metapopulations to the west of Apuseni Mountains is extremely low, given the large areas of lowland that separate this area from other mountain ranges.

In the northern part of the Apuseni Mountains, and in the connection area with the Someșan Plateau, the natural habitats show a high degree of fragmentation, with the exception of the Apuseni Natural Park and parts of the Mare (Big) Mountain, the Gilăului Mountains, the Vlădeasa Mountains and the Pădurea Craiului Mountains. The possibility for large carnivore species to cross the Someșan Plateau from the Apuseni to the Gutâiului and Tibleș Mountains and vice versa, given the long distance, the lack of trully favourable habitats, the narrow corridors, the multitude of physical barriers and the intense human activity in the area, is extremely limited but not excluded. Further studies are needed to explore the connectivity between the Apuseni Mountains and the northern part of the Eastern Carpathians.

The area between the Apuseni Mountains and Poiana Ruscă is by far the most important in terms of connectivity between the Apuseni Mountains and the Retezat-Godeanu Mountains. The Poiana Ruscă Mountains are in fact the only viable bridge for large carnivores between the Apuseni Mountains and the Southern Carpathians.

3.5. Conclusions

The aim of the study was to identify an ecological network that would facilitate the movement of large carnivores in the long term to and from the Apuseni Mountains, taking into account the fragmentation and heterogeneity of landscapes, most of which are dominated by humans. The ecological network and the results obtained in general can be the basis for future sustained conservation actions aimed at maintaining connectivity between the different metapopulations of large carnivores at regional level, more specifically to facilitate the movement of these species between the Apuseni Mountains – Poiana Ruscă Mountains – Retezat-Godeanu Mountains – Banat Mountains and possibly also between the Apuseni Mountains and the Gutâiului and Tibleș Mountains (and vice versa) through the Someșan Plateau.

GIS modelling, together with the integration of a considerable amount of occurrence data of large carnivores and the involvement of key stakeholders through an inter- and trans-

disciplinary approach, allowed the definition of a validated ecological network with realistic individual components, reflecting both the current state of landscape permeability and threats to connectivity and potential additional threats resulting from the imminent extension of various physical barriers.

Key critical ecological corridors for large carnivores in the study area have been identified that connect favourable and suitable habitats to each other in heavily human-dominated landscapes; they should be protected with priority as soon as the legislation allows (specifically when there is a formally approved methodology for designating ecological corridors). Large carnivores are still able to move between the Apuseni Mountains and the Retezat-Godeanu Mountains, but there are significant limitations due to the multitude of LTI and other linear barriers and intense human activity in the landscape. Between the Apuseni Mountains and the northern part of Eastern Carpathians, the status of connectivity is even more critical due to more pronounced fragmentation and greater distance.

The proposed new terminology makes it easier and more efficient to prioritise the effective conservation of the elements of the ecological network, by simplifying the choice of areas to be conserved and adding an extra dose of objectivity in this respect.

Implementing and integrating the network into various plans and strategies, including land-use plans, would reduce the impact of future development projects, and facilitate the development and implementation of measures to maintain landscape permeability/connectivity for large carnivores, especially in critical areas.

4. Transdisciplinary deficit in large carnivore and ecological connectivity conservation[3]

4.1. Introduction

The long-term conservation of large carnivore species in human-dominated landscapes (HDL) is currently intensely debated in academia but also in the policy world, and represents a complex challenge (Hartel et al. 2019). The complexity comes from (1) the overlap of large carnivore territories with areas used by humans, which can lead to various forms of conflicts between humans

[3] *This chapter is based on a manuscript under review at the time when the thesis was publiched* (**Papp C-R**, Scheele B, Rákosy L, Hartel T (202?) Transdisciplinary deficit in large carnivore conservation funding in Europe. Nature Conservation.

and these species (Van Eeden et al. 2017; Bombieri et al. 2019), (2) the existence of divergent societal views on how to best solve these conflicts, (3) global changes leading to changes in the behaviour and distribution of large carnivore species (Penteriani et al. 2019; Titley et al. 2021) plus other societal challenges (Hartel et al. 2019), and (4) the protection of large carnivores through the Habitats Directive 92/43/EEC (EC 1992).

This complexity can only be addressed through a genuine transdisciplinary approach. Transdisciplinarity, is the co-creative process of elicitation and integration of knowledge from science and society in order to generate actionable knowledge that can be used to address different sustainability challenges and issues (Lang et al. 2012), including ensuring acceptable levels of coexistence between humans and large carnivores.

While transdisciplinary projects could improve large carnivore conservation outcomes in HDL, including ecological connectivity, recent literature reviews suggest that transdisciplinary approaches are rarely reported in academic journals (Hartel et al. 2019; Lozano et al. 2019). This lack of transdisciplinarity, can be referred to as the transdisciplinary deficit, "TDD", being present in large carnivore conservation projects.

The objectives of this chapter are to (1) present the main factors of the transdisciplinary deficit (TDD); (2) provide a brief overview of EU funding available to implement transdisciplinary projects; and (3) provide recommendations to improve the transdisciplinary approach to large carnivore conservation projects, including those addressing ecological connectivity.

4.2. Methods

The main factors leading to TDD have been defined on the basis of the accumulated own experience related to the conservation of large carnivore species. The assessment of the capacity of current and previous main funding programmes to encourage transdisciplinary projects to conserve large carnivores, including ecological connectivity, was made by manually exploring and searching the databases and websites of the various key EU programmes (and sub-programmes). These were then placed into one of two main categories, i.e. dedicated or tangential funding, also taking into account the most relevant aspects of the conservation of these carnivore species, including from the perspective of knowledge, but also of the required actions. In addition, the extent to which each type of funding can contribute to the different actions needed for the conservation of large carnivores was also assessed based on the own expertise.

4.3. Results and discussions

4.3.1. The key factors of the transdisciplinary deficit

Twelve key factors, which can lead to TDD, were identified and described, and subsequently grouped into five main categories as follows: (1) factors associated with project implementation, which include limited and/or preferential selection of stakeholders by project teams, superficial stakeholder engagement by project teams, failure to leverage local social innovations and information available in project areas, monopolisation of conservation projects by similar consortia from one project to another, and short project duration that does not allow for in-depth exploration of problems or testing and validation of certain solutions; (2) key stakeholder related factors, i.e. low participation/interest of key stakeholders in the topic of large carnivores based, for example, on previous negative experiences with conservation projects, and the "tyranny" of powerful local groups who impose rules through their powerful leaders and influence local project implementation; (3) institutional factors, which include lack of vision and inter-institutional coordination by responsible authorities, but also institutional/sectoral conflicts that hinder the development of constructive and genuine collaboration between stakeholders; (4) financial factors, which relate to limitations on the possibilities of partnering in projects because of the rules imposed by funders, but also to the co-financing and/or cash flow requirements of funding programmes, which can be a major barrier for some key stakeholders; and (5) ontological and epistemological factors, which relate to the lack of transdisciplinary training in academia, with a focus on classical/"narrow" disciplinary training, with subsequent repercussions in terms of openness to collaboration with other sectors.

These factors (the list is not exhaustive) are particularly prominent in the socio-cultural structures of countries such as Romania, Bulgaria or Greece, and are generally applicable/relevant to South-East Europe and to some extent to the wider EU landscape. These factors can act alone, but also in combination, drastically compromising transdisciplinarity.

4.3.2. EU funding contributing to human-large carnivore coexistence and gaps in funding for transdisciplinary actions

Conservation funding, plays an increasingly important role in shaping societal responses to global biodiversity loss (Waldron et al. 2013). This is especially true when several, often conflicting, interests and knowledge sets interact with each other and solutions/outcomes are not fully satisfactory for different interest groups (Buschke et al. 2019; Popescu et al. 2019).

The assessment of large carnivore conservation issues (carnivore biology and ecology, habitat fragmentation/ecological connectivity, types of conflicts between humans and large

carnivores and their causes, stakeholders' views on the future of large carnivores based on their current opinions and perceptions, communication, awareness and education, novel presence or large carnivores comeback, and management of large carnivores in the context of global change) and the ability of the main EU funding programmes to address them were considered in detail. It highlights that there are more tangential (not specifically dedicated) funding sources/programmes available for wildlife conservation than dedicated, and that most funding programmes contribute only to a moderate or low degree to supporting transdisciplinary actions.

Applicants are generally encouraged to apply for funding for projects dedicated to a single purpose or discipline, e.g. biodiversity conservation. The results and achievements, although robust in many cases, are not necessarily fully compatible with socio-economic development or other societal needs, including favouring coexistence with large carnivores, or maintaining ecological connectivity at landscape level. The results are not always long-lasting and therefore even the efficiency of spending money may be questionable. In addition, the functional effectiveness of different funded measures to improve coexistence with large carnivores is rarely evaluated (Oliveira et al. 2021).

In general, conservation based on EU funding programmes, with a few exceptions, is not compatible with the transdisciplinary approaches needed, for the conservation of large carnivores or other species groups.

An ideal large carnivore conservation programme or project that addresses systematically and in an integrated way the issue of coexistence with large carnivores should address each key issue discussed in this chapter; however, such a programme, initiative or project is not possible under current funding programmes, neither in terms of eligibility nor in terms of implementation period.

4.4. Conclusions

Based on the assessment made, five recommendations can be distinguished to reduce/address TDD in wildlife conservation projects: (1) create/improve the transdisciplinary framework and substance of public funding programmes; (2) encourage the development of new conceptualisations and models regarding human-large carnivores coexistence in HDL, through an improved involvement of academia; (3) encourage the development of communities of practice, laying the foundations for agreed solutions and measures, for large carnivore conservation; (4) reduce the co-financing rates required for integrated projects to increase the attractiveness of funding programmes to all stakeholders, some of which cannot meet the current co-financing requirements; and (5) the 12 key factors defined, which lead to TDD, could be integrated (along

with other factors) into a broader framework to address and complement transdisciplinary needs in various HDL.

Societies in Europe and elsewhere are increasingly facing the challenge of adapting to climate change, political and geopolitical instability, human migration, pandemics, food and water security and the ongoing biodiversity decline. The conservation of large carnivores, and preservation of ecological connectivity, must take place in the broader context of these multidimensional and unprecedented challenges. These challenges cannot be addressed through conventional sectoral approaches. A new culture of collaboration is needed, underpinning innovative solutions. Transdisciplinary conservation projects can be key tools for trigerring this culture (Lang et al. 2012).

5. Actions needed for the conservation of large carnivores and preservation of ecological connectivity in the Carpathian Mountains[4]

5.1. Introduction

The national large carnivore conservation efforts are crucial, but for a more significant and lasting impact, concerted efforts must be made at the entire large carnivore population level (Linnell et al. 2008), namely at transboundary/transnational level, by the countries sharing the same population. Otherwise, the results can be a lack of concrete harmonised measures, or even contradictory measures applied by two or more countries (Kaczensky et al. 2012).

A different management policy for large carnivores between countries sharing the same population may thus create artificial transboundary edge effects and, ultimately, hinder natural processes such as colonisation, or recolonisation of certain territories by large carnivores (Linnell & Boitani 2012; Kutal et al. 2016). Genuine cross-border collaboration requires a paradigm shift from sectoral policy-making to a holistic, transdisciplinary and systemic approach, to the creation of specialised and agile structures in the form of communities of practice that facilitate constant collaboration between stakeholders, even across political boundaries.

In the Carpathian ecoregion, such an approach has started to be put into practice following the adoption of the Framework Convention on the Protection and Sustainable Development of the

[4] *This chapter is based on* **Papp C-R**, Egerer H, Kuraś K, Nagy G (2020) International Action Plan on Conservation of Large Carnivores and Ensuring Ecological Connectivity in the Carpathians. UNEP Vienna Programme Office - Secretariat of the Carpathian Convention, WWF Romania, CEEWeb, Eurac Research. 22pp.

Carpathians (Carpathian Convention) by the Czech Republic, Hungary, Poland, Romania, Serbia, Slovakia and Ukraine (UNEP Vienna Programme Office 2022), which is the only multi-level governance mechanism covering the whole Carpathian region. As part of this convention's efforts to conserve the Carpathian's biodiversity, the International Action Plan on the Conservation of Large Carnivores and Ensuring Ecological Connectivity (Papp et al. 2020; UNEP Vienna Programme Office 2020) was developed and subsequently adopted at the sixth meeting of the Conference of the Parties (COP6).

The aim of the Action Plan is to contribute to maintaining the favourable conservation status of large carnivore populations in the Carpathian ecoregion and their long-term viability in each country through transparent national processes, namely through improved transboundary cooperation and a transdisciplinary approach. This chapter presents the objectives and strategic actions formulated to achieve this goal.

5.2. Methods

The first version of the Action Plan was drafted in April 2019, following several transboundary meetings and consultations with key stakeholders in the Carpathian region, organised under the umbrella of the Carpathian Convention. This was subject to several consultations with various experts in large carnivore conservation. Based on the feedback and recommendations received, the text of the Plan was further improved together with the Secretariat of the Carpathian Convention, and then submitted again for consultations, after which the document was sent for review to the focal points designated by each signatory party to the Convention. The final draft after these consultations was adopted in November 2020 at COP6 to the Carpathian Convention by the Parties, as the International Action Plan on the Conservation of Large Carnivores and Ensuring Ecological Connectivity in the Carpathians.

5.3. Results and discussions

Seven strategic objectives have been defined in the International Action Plan, each with specific actions and expected results (Papp et al. 2020). The plan has an implementation horizon of 2026, by which time it is expected to be revised and updated according to the implementation progress and emerging priorities.

The objectives and actions are summarised below.

Ob. 1: Standardisation of monitoring methods for large carnivores in the Carpathians.

Actions: (A1.1) Develop and implement standardised monitoring mechanisms specific to each of the three large carnivore species present in the Carpathians; (A1.2) Update the report on the conservation status and monitoring of large carnivore populations in the Carpathians every six years; (A1.3) Upload all relevant documents on the Carpathian Convention's website and/or the Carpathian Countries Integrated Biodiversity Information System (CCIBIS).

Ob 2: Prevent habitat fragmentation and ensure ecological connectivity in the Carpathians

Actions: (A2.1) Identify the ecological network for large carnivores in the Carpathians; (A2.2) Integrate into CCIBIS and regularly update the map of the ecological network for large carnivores; (A2.3) Revise and use, as appropriate, the guidelines on identification, conservation, restoration and management of ecological corridors; (A2.4) Promote the use of the publication Wildlife and Traffic in the Carpathians - Guidelines on how to minimize the impact of transport infrastructure development on nature in the Carpathian countries; (A2.5) Conduct a GAP analysis of the needs for improving the tools and processes on identification and conservation of ecological corridors; (A2.6) Address the need to improve ecological connectivity with other mountain ranges and neighbouring areas.

Ob. 3: Improve human-large carnivore coexistence

Actions: (A3.1) Promote the collection and exchange of best practices between Carpathian countries but also with other mountain regions; (A3.2) Develop and test effective methods to reduce human-large carnivore conflicts; (A3.3) Build and develop capacity of specialised intervention teams; (A3.4) Develop and promote effective public awareness campaigns and joint national and Carpathian environmental education projects; (A3.5) Promote and use existing communication materials and recommendations.

Ob. 4: Improve law enforcement in relation to illegal killing of large carnivores

Actions: (A4.1) Ensure proper enforcement of legislation on illegal killing of large carnivores at national level; (A4.2) Promote and strengthen cross-border cooperation between competent/enforcement authorities.

Ob. 5: Improve communication and cooperation between all relevant stakeholders

Actions: (A5.1) Identify relevant stakeholders for the implementation of the Action Plan for the conservation of large carnivores and ensuring ecological connectivity; (A5.2) Ensure the involvement of representatives of different relevant sectors in the joint development and implementation of viable solutions and measures for the conservation of large carnivores, including the implementation of the Action Plan.

Ob. 6: Support institutional capacity building

Action: (A6.1) Ensure availability of resources and technical capacity for responsible authorities at national levels.

Ob. 7: Reduce the impacts of climate change on large carnivores and their habitats

Actions: (A7.1) Initiate and carry out, where possible, an assessment of the effects of climate change on large carnivore species and their habitats; (A7.2) Support the implementation of recommendations and adaptation measures proposed following the assessment of climate change impacts; (A7.3) Promote information and knowledge exchange to identify specific local actions to reduce climate change impacts.

5.4. Conclusions

Conservation of large carnivore species requires complex approaches, especially if populations of these species have a transboundary/transnational distribution, as is the case of the ones in the Carpathian ecoregion. In such circumstances, the existence of a regional transnational body (such as the Secretariat of the Carpathian Convention) to coordinate conservation efforts between countries sharing populations of large carnivores is vital.

Under the umbrella of the Carpathian Convention, the International Action Plan on the Conservation of Large Carnivores and Ensuring Ecological Connectivity in the Carpathians was developed and adopted. This is a unique and innovative initiative in Europe on such a scale, through which the seven Carpathian countries have committed themselves to contribute together, in a united, harmonised and coordinated way, both to the long-term conservation of large carnivores and to maintaining ecological connectivity for these species between favourable habitats, including protected areas of national interest and relevant Natura 2000 sites, in the region.

The strategic objectives defined in the Plan reflect the most important current needs related to the conservation of large carnivores in the Carpathian ecoregion. The success of the implementation of the Plan ultimately depends on the involvement of stakeholders, the fostering of an appropriate transdisciplinary framework, as well as the human, financial and technical resources allocated (which further depend on the political will in each country).

6. Final conclusions and recommendations for the conservation of large carnivores and maintaining ecological connectivity for these species in Romania and the Carpathian ecoregion

Large carnivores are umbrella species at the top of the food chain, which are essential for maintaining optimal structure and functions of various ecosystems (Linnell et al. 2005; Rozylowicz et al. 2010; Hlaváč et al. 2019), which is why they received increased protection at EU level (EC 1992), but also at the level of the Carpathian ecoregion and in Romania. However, the conservation of large carnivore species has never been as difficult and challenging, both economically and socially, as it is today, given the increasing needs of humans to use natural resources and thus land, which creates the conditions for unwanted interactions between humans and large carnivores. In addition, this constant interaction and reduction of the habitats of large carnivores encourages, for example, the habituation of these species, particularly brown bears, in conjunction with other human practices. This further complicates not only the conservation but also the relationship between humans and large carnivores.

Combined with other societal challenges such as climate change, pandemics, political and more recently geopolitical instability, human migration, food and water security, the conservation of large carnivores and biodiversity in general can only be achieved through an equitable, but professional approach, balancing economic, social and ecological objectives. They should take into account some key measures/recommendations.

Firstly, the fragmentation of natural habitats, which is an increasing threat to the three large carnivore species (brown bear, grey wolf and Eurasian lynx) in Romania and the Carpathian ecoregion, should be addressed. In this respect, the causes of fragmentation should be targeted/addressed in an integrated way as much as possible, with the participation of all key stakeholders. As LTI development is one of the main causes, not only in Romania but also in the whole Carpathian ecoregion, specific solutions and measures should be introduced in practice and implemented in order to ensure the permeability of these infrastructures, especially in critical areas for the movement of large carnivores within the landscape.

Secondly, it is necessary to identify and officially recognise the ecological network for large carnivores and to effectively protect in particular the main critical ecological corridors, both at national and Carpathian ecoregion level. In this respect, there is also a need, inter alia, to develop and formally approve a methodology for designating ecological corridors and to further harmonise legislation on ecological connectivity with the ones from other relevant sectors, such as transport, spatial and urban development, agriculture, forestry, etc., at national and Carpathian level. This

would allow the integration of the ecological network into various plans and strategies. The specific legislation should also include the new terminology presented in Chapter 3, in order to mainstream both the identification and management of truly critical ecological corridors. At the same time, special attention should be paid to the Apuseni Mountains, and in general to the isolated mountain areas of the Carpathians, in order to allow for long-term individual/gene exchange with other metapopulations of large carnivores in neighbouring areas.

Thirdly, improving large carnivore conservation, including the coexistence with these species, and ecological connectivity, is not possible without implementing a genuine transdisciplinary and participatory approach. Thus, the development of communities of practice should be encouraged, laying the foundations for agreed and integrated solutions and measures, by facilitating the inclusive participation of stakeholders from key fields/sectors. Furthermore, in order to foster objective, informed and effective decision-making within such a transdisciplinary framework, there is a need for in-depth and relevant studies and research, carried out according to the latest scientific rigour, on topics such as: distribution and dynamics of large carnivore species; effects of various human activities on the distribution and behaviour of large carnivores; identification and understanding of habituation mechanisms of large carnivores; socio-economic advantages and disadvantages of the presence of carnivores in the landscape; effects of LTI development on ecological connectivity, movement and behaviour of large carnivores; assessment of the cumulative impact of various physical threats/barriers, in different contexts, to large carnivores and their movement in the landscape, including effective gene exchange in isolated metapopulations; effects of climate change on carnivores and their habitats, etc. In addition, the 12 key factors leading to transdisciplinary deficit, defined in Chapter 4, could be integrated into a broader framework to address and complement transdisciplinary needs in diverse human-dominated landscapes.

Fourth, as Romania shares populations of large carnivore species with six other countries in the Carpathian ecoregion, there is also a need for cross-border and transnational cooperation on improving conservation of these species and ecological connectivity for greater impact and better coordination of individual efforts. In this respect, all necessary efforts should be made for the successful implementation of the International Action Plan on the Conservation of Large Carnivores and Ensuring Ecological Connectivity in the Carpathians.

Last but not least, humans will either learn to live and coexist with large carnivores, taking into account all the associated challenges, or continue to persecute these species to extinction, with the risk of losing a whole range of ecosystem services provided by them. The first option brings far more benefits and involves minimising the risk of conflict, e.g. by implementing various

methods (individually or in combination) designed to prevent conflict, which used in an appropriate/correct and rational way, have been shown to be effective (e.g. Rigg et al. 2011; Van Eeden et al. 2017; Oliveira et al. 2021). It is also important to have innovative education and awareness-raising programmes at national but also regional level, to determine/encourage humans to change their harmful attitudes and behaviours towards nature, which can lead for example to conditioning of large carnivores and other negative impacts. The practical solution should be to develop a comprehensive national programme to improve coexistence with large carnivores, also through a transdisciplinary approach.

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1. **Papp C-R**, Dostál I, Hlaváč V, Berchi GM, Romportl D (2022) Rapid linear transport infrastructure development in the Carpathians: A major threat to the integrity of ecological connectivity for large carnivores. In: Santos S, Grilo C, Shilling F, Bhardwaj M, **Papp C-R** (Eds) Linear Infrastructure Networks with Ecological Solutions. Nature Conservation 47: 35–63. https://doi.org/10.3897/natureconservation.47.71807 (FI_{2020}=2.417; AIS_{2020}=0.574)

2. Santos S, Grilo C, Shilling F, Bhardwaj M, **Papp C-R** (2022) Ecological Solutions for Linear Infrastructure Networks: The key to green infrastructure development. In: Santos S, Grilo C, Shilling F, Bhardwaj M, **Papp C-R** (Eds) Linear Infrastructure Networks with Ecological Solutions. Nature Conservation 47: 1-8. https://doi.org/10.3897/natureconservation.47.81795 (FI_{2020}=2.417; AIS_{2020}=0.574)

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1. **Papp C-R**, Papp R, Banea OC (2018) Population dynamics and current status of the golden jackal in Romania. In: Giannatos G, Banea OC, Hatlauf J, Sillero-Zubiri C, Georgiadis C, Legakis A (Eds.) (2018) Proceedings of the 2nd International Jackal Symposium, Marathon Bay, Attiki Greece 2018. Hell. Zool. Arch., (9): 146–149. ISSN: 1106-2134.

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2. Hlaváč V, Anděl P, Matoušová J, Dostál I, Strnad M, Bashta AT, Gáliková K, Immerová B, Kadlečík J, Mot R, **Papp C-R**, Pavelko A, Szirányi A, Thompson T, Weiperth A (2019) Wildlife and Traffic in the Carpathians – Guidelines how to minimize the impact of transport infrastructure development on nature in the Carpathian countries. The State Nature Conservancy of the Slovak Republic, Banská Bystrica, 225 pp. https://www.interreg-danube.eu/uploads/media/approved_project_output/0001/35/02caaafe3c1c1365f76574e754ddbdc4e1af4a7a.pdf
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6. Popescu I, Abrudan AM, Stanciu C, Cosmoiu D, Dan R, **Papp C-R** (2021) Foaie de parcurs pentru armonizarea și integrarea conectivității ecologice în legislația și politicile publice din România. Output T4.1.4, proiect ConnectGREEN – ”Restoring and managing eco corridors in mountains as the green infrastructure in the Danube basin”. WWF Romania. 15 pp.

Participation in international and national scientific events

Participation in international scientific events (selection):

• **Papp C-R** (2022) Successful Wildlife Crime Prosecution in Europe. 13th Meeting of the Carpathian Convention Working Group on Biodiversity. On-line, 11–12 April 2022.

• **Papp C-R** (2022) Restoring and managing eco corridors in mountains as the green infrastructure in the Danube basin. 13th Meeting of the Carpathian Convention Working Group on Biodiversity. On-line, 11–12 April 2022.

• **Papp C-R,** Todoran L (2022) Restoring and managing eco corridors in mountains as the green infrastructure in the Danube basin. Policy Learning Week – Interreg Europe, Preserving and restoring ecosystems and biodiversity. On-line, 14th March 2022.

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• **Papp C-R** (2019) Securing ecological connectivity in Romania and in the Carpathian Ecoregion. 10th Meeting of the Carpathian Convention Working Group on Biodiversity. Colțești, Romania, 26 November 2019.

• **Papp C-R** (2019) Improving human coexistence with large carnivores in Europe through communication and transboundary cooperation. Ministerial Conference on large carnivores – challenges and solutions. Bucharest, Romania, 07 June 2019.

• **Papp C-R**, Papp R, Banea OC (2018) Population dynamics and current status of the golden jackal in Romania. 2nd International Jackal Symposium. Marathon Bay, Attiki Greece, 31 Oct-2 Nov 2018.

• **Papp C-R**, Papp R, Hatlauf J, Mititelu C, Banea OC (2018) New records and population density of golden jackal in the Danube Delta Biosphere Reserve. 2nd International Jackal Symposium. Marathon Bay, Attiki Greece, 31 Oct-2 Nov 2018.

• **Papp CR** (2018) Why harmonization of large carnivores’ monitoring in the Carpathian region is needed? 5th Forum Carpaticum, Adapting to Environmental and Social Risk in the Carpathian Mountain Region. Eger, Hungary, 15-18 October 2018.

• Mot R, Georgiadis L, Mazaris A, **Papp C-R**, Voumvoulaki N (2018) The harmonisation of ‘Grey’ and ‘Green’ Infrastructure in South-East Europe: Introducing the GreenWeb platform. IENE (InfraEcoNetworkEurope) 2018 International Conference, Crossing borders for a greener and sustainable transport infrastructure. Eindhoven, The Netherlands, 10-14 September 2018.

• Hlaváč V, **Papp C-R** (2018) Linear infrastructure monitoring - Data collection, analysis, interpretation and integration of results in improving the GI elements and the planning of new infrastructure projects & recommendations. International Conference "Sustainable Transportation Development in the Carpathians. Latest developments and steps forward". Bratislava, Slovakia, 05-06 September 2018.

• **Papp C-R** (2017) Grey & Green Infrastructures development. GreenWEB - International Workshop on Sustainable Harmonization of Green with Grey Infrastructure in South Eastern Europe. Făget, Romania, 25-26 October 2017.

• **Papp C-R** (2017) The Carpathian Convention & sustainable transport infrastructure development. GreenWEB - International Workshop on Sustainable Harmonization of Green with Grey Infrastructure in South Eastern Europe. Făget, Romania, 25-26 October 2017.

• **Papp C-R** (2017) Report on Large Carnivores in the Carpathians and introduction of the idea of an International Action Plan for the conservation and sustainable management of the Carpathian populations of large carnivores. 5th Meeting of the Conference of the Parties to the Framework Convention on the Protection and Sustainable Development of the Carpathians. Lillafüred, Hungary, 10-12 October 2017.

• **Papp C-R** (2017) Restoring and managing ecological corridors in mountains as the green infrastructure in the Danube basin – ConnectGreen. 5th Meeting of the Conference of the Parties to the Framework Convention on the Protection and Sustainable Development of the Carpathians. Lillafüred, Hungary, 10-12 October 2017.

Participation in national scientific events (selection):

• **Papp C-R**, Rákosy L (2021) Identificarea și conservarea coridoarelor ecologice pentru carnivorele mari în România: de la teorie la practică. B I O. T. A. - BIOdiversitate: Tradiţii şi Actualitate, ediţia a VII-a. Cluj-Napoca, 21 noiembrie 2021.

• **Papp C-R**, Rákosy L (2019) Șacalul auriu (*Canis aureus*), specie invazivă/problematică sau benefică pentru ecosistemele din România? B I O. T. A. - BIOdiversitate: Tradiţii şi Actualitate, ediţia a VI-a. Cluj-Napoca, 6 aprilie 2019.

• **Papp C-R**, Rákosy L, Ghira I (2018) Identificarea coridoarelor ecologice prin intermediul carnivorelor mari. B I O. T. A. - BIOdiversitate: Tradiţii şi Actualitate, ediţia a V-a. Cluj-Napoca, 17 martie 2018.

Research and conservation projects

(*selection*)

• H2020 CSA – BISON: Biodiversity and Infrastructure Synergies and Opportunities for European Transports Networks (https://cordis.europa.eu/project/id/101006661). Financed by H2020-EU.3.4., implementation period January 2021 – June 2023. Position: Project coordinator/supervisor and expert on behalf of WWF Romania.

• SAVEGREEN – Safeguarding the functionality of transnationally important ecological corridors in the Danube basin (http://www.interreg-danube.eu/approved-projects/savegreen). Financed by Interreg Danube Transnational Programme, implementation period July 2020 – December 2022. Position: Project coordinator/supervisor on behalf of WWF Romania.

• OBWIC – Open Borders for Wildlife in the Carpathians (https://openbordersforbears.com/en/). Financed by HU-SK-RO-UA ENI Cross-border Cooperation Programme, implementation period October 2019 – March 2022. Position: Ecological connectivity coordinator/expert on behalf of WWF Romania.

• ConnectGREEN – Restoring and managing ecological corridors in mountains as the green infrastructure in the Danube basin (http://www.interreg-danube.eu/approved-projects/connectgreen/section/contact). Financed by Interreg Danube Transnational Programme, implementation period June 2018 – October 2021. Position: Project coordinator.

• TRANSGREEN – Integrated Transport and Green Infrastructure Planning in the Danube-Carpathian Region for the Benefit of People and Nature (http://www.interreg-danube.eu/approved-projects/transgreen/section/contact). Financed by Interreg Danube Transnational Programme, implementation period January 2017 – June 2019. Position: Technical manager at project level and project manager on behalf of WWF Romania.

• Life EUROLARGECARNIVORES – Improving human coexistence with large carnivores in Europe through communication and transboundary cooperation (https://www.eurolargecarnivores.eu/en/). Financed by Life Programme, implementation period September 2017 – February 2022. Position: Project coordinator/supervisor on behalf of WWF Romania.

Other results

• Major contributions to large carnivore conservation, identification of ecological corridors and maintenance of ecological connectivity in the Carpathian ecoregion (e.g. Papp et al. 2020). Important contributions also in terms of harmonising the development of grey (LTI) and green

infrastructure (ecological networks), through the development and implementation of conservation projects and specific tools (e.g. app for recording the roadkills), development of relevant guidelines and strategies at all levels: national (e.g. Popescu et al. 2021), Carpathian (Hlaváč et al. 2020; Okániková et al. 2021) and global (Georgiadis et al. 2020).

• Member of the IUCN World Commission on Protected Areas, member of the Connectivity Conservation Specialist Group, of the Transboundary Conservation Group and other specialist groups within IUCN. Member of various other international working groups on biodiversity and ecological connectivity conservation (e.g. Wildlife Practice of WWF International, Infrastructure and Ecology Network Europe (IENE); Golden Jackal Informal Study Group in Europe (GOJAGE)), but also of national (Working Group for the Conservation of Large Carnivores in Romania, of the Ministry of Environment, Water and Forests) or local (Scientific Council of the Maramureș Mountains Natural Park) conservation bodies.

• Participation as an expert on large carnivores in a BBC scientific documentary on "World canids", which is in the final stages of production. Interviews on large carnivores and ecological connectivity for the New York Times, BBC, Euronews, Le Figaro, RFI, etc.