

A Methodology for Standardised Monitoring of Ecological Connectivity

Guidelines for the Analysis of Structural
and Functional Connectivity

Output T1.1 “Standardised Methodology for Monitoring”

ENVIRONMENT
AGENCY AUSTRIA **umweltbundesamt**^U

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A Methodology for Standardised Monitoring of Ecological Connectivity

Guidelines for the Analysis of Structural and Functional Connectivity

Output T1.1 Standardised Methodology for Monitoring

SaveGREEN “Safeguarding the functionality of transnationally important ecological corridors in the Danube basin”

Danube Transnational Programme, DTP3-314-2.3

June 2022



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About SaveGREEN

The SaveGREEN project, funded by the Interreg Danube Transnational Programme is focused on the identification, collection, and promotion of the best solutions for safeguarding ecological corridors in the Carpathians and further mountain ranges in the Danube region. Currently, ecological corridors in the region are under threat due to the lack of adequate planning of economic development initiatives. Therefore, basing its work on integrated planning, SaveGREEN will monitor the impact of mitigation measures in 8 pilot areas and derive proper recommendations for follow-up actions and policy design.

www.interreg-danube.eu/saveGREEN

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Foreword

The possibility to freely move and migrate responds to one of the most important needs of wild animals, after survival and reproduction.

But how can species satisfy this fundamental need when the Earth's overall terrestrial surface is fragmented into approximately 600 000 individual patches, of which more than half are surfaces that cover less than 1 km² and only 7% cover areas larger than 100 km²?

In 2018, the Convention on Biological Diversity (CBD) set the mainstreaming of biodiversity across multiple sectors of development as a major goal on the road to achieving the Aichi Biodiversity Targets of the United Nations by 2020.

However, when assessing our progress to date, the global community has had to acknowledge that these commonly agreed on targets were not met. The desired aim of Aichi Biodiversity Target 5 for instance, stimulating a significant reduction of the rate of loss of all natural habitats and their degradation and fragmentation by 2020, was not realised. Although Aichi Target 11 states that achieving well-connected systems of protected areas is vital for conservation and highlights that initiatives exist to develop corridors and transboundary parks, the degree of connectivity of today's landscapes remains insufficient, and there continues to be lack of specific targets and comprehensive indicators for ecological connectivity.

The 5th Global Biodiversity Outlook made it very clear that loss, degradation and fragmentation of habitats remain high in forests and other biomes, especially in the most biodiversity-rich ecosystems in tropical regions; wilderness areas and global wetlands continue to decline; fragmentation of rivers remains a critical threat to freshwater habitats.

Urgent action is therefore needed to reduce the impact of human activities on ecological connectivity and biodiversity in order to halt the rate of loss we observe today, incurred by our insatiable appetite for land and constant degradation of natural areas and landscapes.

Ensuring the functionality of ecological corridors and the cohesion of ecosystems, species habitats and protected areas is one of the central challenges of the 21st century.

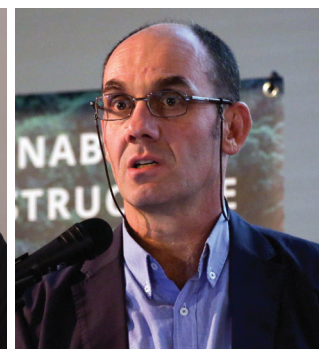
In recognition of the gravity of the situation, nature restoration was placed at the centre of the EU Green Deal and the decade of 2020 was declared a Decade of Restoration by the United Nations.

A crucial first step towards safeguarding ecological connectivity is the development of useful tools and indicators to support their identification and preservation on the ground. One of these tools is the Methodology for Standardised Monitoring of Ecological Connectivity developed in the framework of the SaveGREEN project. Defining and distinguishing structural and functional connectivity is of critical importance. Indeed, once measures to improve structural connectivity have been planned and implemented, it is vital to assess whether and how they perform in practice, to see whether they truly allow for an effective dispersal of wildlife.

By applying the Methodology for Standardised Monitoring of Ecological Connectivity and confirming findings with relevant experts and local stakeholders, decision makers, planners and implementing authorities can perform a scientifically sound analysis of both structural and functional connectivity to inform the urgently needed next steps to safeguard ecological connectivity.



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Austrian Ministry
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CHAPTER 1

Introduction

Glossary for the used terms:

Connectivity (structural + functional): structural connectivity indicates the part of the landscape that is actually connected through e.g. corridors. In contrast, functional connectivity includes species-specific aspects and their interaction with landscape structures. Thus, functional connectivity is actual connectivity from a species' perspective.

Ecological corridors: ecological corridors are elongated, naturally vegetated parts of the landscape used by animals to move from one habitat to another. They exist at different scales and frequently link or border natural areas.

Landscape/matrix: the matrix is defined as the land cover that is dominant and interconnected over the majority of the land surface in which habitat patches and corridors are embedded.

Green infrastructure: can be broadly defined as a strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings.

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The present document is the output of two working steps of the SaveGREEN project, dealing with the various aspects of the analysis of ecological connectivity.

In the first step, the analysis of the **structural connectivity** in the designated pilot areas of the project was assessed. Based on the habitat qualities and distribution, available corridors and stepping stones, but also potential obstacles and barriers were made visible by modelling. Special attention was paid to bottleneck situations with regard to permeability, where a pronounced human influence and a high level of human activities occurred. As connectivity is particularly important in these significantly affected areas, the maintenance or even improvement of the landscape and its features as well as the quality of the individual biotopes is crucial to sustain the interconnection between different habitats.

In a second step, the methodology for the analysis of **functional connectivity** was compiled. This methodology is intended to analyse the actual acceptance and operative effect of corridors and connecting structures, like green bridges, wildlife underpasses and other crossing structures. For this purpose, an existing national monitoring methodology of Austria's motorway network provider ASFINAG was adapted to the needs of the project and comprehensively supplemented to fulfil the various needs of the SaveGREEN pilot areas. This enabled the comprehensive monitoring in all eight pilot areas, although a wide range of methods for diverse species (including, e.g. aquatic macroinvertebrates, red deer and pollinators) had to be covered and described. The main focus of the monitoring approach applied in SaveGREEN, lies on large and medium-sized mammals, due to their wide distribution range and therefore comparability

of the monitoring results between the pilot regions.

The obtained and evaluated monitoring results ideally should show explicitly:

- » which corridors are being actually used by wildlife;
- » which sections are not (yet) functional for the migration of wild animals;
- » where migration axes are well structured and present appropriate landscape features;
- » where the landscape lacks suitable structures and therefore should be defined as target areas for ecological enhancement.

This document provides guidance on the analysis of focus areas, the identification of connecting elements in the landscape and the use of these structures by wildlife.

It therefore represents an evidence-based decision-making aid and source of information providing stakeholders, land-managers, administration, policy makers, experts and communities the tools and the knowledge that they need to ensure migration and dispersal possibilities based on a qualitative assessment of habitats and connectivity structures.

1.1 Importance and Aim of Standardised Monitoring

Many valuable ecological corridors are impeded or threatened by human activities and their impacts such as linear transport

infrastructure and its construction, housing and industrial area development, forestry or water management practices and intensive agriculture and the resulting economically optimized landscapes.

Mitigation measures of transport infrastructure such as green bridges are often missing or dysfunctional because of inadequate design, location, and inappropriate management of surrounding land use by e.g., poorly structured agricultural areas or monoculture in agriculture and forests. Furthermore, green crossings and corridors for migration represent bottlenecks for wildlife in the landscape. Therefore, the use of connecting structures, such as green bridges and underpasses, by local wildlife and the functionality of corridors in general are highly important.

Therefore, the preservation of unobstructed corridors by adequate regional development planning and the appropriate designation of land is equally important.

The present monitoring methodology developed within SaveGREEN aims at determining the actual degree of utilization of the various elements of green infrastructure by wildlife, the possible degree of influence of disturbance factors such as noise and light pollution as well as other aspects supporting migration.

Target audience

This Methodology aims at the support of public authorities, as well as experts and field workers. Within SaveGREEN the Methodology was applied in eight pilot areas in a consistent way by testing the approach under different conditions across Central and Eastern Europe. The Methodology includes the development of standard data forms for fieldwork as well as a decision matrix to specify parameters/ measurements for relevant species and the methods to be applied. In addition, this Methodology can be used in all biogeographic regions, except marine and coastal habitats.

Resources used

As a planning aid, the results of the “SaveGREEN - Monitoring” survey, which obtained information on monitoring status and future needs of the project partners, were used. The same applies to the previous Interreg Danube Transnational Programme projects, [TRANSGREEN](#) “Integrated Transport and Green Infrastructure Planning in the Danube-Carpathian Region for the Benefit of People and Nature” and [ConnectGREEN](#) “Managing Ecological Corridors in Mountains as the Green Infrastructure in the Danube Basin”. The basis for this joint monitoring approach is a recent Austrian study that is concerned with the monitoring of wildlife on green bridges and underpasses (ASFINAG 2020).

and assessed by using GIS techniques based on data mostly derived by means of remote sensing. In contrast, monitoring the functional connectivity (the “species perspective”) requires information and data surveyed in the field by collecting relevant parameters. Figure 2 show how both monitoring steps interact.

1.2 Structural vs. functional connectivity

The monitoring methodology of SaveGREEN combined two separate aspects and aimed at the evaluation of both, the structural and functional connectivity. The guidelines for the monitoring of structural and functional connectivity are described in this joint document.

These two aspects of connectivity focus on different demands of corridors. While structural connectivity indicates the part of the landscape that is actually connected through e.g. corridors, functional connectivity in contrast includes species specific aspects and their interaction with landscape structures. Thus, functional connectivity is actual connectivity from a species' perspective (e.g. Mönkkönen & Reunanen 1999, Brooks 2003, Kindlmann & Burel 2008, Andersson & Bodin 2009, Kadoya 2009). The structural connectivity of corridors can be designated

Functional connectivity monitoring approach: Monitoring of functional connectivity based on office and field mapping campaign

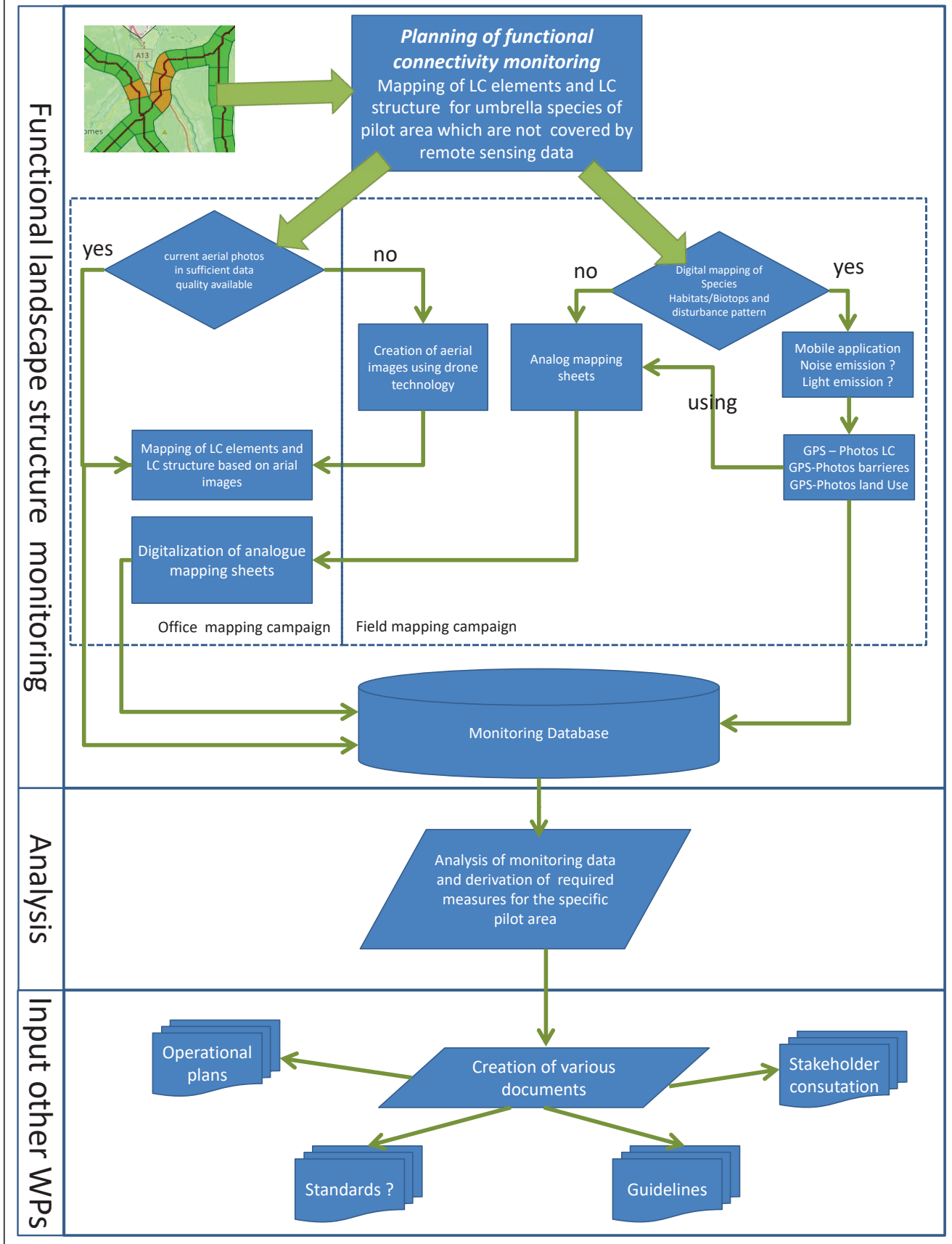


Figure 1: Overall overview of the workflow of the monitoring methodology. Monitoring of functional connectivity

1.3 Background

SaveGREEN will map the structural and functional connectivity of ecological corridors in the Carpathians and other mountain ranges of the Danube region, based on considerations, methods, and results developed in the following previous projects:

Creation of Ecological Corridors in the Ukrainian Carpathians, Poland, Ukraine and Romania, 2010: https://www.researchgate.net/publication/290367845_Creation_of_Ecological_Corridors_in_the_Ukrainian_Carpathians

Open Borders for Bears between Romanian and Ukrainian Carpathians, Romania and Ukraine, 2012-2014: http://assets.panda.org/downloads/wwf_factsheet_bear_project2014.pdf

MEMO on the Negative Impact of the Planned Lugoj-Deva Motorway and Presentation of Possible Mitigation Solutions, Romania, 2010: http://assets.panda.org/downloads/memo_lugoj_deva.pdf

Southwestern Carpathian Wilderness and Sustainable Development Initiatives, Romania, 2013-2017: https://www.wwf.ro/ce_facem/arii_protejate/salbaticia_din_carpati/

TRANSGREEN Integrated Transport and Green Infrastructure Planning in the Danube-Carpathian Region for the Benefit of People and Nature, Czech Republic, Slovakia, Hungary, Romania, Ukraine, 2017-2019 : <http://www.interreg-danube.eu/approved-projects/transgreen/outputs?page=1>

MARAMURES The Green Heart of the Carpathian Mountains, with Virgin Forests and Bears Roaming across EU Frontiers, Romania, 2013-2016

Land Development Instrument Testing in Pilot Site of Maramures, Romania for connectivity, Romania, 2017-2019

Development of the methodology for establishing ecological corridors and training the administrators of the protected areas for their better management, Romania, 2015-2017: <https://www.gnm.ro/ro02/?lang=en>

Ecological Corridors for Habitats and Species in Romania (COREHABS), Romania, 2015-2019: <http://corehabs.ro/en/>

Alpine-Carpathian Corridor, Austria, Slovakia, 2007-2013: https://ec.europa.eu/regional_policy/en/projects/austria/innovative-alps-carpathianscorridor-re-establishes-a-major-migration-route-for-wild-animals

ConnectGREEN, Restoring and Managing Ecological Corridors in Mountains as the Green Infrastructure in the Danube Basin, Romania, Czech Republic, Slovakia, Serbia, and Hungary, 2018-2021: <http://www.interreg-danube.eu/approved-projects/connectgreen>

Open Borders for Wildlife in the Carpathians (OBWIC), 2019-2022: https://openbordersforbears.com/wp-content/uploads/2020/03/1-Connectivity-report_OBWIC_February-2020.pdf



CHAPTER 2

Monitoring of structural connectivity



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One claim of SaveGREEN is the goal to develop corridor maps for more than one species group, and to derive an overall map for each pilot area by combining the model results. This combination will include designated corridors from previous projects, which focused on large carnivores. The list of further species groups (e.g. herbivores, small mammals, reptiles) that will be considered in the monitoring process has to be developed by screening available information and data sources. In order to assess the quality of the structural connectivity of the identified corridors, the reduction of permeability based on structural parameters will be calculated. This step will help to highlight bottleneck situations reducing the structural connectivity of corridors and hence are an important measure of corridor system performance at a given location (Figure 2). Knowledge of such bottlenecks can help to develop appropriate improvement strategies. Moreover, these results will provide important information for the selection of

areas suitable for monitoring the functional connectivity by detailed field surveys.

Usually, based on the patch-corridor-matrix model, corridors are considered as more or less wide linear areas connecting patches. In simplified terms, patches are usually understood as mosaic-like parts of the landscape that are essential for the persistence of populations of the group of organisms under study. In our case patches correspond to core areas. These patches are embedded in the matrix that represents the dominant land use type for the study area, e.g. arable land in anthropogenically overformed landscapes. It should be emphasised, however, that the matrix is both context and scale dependent.

In SaveGREEN the application of this concept to landscapes that have retained a certain heterogeneity and thus an accompanying structural richness could prove difficult. This is because in such landscapes, the distinction

Structural connectivity monitoring approach – Designation and evaluation of ecological corridors based on GIS-models

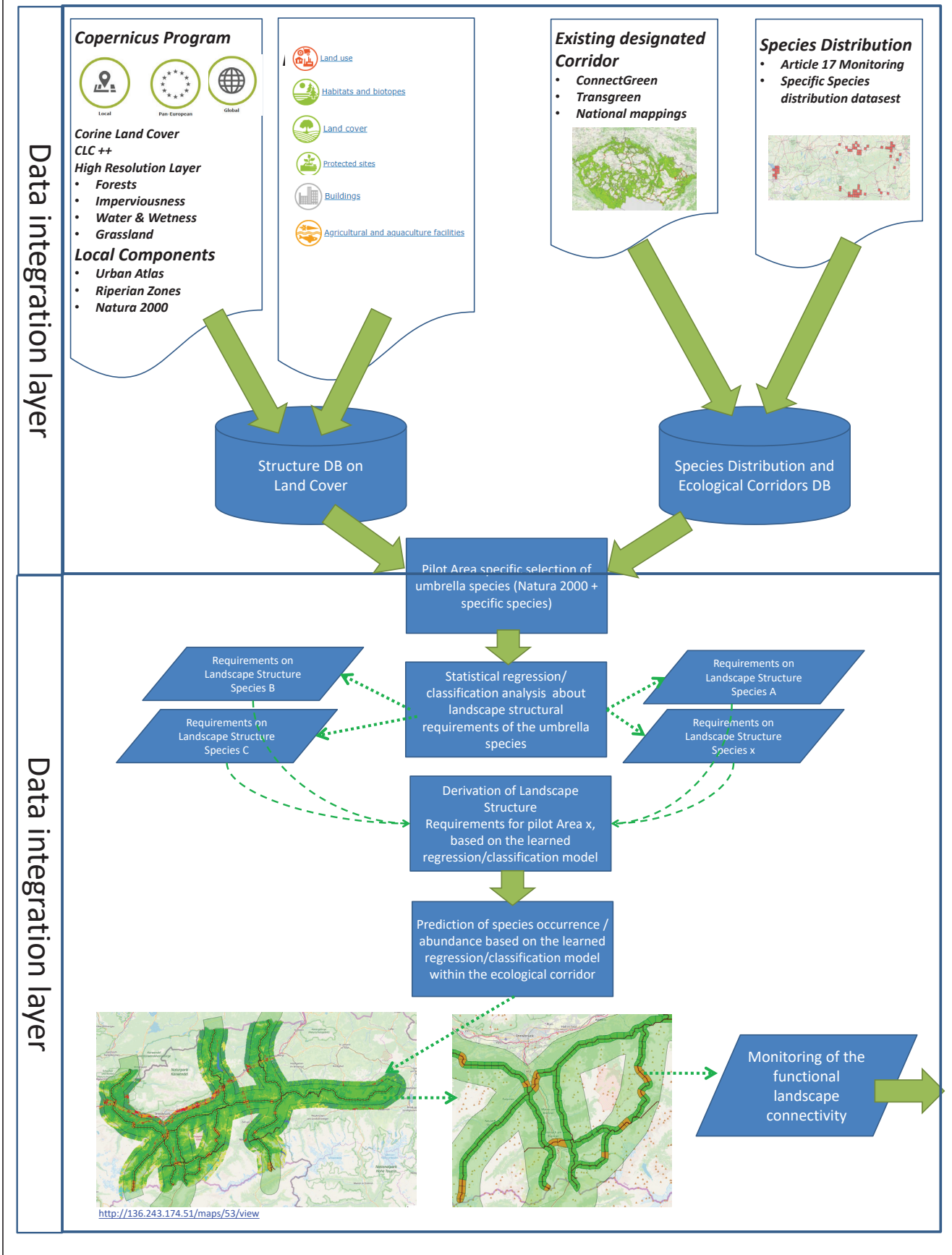


Figure 2: Overall overview of the workflow of the monitoring methodology. Monitoring of structural connectivity

between patches and matrices over wide areas can be complex, making a delineation of linear corridors more challenging. This difficulty must be taken into account in the development of the appropriate methodology.

2.1 General considerations

The starting point is the consideration to develop a uniform approach for all pilot areas, which is based on homogeneous data sets and identifies the structural corridors with the same methodology. Since there is no species distribution data available for most of the pilot areas in order to develop a data-driven bottom-up approach, it was decided, following the meeting on December 7, 2020, to conduct the modelling for structural monitoring using an expert-based model.

For this purpose, rules for the designation of core areas and for the definition of resistance surfaces – both substantial inputs for the calculation of the corridors – have to be specified for the selected organism groups based on available information and knowledge. These calculations should use data sets that are largely available in comparable form for all pilot areas. As an added benefit, periodically updated data on an ongoing basis will be preferred. In this way, an established set of rules that is transparent and comprehensible can be applied in an analogous manner to future studies. Such an approach has to make trade-offs in terms of the quality of the results for a variety of reasons. After all, essential spatially explicit information suitable for making detailed predictions about core areas or spatial resistances is lacking for most groups of organisms. Although a recent study (Febbraro et al., 2018) shows that bottom-up models, such as MAXENT (Phillips et al., 2006), provide more accurate results, the authors emphasize that when data availability is poor, the use of expert-

based methods is warranted. Thus, the approach presented here represents a compromise that should serve to make statements of sufficient quality based on the available information. Finally, the results should serve to identify bottleneck situations in the corridor network that are suitable for the establishment of functional monitoring. In these areas, fine adjustments of the corridors can subsequently be made on the basis of spatially and thematically improved data sets in order to better reflect local conditions.

The modelling of the structural connectivity includes the following steps:

- » Screening of potential data sources and selection of suitable input data in order to designate core areas and define resistance surfaces for umbrella species in the pilot areas
- » Gather information on species distribution as well as ecological corridors and defining target species (groups) for the pilot areas
- » Development and application of an appropriate model to define core areas and resistance surfaces for the selected species (groups) depending on data availability and quality
- » Calculation of species (group) specific corridors for each pilot area
- » Identification of bottleneck situations

2.2 Input data for the calculation of core areas and resistance surfaces

A first crucial point of the monitoring process is the preparation of adequate datasets describing the landscape for each pilot area that best

possible fits the modelling needs. In selecting the datasets, the following minimum landscape description requirements were identified as a basis for monitoring structural connectivity:

- » Land cover / land use, setting the general framework describing the potential for suitable habitats that can be part of a core area and also affects the resistance surface
- » Elevation / slope, influencing the suitability of a given area for species (groups)
- » Rivers and streams, potentially having considerable barrier effects for many species (groups)
- » Infrastructure (such as roads, railways, and buildings), having barrier characteristics but

also serving to overcome barriers, such as crossing structures over or under highways, roads, rails and rivers.

In order to ensure the best possible comparability between the pilot areas, the following data sets were identified as well-suited possible sources. It must be emphasised that these data sets are not available for all pilot areas - in these cases, alternatives have to be found.

2.2.1 Land cover / land use

An essential information for the monitoring of structural connectivity is land cover, which is crucial for the presence of suitable habitats that can serve as core areas. However, land cover is also an important parameter for permeability,

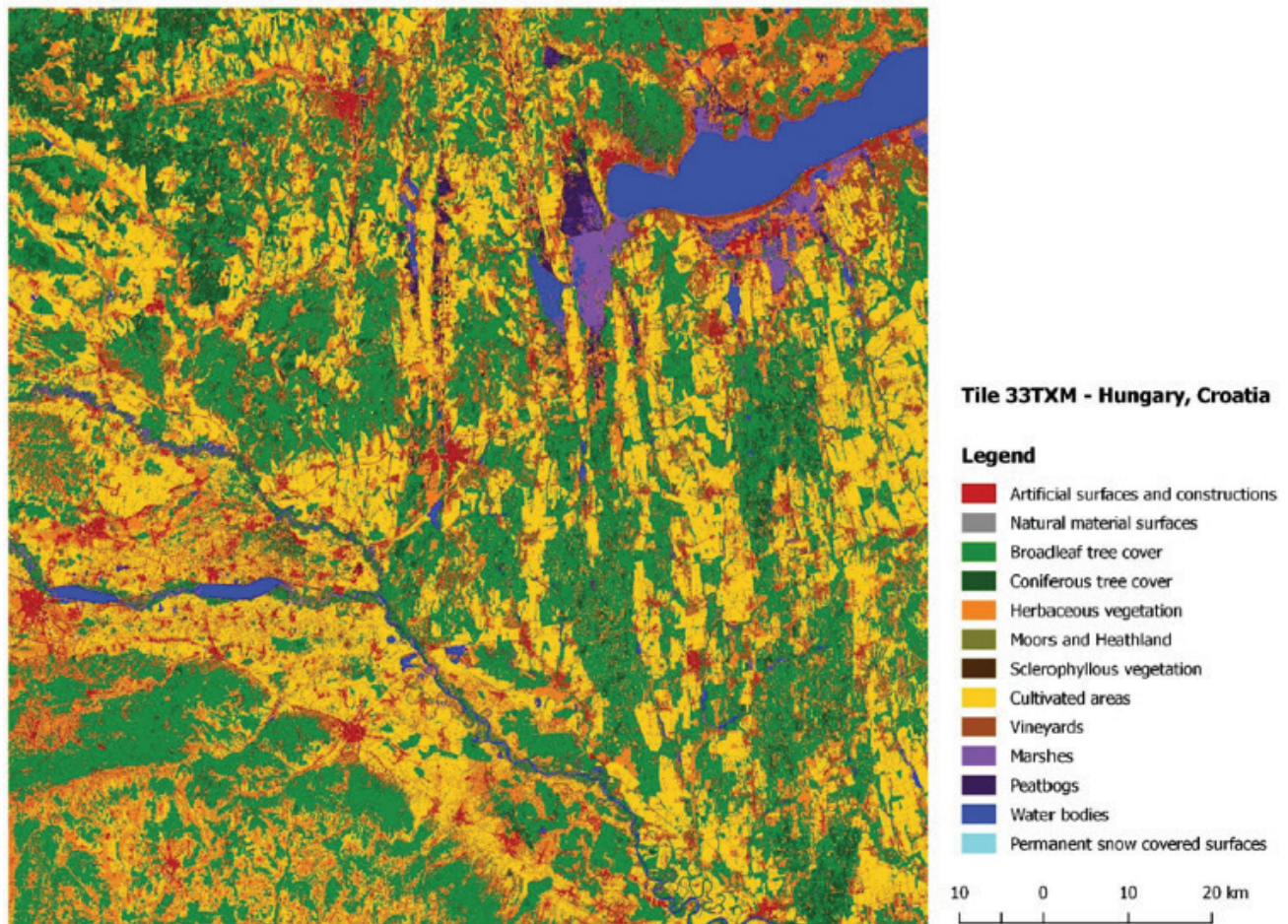


Figure 3: Extract of the 10 m S2GLC land-cover map (source: http://users.cbk.waw.pl/~mkrupinski/S2GLC_Phase2_FinalReport.pdf)

i.e. how well a group of organisms can cross the landscape. Here, a dataset based on classification of **Sentinel-2** images (Malinowski et al., 2020) was identified as the most appropriate. The advantages are the high spatial resolution (10 m) given the coverage of the map, the availability, as well as the planned update cycles, allowing future recalculations on a comparable basis. The low thematic resolution can be seen as a disadvantage - the dataset distinguishes 13 different classes (Figure 3), which inadequately address many demands of the studied organism groups. Furthermore, this dataset is not available for Ukraine, here an appropriate alternative had to be found and adapted.

2.2.2 Elevation / slope

Areas above a certain sea level or very steep surfaces represent obstacles for most animal groups, which should be included in the modelling. Although this effect is expected to

be rather small in the pilot areas, it should be considered in the calculations. A suitable data set for this purpose is **EU-DEM** (European Environment Agency, 2014; see <https://land.copernicus.eu/imagery-in-situ/eu-dem>), if better data are available for a pilot area, this can be included in the modelling instead.

2.2.3 Rivers and streams

The water network, especially large river courses, often represent barriers for many groups of organisms. For an implementation of this information, the consideration of the ranking of a watercourse is essential, since permeability in most cases depends on it. The **EU-HYDRO** dataset (see <https://land.copernicus.eu/imagery-in-situ/eu-hydro>) has emerged as a promising candidate. It provides the watercourse network for the basins and differentiates the individual sections on the basis of Strahler stream order (Figure 4).

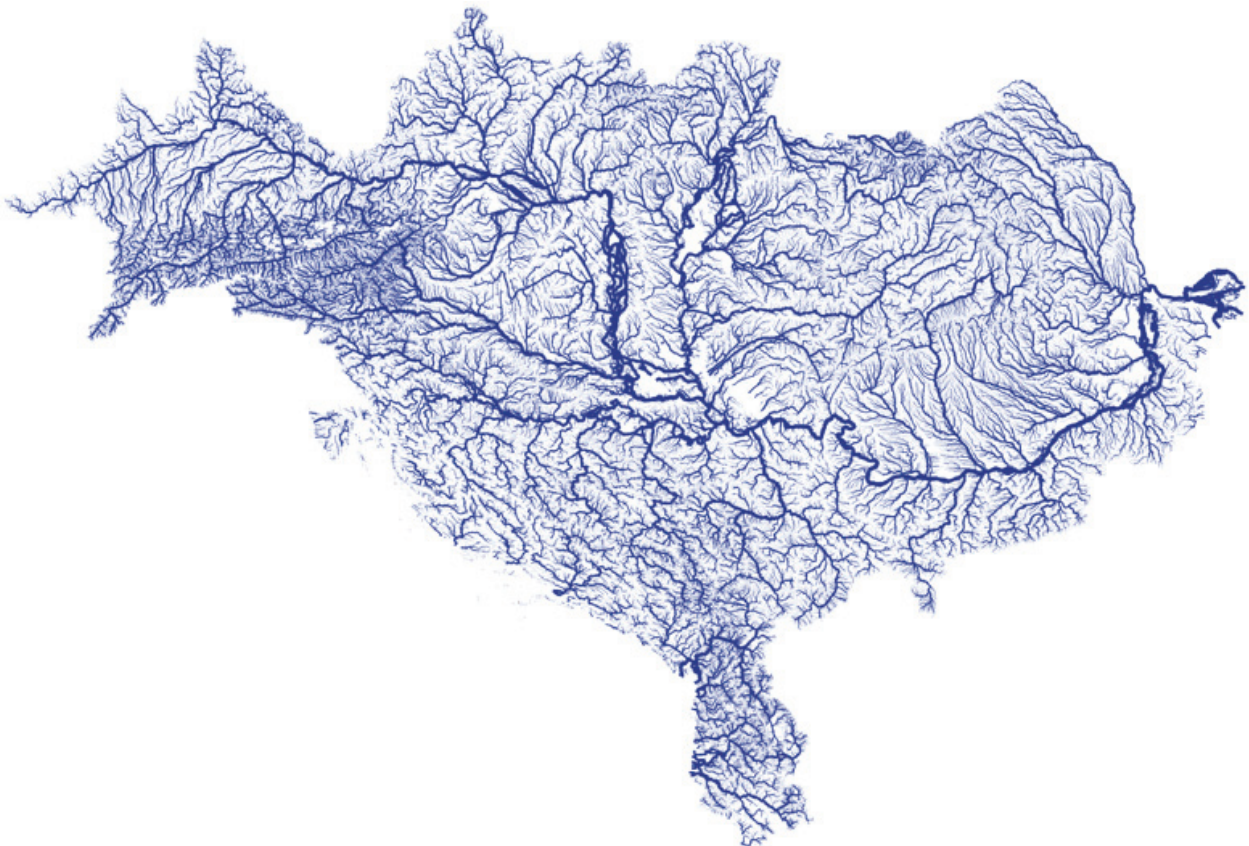


Figure 4: Stream network of the river Danube basin, based on EU-HYDRO

2.2.4 Infrastructure

Anthropogenic facilities and infrastructure are a major cause of mobility restrictions for the vast majority of species groups, and therefore need to be integrated into the assessment of structural connectivity. However, there is a lack of corresponding data on EU-level. Furthermore, the national availabilities and qualities of this information differ essentially between the pilot areas. Therefore, a collaborative project dataset will be used that provides - at least for European countries - infrastructure data with sufficient quality, namely the collaborative mapping project **Open Street Map** (OSM, see <https://www.openstreetmap.org/about>). In SaveGREEN, three data layers will be used: (1) the road network, (2) the rail network and (3) individual buildings.

For the road and rail network, analogous to the watercourse network, a hierarchical differentiation of the individual sections is necessary, since the ranking level influences the permeability of the infrastructure to the different species groups. This distinction will essentially follow reasoning of Haberl et al. (2021) and provide a hierarchy of three different levels for the road and two for the rail network.

Settlement areas, which influence core zones and the resistance to species groups, are adequately represented in the Sentinel-2 dataset, however individual buildings, which can also affect structural connectivity, are missing in this dataset. Therefore, these have to be extracted from the OSM dataset and incorporated into the model.

Besides the barrier effects of anthropogenic infrastructure, there are also structures facilitating animal movements. Typically, these are structures located above (bridges, overpasses) or below (tunnels, underpasses) these barriers. Of particular note are green

bridges, structures that were created specifically for this purpose. OSM often does not provide this information in satisfying quality, so this should be provided by the partners of the pilot areas using regional datasets or mapping data, to be included in the modelling.

2.3 Selection of target species (groups)

In parallel with the identification of input data describing the landscape of a pilot area, suitable species (or species groups) of interest have to be selected. In previous projects (e.g. OBWIC), for a small number of species (large carnivores), point distribution data were used to develop Habitat Suitability Index (HSI) models to derive spatially explicit delineations of core areas and hence the corridors connecting them.

As a starting point, the project partners compiled a long list of species (or species groups) that will be monitored in the subsequent functional monitoring, which serves as a pool for selecting suitable umbrella species (or groups of umbrella species) for the structural connectivity monitoring (Table 1).

► **Table 1: List of umbrella species in the pilot areas (PA).**

*** indicates species (or species groups) where distribution data are available**

**** indicates species (or species groups) where modelled data are available**

Species group	Species
PA Beskydy-Kysuce (CZ-SK)	
Large carnivores	Brown bear (<i>Ursus arctos</i>)**, Grey wolf (<i>Canis lupus</i>)**, Eurasian lynx (<i>Lynx lynx</i>)**
Medium-size mammals	European wildcat (<i>Felis silvestris</i>)* Eurasian otter (<i>Lutra lutra</i>)
Herbivores	
Birds	Hazel grouse (<i>Bonasia bonasia</i>)**
PA Arad-Deva (RO)	
Large carnivores	Brown bear (<i>Ursus arctos</i>)**, Grey wolf (<i>Canis lupus</i>)**, Eurasian lynx (<i>Lynx lynx</i>)**
Other large mammals	Red deer (<i>Cervus elaphus</i>), Roe deer (<i>Capreolus capreolus</i>), Wild-boar (<i>Sus scrofa</i>)
Bats	various
Amphibians	various
Reptiles	various
Fish	various
PA Eastern Carpathians (RO)	
Large carnivores	Brown bear (<i>Ursus arctos</i>), Grey wolf (<i>Canis lupus</i>), Eurasian lynx (<i>Lynx lynx</i>)
Large herbivores	Red deer (<i>Cervus elaphus</i>), Wild-boar (<i>Sus scrofa</i>)
PA Novohrad-Nógrád (SK-HU)	
Aquatic macroinvertebrates	Crayfishes, fishes
Large herbivores	Ungulates
Large carnivores	Brown bear (<i>Ursus arctos</i>), Grey wolf (<i>Canis lupus</i>), Eurasian lynx (<i>Lynx lynx</i>)
Medium-size mammals	European wildcat (<i>Felis silvestris</i>)
PA Rila-Verila-Kraishte (BG)	
Large carnivores	Brown bear (<i>Ursus arctos</i>)**, Grey wolf (<i>Canis lupus</i>)**
Reptiles	Greek tortoise (<i>Testudo graeca</i>), Hermann's tortoise (<i>Testudo hermanni</i>)
Medium-sized mammals	Red deer (<i>Cervus elaphus</i>), Badger (<i>Meles meles</i>)
Large herbivores	Ungulates
PA Zakarpattia Region (UA)	
Large carnivores	Brown bear (<i>Ursus arctos</i>)*, Grey wolf (<i>Canis lupus</i>)*, Eurasian lynx (<i>Lynx lynx</i>)*
PA Kobernausser forest (AT)	
Large carnivores	Brown bear (<i>Ursus arctos</i>), Grey wolf (<i>Canis lupus</i>), Eurasian lynx (<i>Lynx lynx</i>) - in case of establishment
Large herbivores	Red deer (<i>Cervus elaphus</i>), Wild-boar (<i>Sus scrofa</i>)
Medium-size mammals	Roe deer (<i>Capreolus capreolus</i>), Red fox (<i>Vulpes vulpes</i>), European badger (<i>Meles meles</i>), European wildcat (<i>Felis silvestris</i>), European hare (<i>Lepus europeus</i>), Beech marten (<i>Martes foina</i>), European pine marten (<i>Martes martes</i>)
Small size mammals	Red squirrel (<i>Sciurus vulgaris</i>), Polecat (<i>Mustela putorius</i>), Hedgehog (<i>Erinaceinae</i>), Stoat (<i>Mustela ermine</i>), Dormice (<i>Gliridae</i>), Common Vole (<i>Microtus arvalis</i>)
PA Pötsching (AT)	
Large carnivores	Brown bear (<i>Ursus arctos</i>), Grey wolf (<i>Canis lupus</i>), Eurasian lynx (<i>Lynx lynx</i>), Golden jackal (<i>Canis aureus</i>) – in case of establishment
Large herbivores	Red deer (<i>Cervus elaphus</i>), Wild-boar (<i>Sus scrofa</i>)
Medium-size mammals	Roe deer (<i>Capreolus capreolus</i>), Red fox (<i>Vulpes vulpes</i>), European otter (<i>Lutra lutra</i>), Eurasian beaver (<i>Castor fiber</i>), European badger (<i>Meles meles</i>), European wildcat (<i>Felis silvestris</i>), European hare (<i>Lepus europaeus</i>), Beech marten (<i>Martes foina</i>), European pine marten (<i>Martes martes</i>)
Small size mammals	Red squirrel (<i>Sciurus vulgaris</i>), Polecat (<i>Mustela putorius</i>), Hedgehog (<i>Erinaceinae</i>), Stoat (<i>Mustela ermine</i>), Dormice (<i>Gliridae</i>), Common Vole (<i>Microtus arvalis</i>)

2.4 Calculation of corridors

2.4.1 Tool: Linkage Pathways

A widely used tool for calculating wildlife corridors is the application Linkage Pathways, which is part of the Linkage Mapper Toolbox (see <https://linkagemapper.org/linkage-mapper-tools/>), which has proven its usefulness in many application examples (e.g. Dutta et al. 2016, Littlefield et al. 2017). To calculate corridors (Figure 5),

Linkage Pathways requires spatially explicit information about a species' core area containing the most important habitats, which serve as the start and end points for the corridors. The permeability of a terrain for a species is described by a resistance surface, where low values describe easy permeability, while areas with high values are difficult to cross. Barriers are described by very high resistance values. One advantage of Linkage Pathways is that it relies on the circuit theory, originated from the electronics, and enhances conventional least-cost path approaches by accounting all possibilities connecting core areas simultaneously.

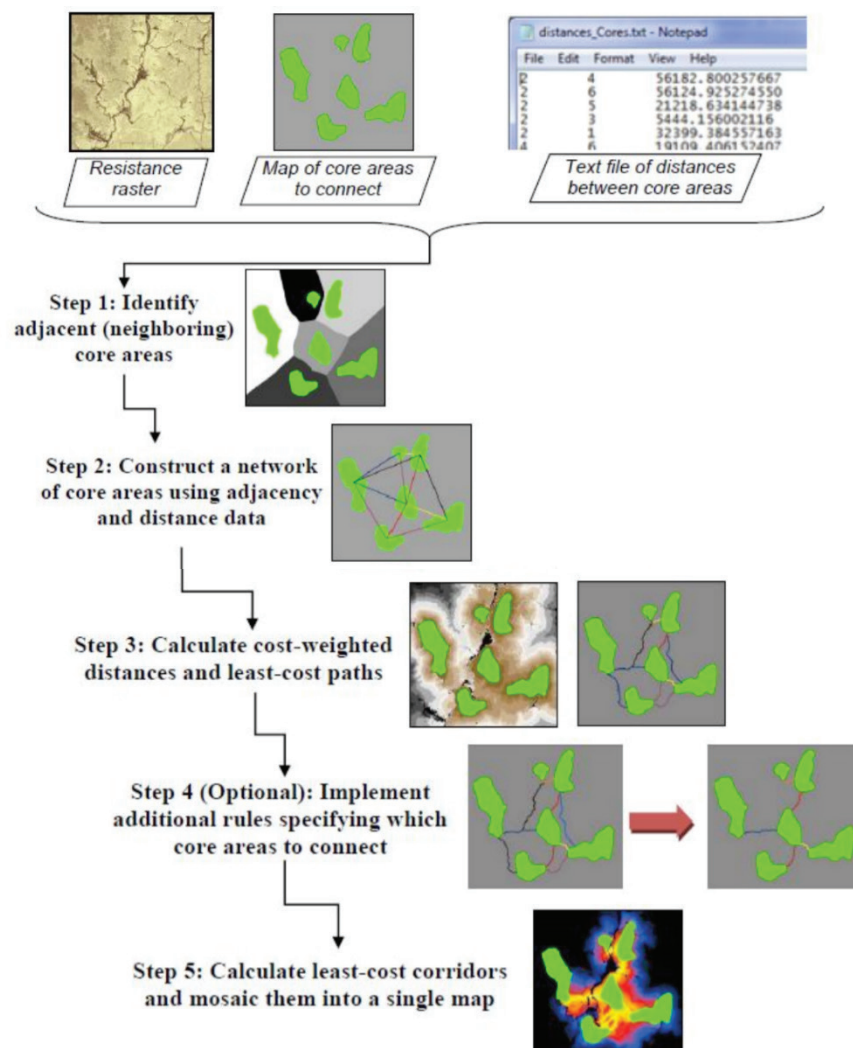


Figure 5: General workflow of the calculation of specie-specific corridors using the tool Linkage Pathways

2.4.2 Calculation of core areas

For the delineation of core areas the mapping of Boolean values, representing a truth value (yes/no), will be derived based on the input data sets, as described below.

For the categorical input data (land cover, buildings as well as stream, road and rail network), for each category is decided whether it can become part of a core zone or not. For linear structures (like rivers, roads, railways), this means whether their hierarchical level makes them likely to dissect a potential core area. For the metric input data (sea level, slope), thresholds are defined to indicate suitability as a core zone.

An overlay of all of maps of Boolean values (yes/no) using a minimum operator,

preferring no-values, results in a first intermediate result. In order to provide the resulting areas with the compactness necessary for some animal groups, appropriate GIS work steps are taken to clean lacerated borders. Subsequently, areas that do not meet a species (or species group) specific minimum size are excluded. An overview of the calculation process is given in Figure 6. The specific designations for the species (or species groups) still have to be developed.

It must be emphasized that the concept of core areas - although the Linkage Pathway tool is based on it - is not applicable to all species groups for all pilot areas. For example, there might be the case that there are no suitable habitats that are large enough to serve as core areas, e.g. for large carnivores. Therefore, in such cases it is more accurate to speak of areas that provide enough suitable habitats to function as part of a corridor, which have to be identified.

2.4.3 Calculation of resistance surfaces

The land cover categories of the Sentinel-2 classification are assigned to resistance values due to their respective permeability. Using additional datasets, these resistance values can be modified accordingly. For example, road and rail networks, as well as watercourses, can increase the resistance value and even act as a barrier. If available, information about green bridges/crossings can also change the spatial resistance. Distance to buildings and elevation/slope are additionally used to identify areas that have barrier character. For example, areas that are close to settlements are treated as barriers on an animal group-specific basis, with distance varying between groups. Similarly, areas above a certain sea level or slope are designated as barriers. An overview of the work flow is shown in Figure 7.

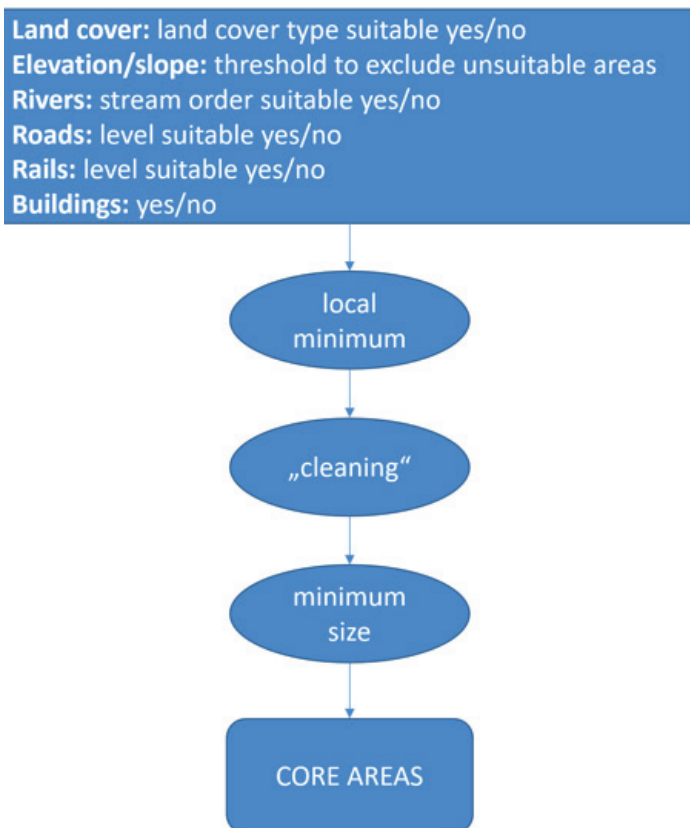


Figure 6: Workflow to delineate core areas

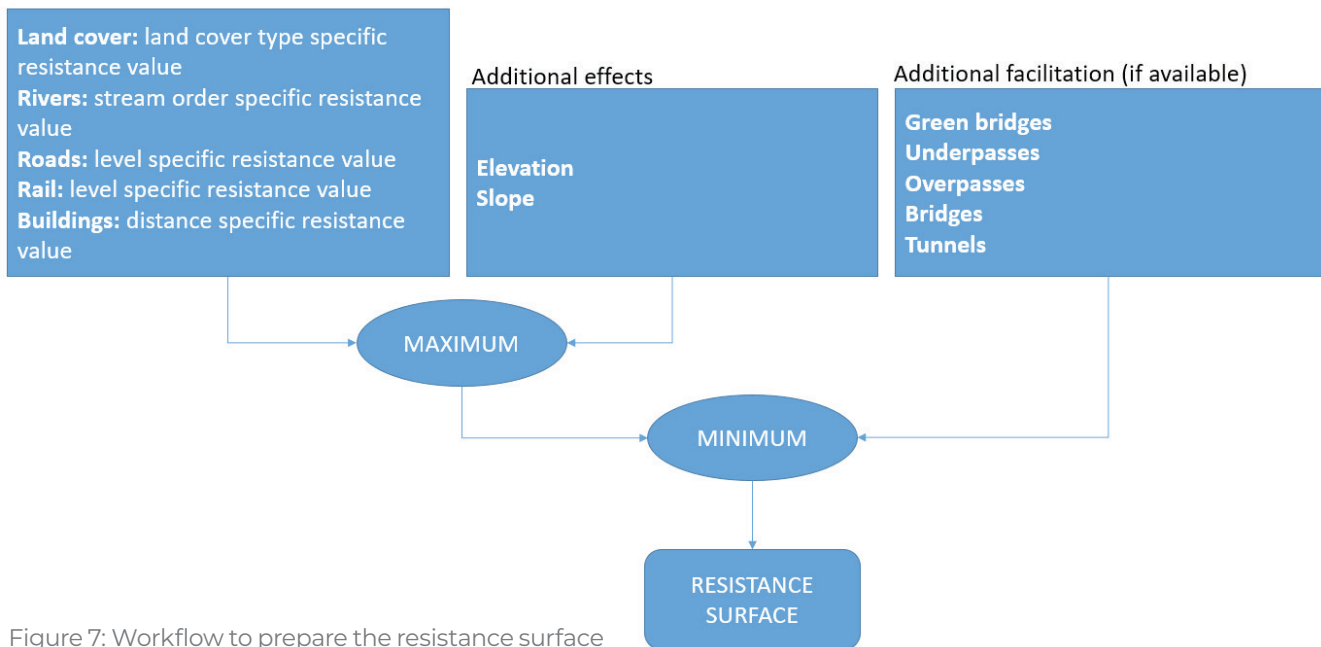


Figure 7: Workflow to prepare the resistance surface

2.4.4 Calculation of the corridors

After the preparation of data on core areas and the resistance surface, the Linkage Pathways tool is used to

calculate corridors. This calculation is done specifically for each species group selected as umbrella species for the respective pilot area. Figure 8 shows a preliminary result, based on initial assumptions, for red deer in the Austrian pilot area Kobernausser forest.

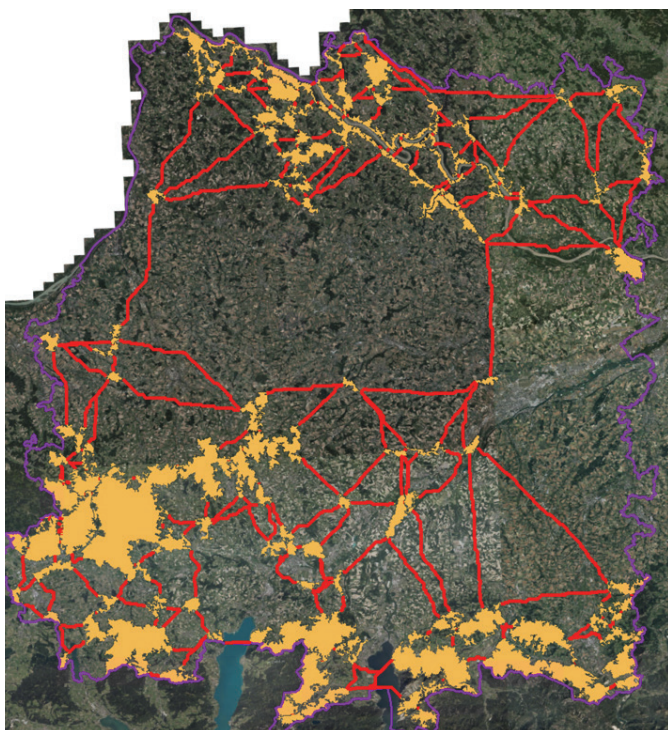
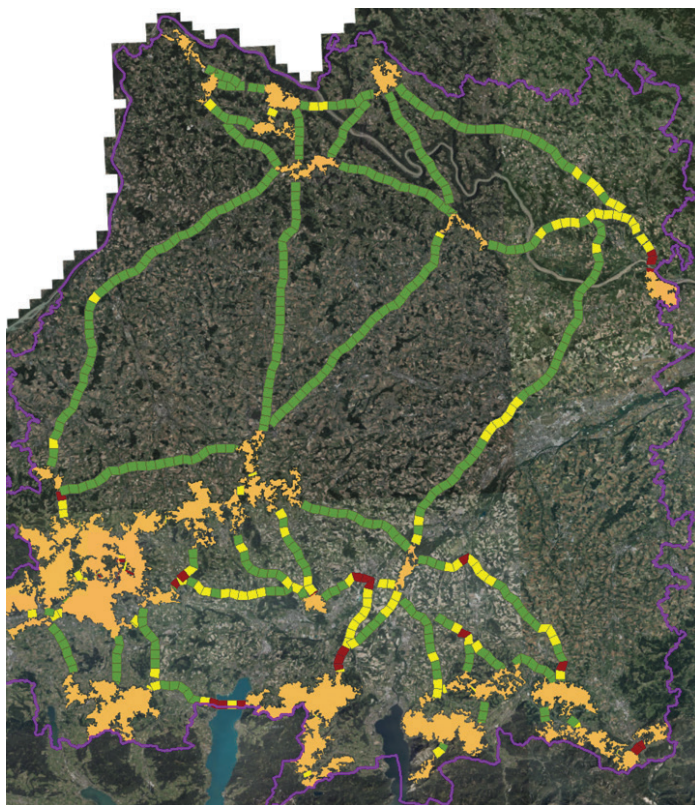


Figure 8: Preliminary corridors for the red deer in the PA Kobernausser forest

2.5 Calculation of pinch points

A crucial point for selecting suitable areas for monitoring the functional connectivity of the corridors, is the identification of bottleneck situations based on the structural connectivity. Again a component of the Linkage Mapper toolbox will be used, the Pinchpoint Mapper (McRae 2012). This tool tags areas within the corridors that are particularly sensitive to connectivity intactness and whose loss would particularly impact the network. Based

Figure 9: Representation of the permeability status of the corridor segments for the brown bear in the pilot area Kobernausser Forest based on preliminary results



on the results from 2.4.4, bottleneck situations can be calculated for the corridors for all selected species (or species groups).

In order to highlight possible target areas for monitoring the functional connectivity of the corridors identified, a permeability quality assessment of the corridors are conducted. For this, the corridors are split into segments with different ecological permeability status, which is derived from the previous steps. Figure 9 shows preliminary results for testing the approach for the brown bear in the pilot area Kobernausser forest: green segments represent landscape areas within the corridor with a high ecological permeability status, orange corridor segments are parts with a lower permeability status, while red segments represent landscape areas with barrier characteristics.

2.6 How to calculate wildlife corridors

The following section describes step-by-step the calculation of wildlife corridors and the detection of so-called bottleneck situations using spatially explicit GIS data and assumptions about how wildlife uses and moves across the landscape.

Two tools from the Linkage Mapper framework (<https://linkagemapper.org/linkage-mapper-tools/>) are used for this purpose:

Linkage Pathways: calculates corridors using (a) a layer of core areas to be linked, (b) a layer of resistance values that indicate how costly it is for an animal to move across the terrain, and (c) a distance matrix that reflects the distance between core areas.

Pinchpoint Mapper: identifies bottleneck situations based on the results of the Linkage Pathways tool from the previous step

To calculate the required core areas, the resistance map as well as the distance matrix as a set of relevant GIS layers is required. In addition, a set of rules on how these layers should be linked, is necessary.

This set of rules is mapped by implementing two Python scripts (see SaveGREEN library <https://www.interreg-danube.eu/approved-projects/savegreen/outputs:> calculation_corearea.py and calculation_resistance.py), which calculates the required inputs from the available data and input information. The parameters of the calculation are specific for each species or species group and can be entered in a table (see SaveGREEN library <https://www.interreg-danube.eu/approved-projects/savegreen/outputs:> InputParameters.xlsx) in advance to facilitate the definition of the parameters.

In a final step, after calculating corridors and bottlenecks, the corridors are divided into segments and the result of the bottleneck calculation is transferred to the segments. This enables an evaluation and further a prioritization of the corridor segments based on their permeability.

The two tools to be used (Linkage Pathways, Pinchpoint mapper) require the GIS-software ESRI ArcGIS (ArcMap 10.x) including the extension "Spatial Analyst", while the execution of the scripts are based on Python 2. For some steps in the calculation of the corridor segments, the freely available software QGIS 3.x is most suitable.

The following steps describe the calculation process:

1. Preparation of the GIS layers
2. Preparation of the species-specific input parameters
3. Calculation of the core zones using the script `calculation_corearea.py`
4. Calculation of the resistance values using the script `calculation_resistance.py`
5. Calculation of the corridors with the tool Linkage Pathways
6. Calculation of the bottleneck areas with the tool Pinchpoint Mapper
7. Segmentation of the corridors
8. Intersection of the corridor segments with the bottleneck areas

2.6.1 Preparation of the GIS layers

With one exception, all required input files have to be prepared to congruent raster files (Geo-Tiffs) with a resolution of 10 meters and EPSG 3035 projection, which is included in the script's directory finally

(see script: `theInputPath`). The availability of suitable data for pilot areas and the good comparability between pilot areas played a major role in selecting relevant input datasets. Also, the guarantee of future updates of the input data and the associated permanent maintenance, was relevant and therefore a reason to rely on datasets produced within the Copernicus program. Another criterion was a good balance between spatial and thematic resolution. The following illustrations exemplary show the workflow and date used for the Austrian pilot area Pötsching.

Mask

The mask defines the study area for which all calculations are performed. Cells within the study area have the value 1, all others are NoData. This data set is derived from other sources, in this case from the landcover data set (see below).

Usage in scripts:

Input: *theMask*

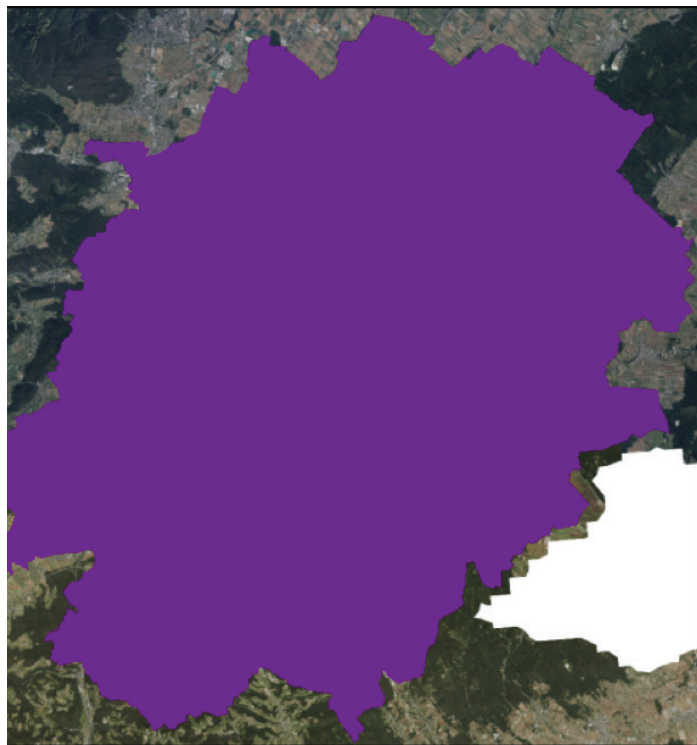


Figure 10: Layer „Mask” as delimitation of study area

Landcover

The landcover dataset used for SaveGREEN is based on Copernicus Sentinel-2 data for the reference year 2017 and a resolution of 10 meters (Malinowski et al., 2020; see <http://s2glc.cbk.waw.pl/extension>).

The dataset distinguishes between the following classes:

Value	Landcover class
62	Artificial surfaces
73	Cultivated areas
75	Vineyards
82	Broadleaf tree cover
83	Coniferous tree cover
102	Herbaceous vegetation
103	Moors and heathland
104	Sclerophyllous vegetation
105	Marshes
106	Peatbogs
121	Natural material surfaces
123	Permanent snow
162	Water bodies

Usage in scripts:

- » Input: theS2GLC
- » Script calculation_corearea.py: theRemapValList_S2GLC defines if a certain landcover class can serve as part of a core area.
- » Script calculation_resistance.py: theRemapValList_S2GLC_res defines the resistance values of the landcover classes.

Digital Elevation Model

For altitudinal information, the Digital Elevation Model over Europe (EU-DEM) with a resolution of 10 meters was used (source: <https://land.copernicus.eu/imagery-in-situ/eu-dem>).

Usage in scripts:

- » Input: theDEM

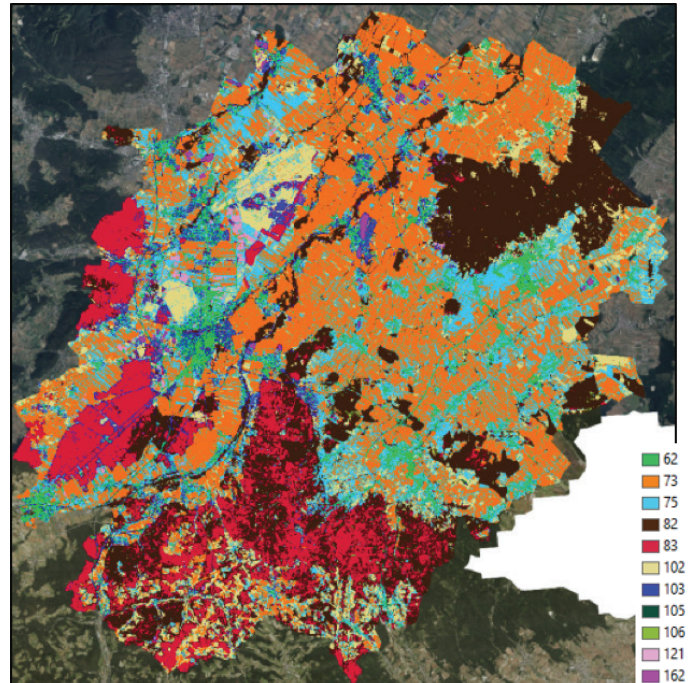


Figure 11: Layer “Landcover” represents spatial information on different types of physical coverage of the surface area

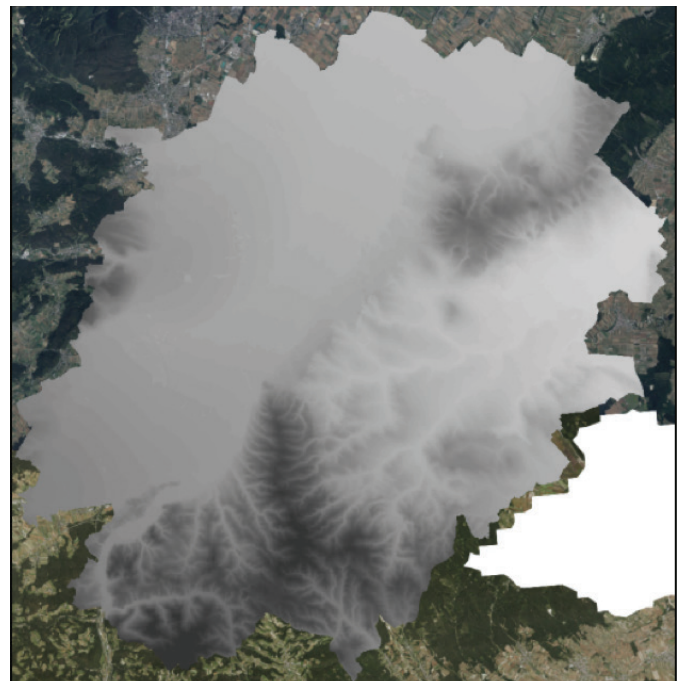


Figure 12: Layer “Digital Elevation Model” represents the ground elevation data of the terrain

- » Script calculation_corearea.py: theThresholdsList defines a threshold which altitude can be part of a core area.

Reclassified Digital Elevation Modell

For calculating the resistance layer a reclassified digital elevation model was used, based on the EU-DEM using following reclassification table:

Meters a.s.l.	Level
0-1500	1
1501-1750	2
1751-2000	3
>2000	4

Usage in scripts:

- » Input: theDEMrc1
- » Script calculation_resistance.py:
theRemapValList_dem_res defines the resistance values of the altitudinal classes.

Slope

The slope layer (*script: theSlope*) was calculated using EU-DEM. The units are given in degrees.

Usage in scripts:

- » Input: theSlope
- » Script calculation_corearea.py:
theThresholdsList defines a threshold which degree of slope is still permeable and therefore can be part of a core area.

Reclassified slope

Like the reclassified digital elevation model, a reclassified slope layer was created using following reclassification table:

Slope in °	level
< 40	1
40-60	2
> 60	3

Usage in scripts:

- » Input: theSlopercl
- » Script calculation_resistance.py:
theRemapValList_slope_res defines the resistance values of the slope classes.



Figure 13: Layer "Reclassified Digital Elevation Model" ■ 1

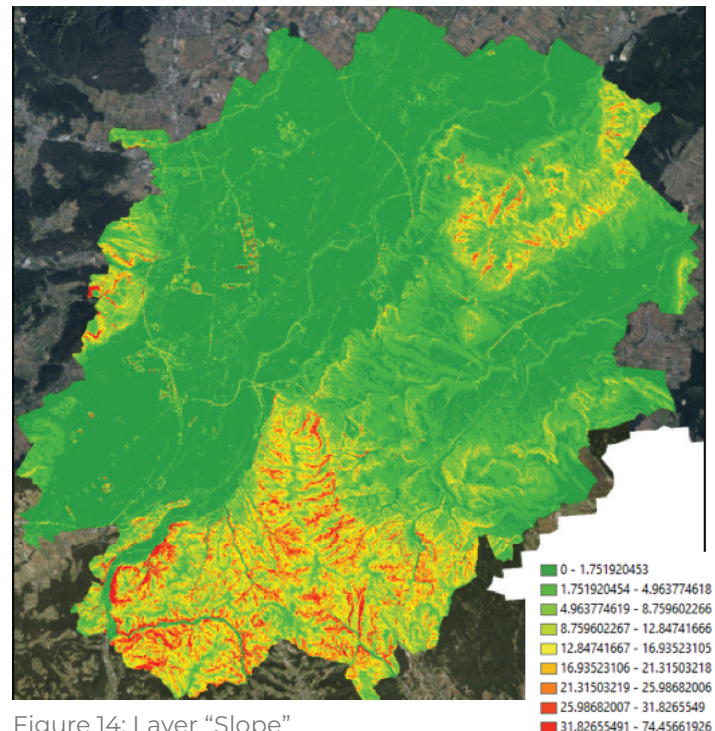


Figure 14: Layer "Slope"

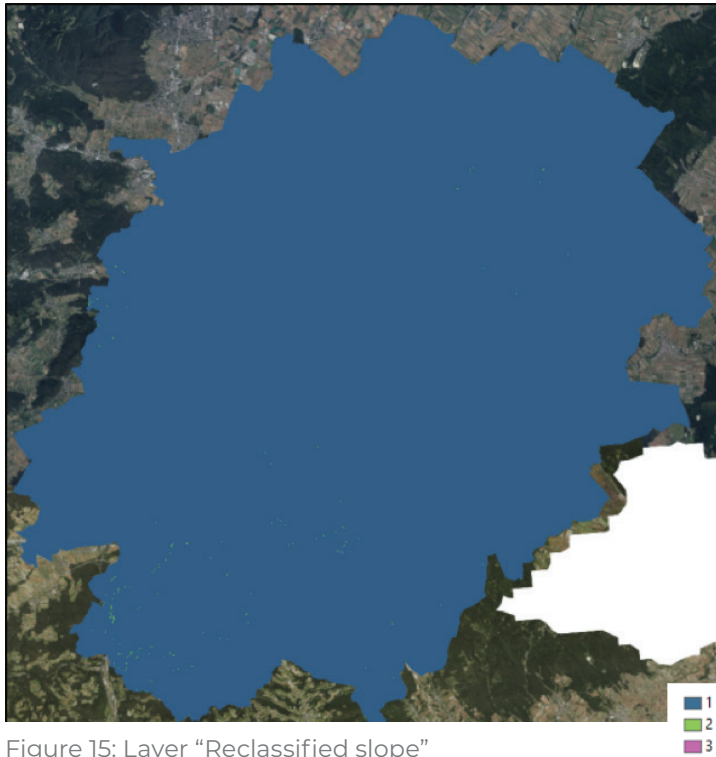


Figure 15: Layer "Reclassified slope"

Roads

Information on roads was retrieved from Open Street Map (OSM, <https://www.openstreetmap.org>, accessed from <https://www.geofabrik.de/en/index.html>), a collaborative project to provide free and regularly updated geographic data of the world.

The different categories were classified as follows:

fclass	level
bridleway	1
cycleway	1
footway	1
living_street	2
motorway	3
motorway_link	3
path	1
pedestrian	2
primary	3
primary_link	3
residential	2
secondary	3
secondary_link	3
service	2
steps	1

fclass	level
tertiary	2
tertiary_link	2
track	2
track_grade1	2
track_grade2	2
track_grade3	1
track_grade4	1
track_grade5	1
trunk	3
trunk_link	3
unclassified	2
unknown	1

Usage in scripts:

» Input: theRoads

» Script calculation_corearea.py:
theRemapValList_roads defines if a given road class splits a core area.

» Script calculation_resistance.py:
theRemapValList_roads_res defines the resistance values of the road classes.

Attention: Bridges and tunnels have to be removed from the layer before rasterizing the vector data!

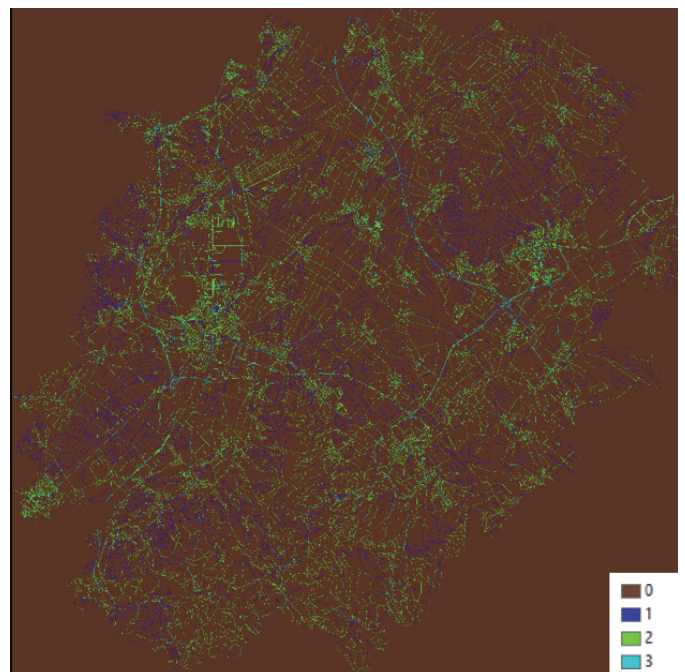


Figure 16: Layer "Roads"

Railways

Like the road layer the railways were prepared using the OSM database (accessed from <https://www.geofabrik.de/en/index.html>), using the following categories:

fclass	level
rail	2
all other	1

Usage in scripts:

- » Input: theRail
- » Script calculation_corearea.py: *theRemapValList_rail* defines if a given rail class splits a core area.
- » Script calculation_resistance.py: *theRemapValList_rail_res* defines the resistance values of the rail classes.

Attention: Bridges and tunnels have to be removed from the layer before rasterizing the vector data!

Rivers

Rivers are represented based on the EU-HYDRO dataset (see <https://land.copernicus.eu/imagery-in-situ/eu-hydro>) using the cell value “Strahler”, representing the hydrological stream order as information. The Strahler value is defined by the stream size based on the hierarchy of tributaries (Strahler, 1957).

Usage in scripts:

- » Input: theRivers
- » Script calculation_corearea.py: *theRemapValList_rivers* defines if a river with a given Strahler value splits a core area.
- » Script calculation_resistance.py: *theRemapValList_rivers_res* defines the resistance values of rivers by applying Strahler values.

Distance to buildings

In a first step the OpenStreetMap (OSM) dataset “buildings” (accessed from <https://www.geofabrik.de/en/index.html>) served as input for the calculation of Euclidian Distances,

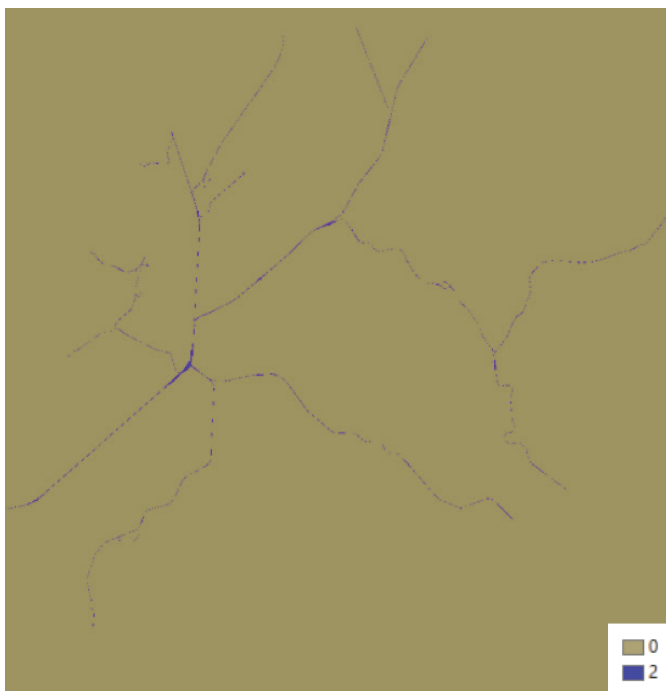


Figure 17: Layer “Railways”

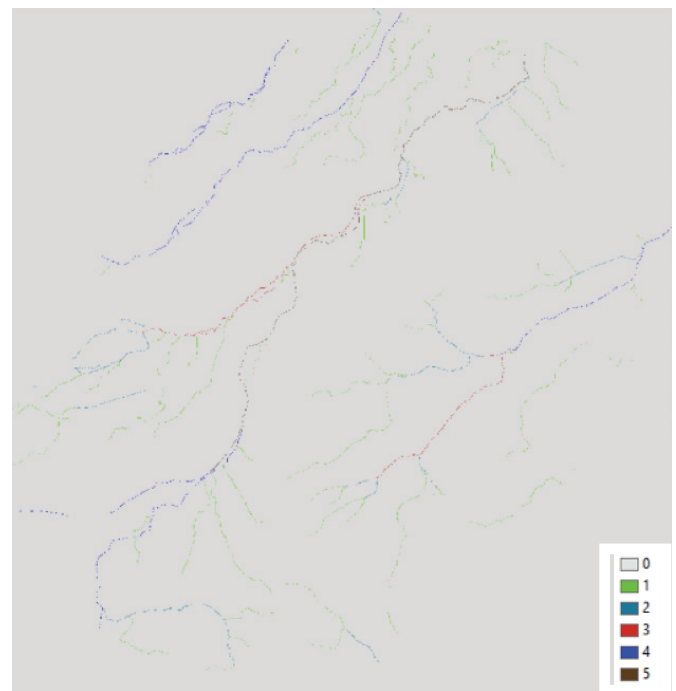


Figure 18: Layer “Rivers”

which were later reclassified in a second step using following reclassification table:

Euclidian distance in meters	level
< 10	1
< 50	2
< 100	3
< 250	4
< 1000	5
> 1000	6

Usage in scripts:

- » Input: theDist2Buildings
- » Script calculation_resistance.py:
theRemapValList_dist2buidlings_res
defines the resistance values of the Euclidian Distance values.

Green bridges

Green bridges are areas designed to allow wildlife to cross heavily frequented roads. To ensure that these crossing aids are addressed in the corridor model, it is recommended to

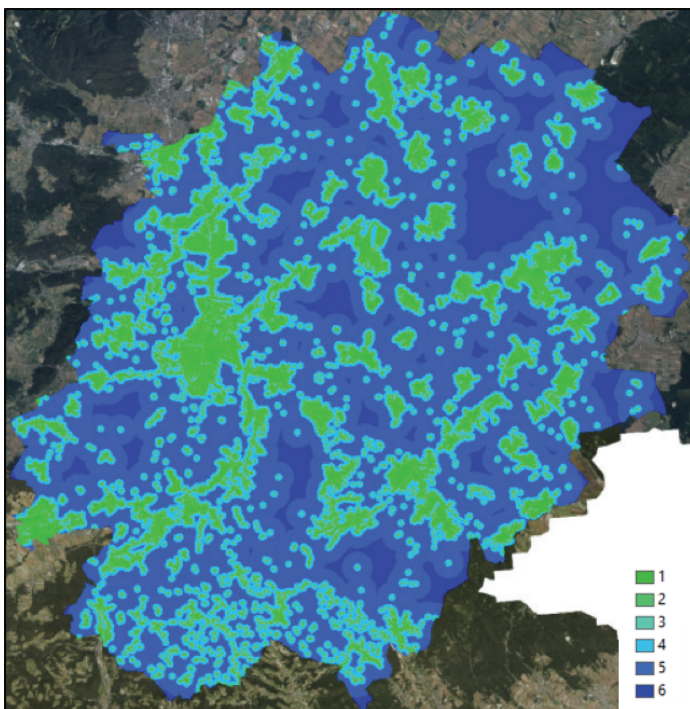


Figure 19: Layer "Distance to buildings"

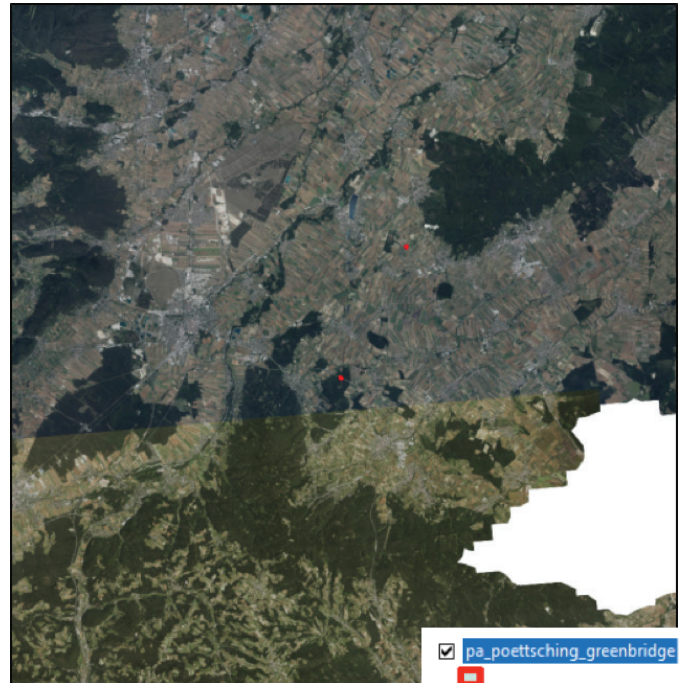


Figure 20: Layer "Green bridges"

include green bridges as core areas in the modelling, if desired. This is the only input dataset, which is included in the calculation in form of vector data (polygons). Due to the specific nature of these crossing aids, relevant data sets are not available to the public and have to be prepared on a project-specific basis.

Usage in scripts:

- » Input: theGreenbridges

Facilities

Facilities are defined as additional structures that facilitate or restrict wildlife movement that are not appropriately mapped in other input geodata sets. These include, for example, overpasses and underpasses, but also other structures like fences. As the dataset on green bridges, such a dataset must be created using information that requires specific knowledge of the area or field mapping data. The assigned resistance values must be aligned individually based on the values of the other input data, which are then increased or decreased accordingly based on the values of this data set.

Usage in scripts:

- » Input: theFacilities



Figure 21: Layer “Facilities”

2.6.2 Preparation of the species-specific input parameters

The determination of species or species group specific input parameters for the core area and resistance layer calculations followed expert-based valuations. This assessment can be done in different ways, but in any case, require a species-dependent rating. As an aid, an Excel spreadsheet (InputParameters.xlsx) has been created to summarize the values assigned for the different species (see SaveGREEN library <https://www.interreg-danube.eu/approved-projects/savegreen/outputs>).

For the calculation of the core areas, different yes/no decisions as well as certain thresholds, such as the maximum sea level for a core area, are determined. These values are then transferred to the corresponding Python script (see chapter 2.6.3).

The determination of the resistance values is a particularly crucial point in the calculation of the corridors, which requires special attention. It is recommended to find linguistic categories for the evaluation, as

This part is to identify core areas and (large) stepping stones that should be connected by corridors using the Linkage Mapper tool. Suitable areas can be divided by linear structures like motorways or large rivers. In addition, areas above a certain altitude or steep areas can be excluded. A crucial point is the patch minimum area that can differ significantly between the pilot areas.

CORE AREA		Red deer (Cervus elaphus)
Land cover (Sentinel 2)		
Artificial surfaces and constructions	Suitability [yes/no]	no
Cultivated areas		no
Vineyards		no
Broadleaf tree cover		yes
Coniferous tree cover		yes
Herbaceous vegetation		yes
Moors and Heathland		yes
Sclerophyllous vegetation		yes
Marshes		no
Peatbogs		no
Natural material surfaces		yes
Permanent snow covered surfaces		no
Water bodies		no
Landscape		
patch minimum area	[km ²]	2
Elevation (EU-DEM)	maximum [m]	2500
Slope (EU-DEM)	maximum [°]	80
Infrastructure (OSM)		
high-level road network	Suitability [yes/no]	no
medium-level road network		yes
low-level road network		yes
railroad		yes
Rivers (EU-Hydro) Strahler		
< 4	Suitability [yes/no]	yes
>= 4 and < 7		yes
>= 7		no

Figure 22: Screenshot of InputParameters.xlsx showing the input parameters for the calculation of core areas of red deer as an example.

this enables faster agreement in an expert-based process. Here five categories (no, low, medium, high, barrier) are defined, which in an ordinal scale describe the permeability by wildlife through the terrain. This system can of course be adapted if necessary. The classes of slope and sea level have an additional effect on the value of permeability through the terrain, here four possible effects are realized (-: no additional effect, +: low additional effect, ++: medium additional effect, +++: high additional effect).

These ordinally scaled evaluations must then be translated to numbers in the script

This part is to assign resistance values to the landscape and the features inside in order to derive a resistance map for the Linkage Mapper tool using linguistic terms. Resistance categories range from no, low, medium and high resistance to barriers. Elevation and slope act as amplifiers, where - means no effect, + medium effect and ++ large effect. For calculation these categories will be translated to values. For each location the maximum value will be used. In a final step spatial information on over- and underpasses and greenbridges (if available) will be used to assign places of passability.

RESISTANCE		Red deer (<i>Cervus elaphus</i>)
Land cover (Sentinel 2)		
Artificial surfaces and constructions		high
Cultivated areas		low
Vineyards		medium
Broadleaf tree cover		no
Coniferous tree cover		no
Herbaceous vegetation		low
Moors and Heathland		low
Sclerophyllous vegetation		low
Marshes		low
Peatbogs		low
Natural material surfaces		low
Permanent snow covered surfaces		high
Water bodies		high
Infrastructure (OSM)		
high-level road network		barrier
medium-level road network		medium
low-level road network		low
railroad		medium
Rivers (EU-Hydro)		
1		low
2		low
3		low
4		medium
5	[Strahler value]	medium
6		high
7		high
8		high
9		barrier
10		barrier
Elevation (EU-DEM)		
0-1500		-
1500-1750	[m a.s.l.]	-
1750-2000		+
>2000		++
Slope (EU-DEM)		
< 40		-
40-60	[°]	+
> 60		+
Distance to buildings (OSM)		
< 10		barrier
< 50		high
< 100		low
< 250	[m]	low
< 1000		no
> 1000		no
Facilities		
Overpasses		low
Underpasses		low
Green bridges		low

◀ Figure 23: Screenshot of InputParameters.xlsx showing the input parameters for the calculation of a resistance layer for e.g. red deer.

(see chapter 2.6.4), with very low values recommended for the class “low” and very high values for the class “barrier”. A good translation into numerical values requires both, knowledge on wildlife ecology and modelling experience, but also an appropriate process of trial and error.

2.6.3 Calculation of the core zones using the script calculation_corearea.py

The script uses lists of lists to specify several input parameters for each species or species group separately. At this time such parameter tables are provided for 11 species and species groups are provided. However, this list can be extended easily. The main advantage of this approach is an on-the-fly documentation of the modelling environment for each species or species group, which can be modified without difficulty.

Following inputs have to be specified:

INPUT VARIABLE / PARAMETER	MEANING
thePraefix	Path defining the work directory besides the argument for the pilot area and the data subfolder.
theRemapValList_S2GLC	Assigns suitability of land cover classes for a species (group)
theRemapValList_rivers	Assigns suitability of Strahler values for a species (group)
theRemapValList_roads	Assigns suitability of road classes for a species (group)
theRemapValList_rail	Assigns suitability of rail classes for a species (group)
theRemapValList_S2GLC_border	

INPUT VARIABLE / PARAMETER	MEANING
theShrinkValues	Shrinks the core areas by the number of cells specified by this parameter
theMinimumSize	Minimum size of the core area
theMask	Mask specifying the study area
theS2GLC	The land cover raster file
theDEM	The digital elevation model
theSlope	The slope raster file
theRoads	The roads raster file
theRivers	The rivers raster file
theRail	The rails raster file
theGreenbridges	The shapefile including green bridges which should serve as core areas

After preparing all input files and specifying the input parameters, the script can be executed with the python command prompt by using two additional arguments:

- » The name of the pilot area / study area
- » The species (group) to be modelled

Example:

> calculation_corearea.py poettsching 3

runs the script for the study area “poettsching” for the species “red deer”, assuming that the input files needed are located in the directory: thePraefix + „poettsching“ + „data“

So, if thePraefix is “C:\model” the input files should be located in: C:\model\poettsching\data

Attention: due to fact that Python starts counting with the value 0, the number defining the row of the species has to be reduced by one (Greywolf: 0, Brown bear: 1, etc.)

After running the script successfully, results can be found in the following directory: thePraefix + study area + species (group)

In this example this is: C:\model\poettsching\red_deer

Besides several intermediate results, two files, the core areas and the distance matrix, are of special interest, because they are used as inputs for the Linkage Mapper:

- » “corearea” + study area + species (group) + “.shp”
- » “neartable” study area + species (group) + “.txt”

In this example:

- » corearea_pottsching_red_deer.shp
- » neartable_poettsching_red_deer.txt

2.6.4 Calculation of the resistance values using the script calculation_resistance.py

Similar to the script calculation_corearea.py, the script calculation_resistance.py calculates a resistance layer for the Linkage Mapper tool using the following input information:

INPUT VARIABLE / PARAMETER	MEANING
thePraefix	Path defining the work directory besides the argument for the pilot area and the data subfolder.
theRemapValList_S2GLC_res	Assigns resistance values of land cover classes for a species (group)
theRemapValList_rivers_res	Assigns resistance values of Strahler values for a species (group)

INPUT VARIABLE / PARAMETER	MEANING
theRemapValList_ roads_res	Assigns resistance values of road classes for a species (group)
theRemapValList_ rail_res	Assigns resistance values of rail road classes for a species (group)
theRemapValList_ dist2buildings_res	Assigns resistance values of distance to buildings classes for a species (group)
theRemapValList_ dem_res	Assigns extra values of altitudinal classes for a species (group) that will be added on top of the resistance values
theRemapValList_ slope_res	Assigns extra values of slope classes for a species (group) that will be added on top of the resistance values
theMask	Mask specifying the study area
theS2GLC	The land cover raster file
theRoads	The roads raster file
theRivers	The rivers raster file
theRail	The rails raster file
theDist2Buildings	The distance to buildings raster file
theDEMrc1	The classified digital elevation model
theSlopercl	The classified slope raster file
TheFacilities	The prepared raster file indicating facilitations and complications using appropriate resistance values

Just like the previous script, the calculation starts with the execution of the script in a Python environment with two additional arguments that specify the study area and the species (group) to be calculated.

Example:

> calculation_resistance.py poettsching 3

calculates the resistance layer for red deer for the study area Pötttsching.

The resistance layer can be found in the same directory as the core areas and the distance matrix, and is named as follows:

“resistance” + study area + species (group) + “.tif”

In this example: resistance_poettsching_red_deer.tif

2.6.5 Calculation of the corridors using the Linkage Pathways tool

After the required input files have been prepared, the corridors are calculated using the Linkage Pathway tool, which offers a quite complex framework - a detailed description of the procedure would go beyond the scope of this manual. Therefore, we refer to the relevant website, where detailed information is available: <https://linkagemapper.org/linkage-mapper-tools/>

A challenge is posed by the numerous setting options of the tool and its optimization, which requires an in-depth study of the various effects of the measures. Furthermore, the specific characteristics of a study area as well as the studied species (or species group) have certain demands to the settings of the calculation. Therefore, an optimization should be carried out in an iterative process. Hereafter a screenshot with settings for red deer can be found, which provided satisfactory results for most of the pilot areas examined.

Process Steps

Step 1 - Identify Adjacent Core Areas

Step 2 - Construct a Network of Core Areas

Network Adjacency Method
Cost-Weighted & Euclidean

Core Area Distances Text File. Leave blank to generate (ArcInfo license only)
C:\SaveGREEN\work\pa_kobernausserwald\red_deer\wbnf\neartable_kobernausserwald_red_deer_wbnf.txt

Step 3 - Calculate Cost-Weighted Distances and Least Cost Paths

Drop Corridors that Intersect Core Areas

Step 4 - Prune Network Using Options Below (optional)

Option A - Maximum Number of Connected Nearest Neighbors
5

Option B - Nearest Neighbor Measurement Unit
Euclidean

Option C - Connect Neighboring Constellations

Step 5 - Calculate, Normalize and Mosaic Corridors

Truncate Corridors

Cost-Weighted Distance Threshold to Use in Truncating Corridors
20000000

Additional Options

Bounding Circles Buffer Distance (optional)
25000

Maximum Cost-Weighted Corridor Distance (optional)

Maximum Euclidean Corridor Distance (optional)
35000

Output for ModelBuilder Precondition (optional)

Custom Settings File (optional)

Figure 24: Screenshot of Linkage Pathways tool showing proposed settings for red deer

2.6.6 Calculation of the bottleneck areas with the Pinchpoint Mapper tool

Building on the calculation of the corridors in the pilot areas, the determination of bottleneck situations is performed using the Pinchpoint Mapper tool. For in-depth details on the tool, please visit <https://linkagemapper.org/linkage-mapper-tools/>. As in the previous step, the appropriate parameters must be optimized based on the general conditions of the area and the species (or species group).

2.6.7 Segmentation of the corridors

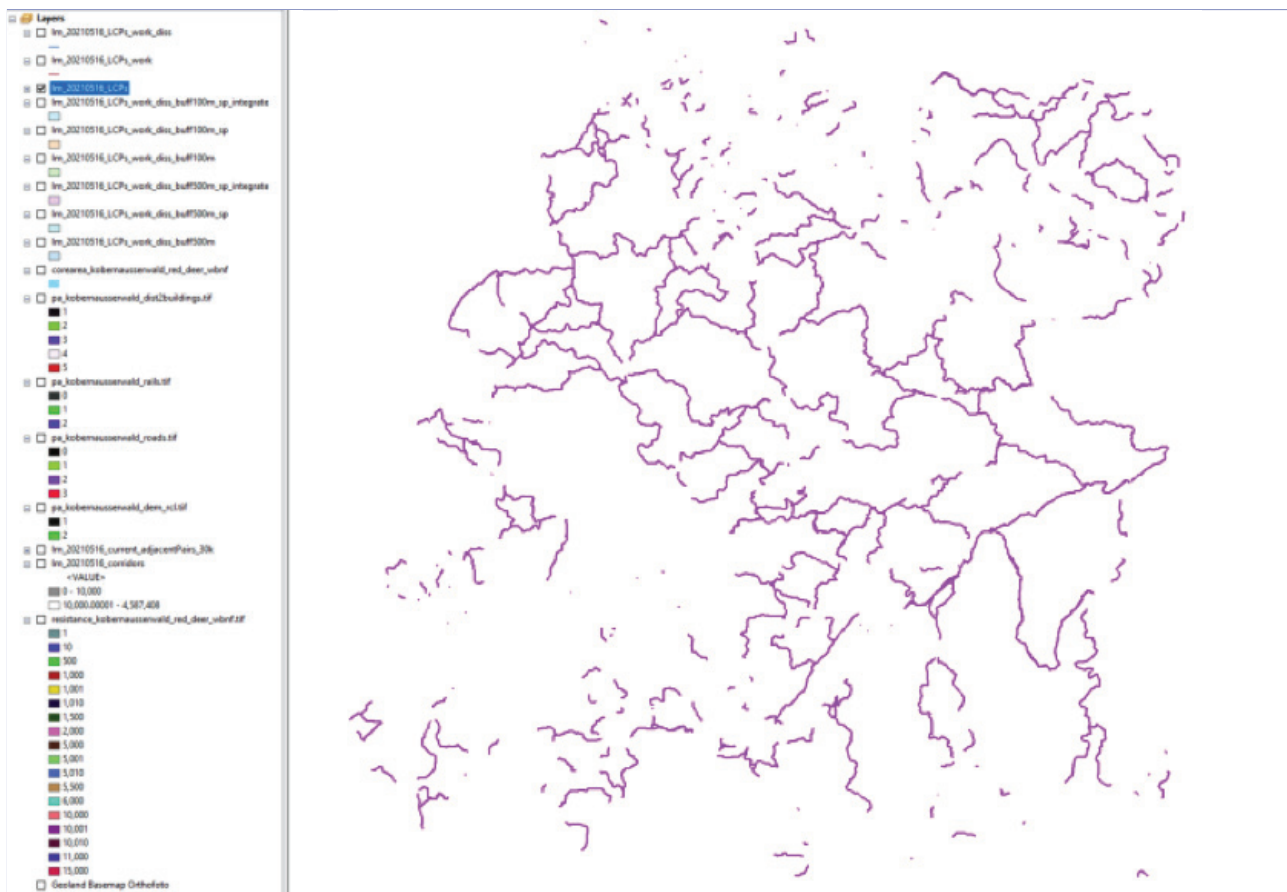
Following the calculation of the corridors, various results are available as output of the Linkage Pathway tool. The

resulting corridors are provided on the one hand as a raster file, reflecting the suitability of the cells as corridors, and on the other hand as a line vector file, where the lines connect the core areas in a certain area. In order to evaluate certain sections of the corridors, they must first be divided into individual segments, which can then be assigned certain attributes. This following example shows a step-by-step procedure to derive the segments using ArcGIS and QGIS for the Kobernausser Forest pilot area in Austria.

ArcGIS

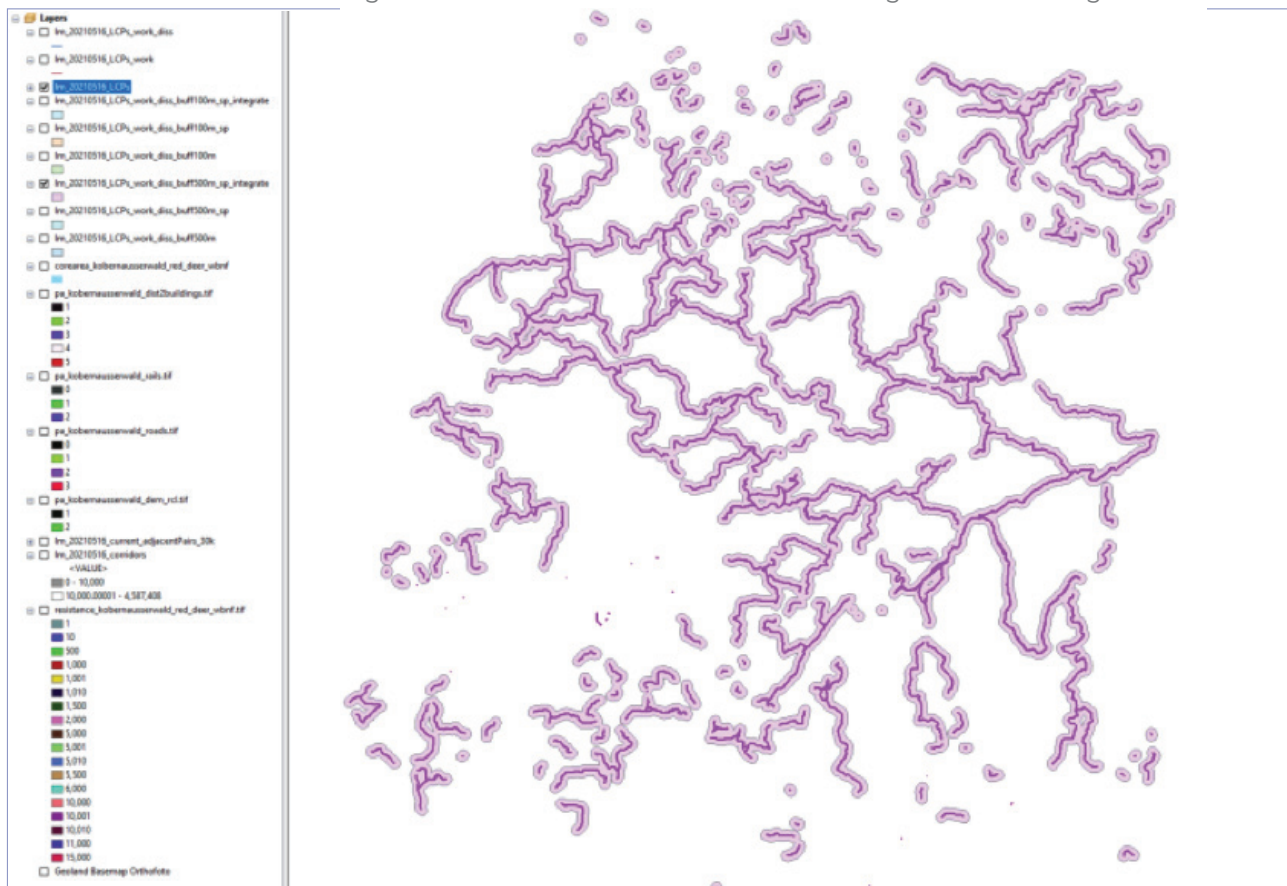
a) Starting point: line vector file representing the corridors (Figure 25)

b) Calculating a “Buffer by distance” (here 500m), followed by the application of the instrument “Integrate” (here 30m) (Figure 26)



▲ Figure 25: Vector file of corridors

▼ Figure 26: Buffering of the corridors



Step 1



▲ Figure 27: Screenshot of the initial step of applying the “Centerlines” tool in QGIS

Step 2

▼ Figure 28: Screenshot of the subsequent step of applying the “Centerlines” tool in QGIS

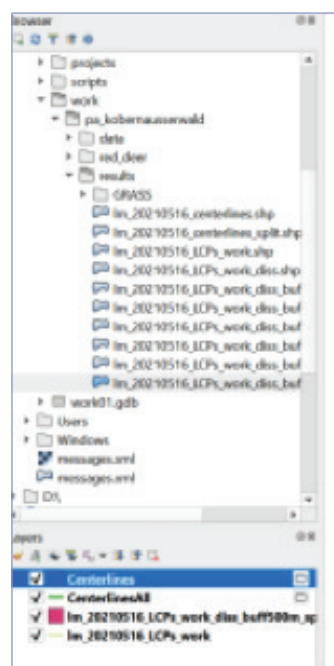
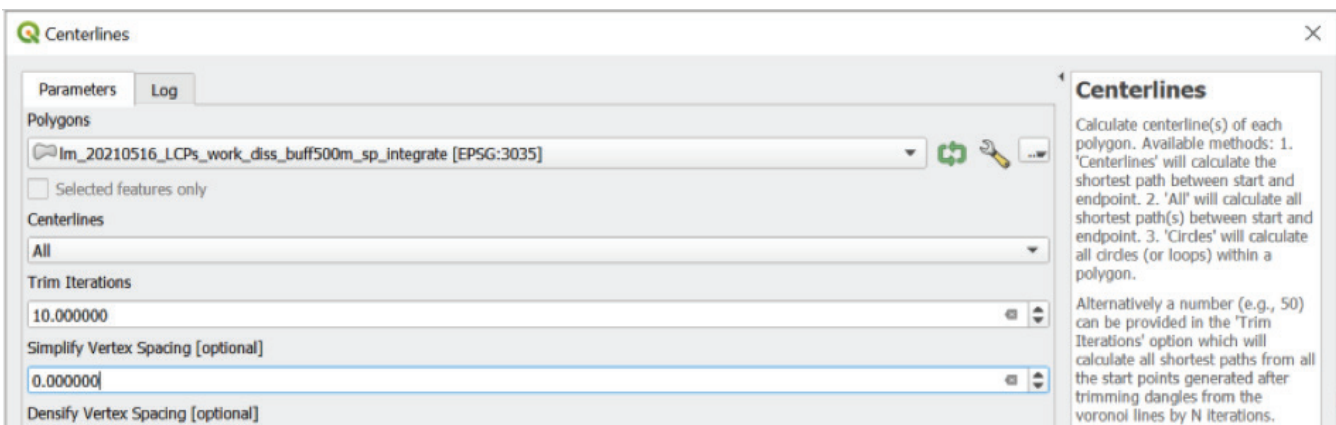


Figure 29: Result of applying the “Centerlines” tool in QGIS

Change to QGIS

c) Calculation of centerlines using the tool “Centerlines” of the plug-in „Geometric Attributes“(Figure 27, Figure 28 and Figure 29).

d) Merging and segmentation with the help of the following steps of “Merge”, “Dissolve”

and “Single Parts”. Calculation of transects using the tool “Transects by Distance” of the plug-in „Geometric Attributes“ (Figure 30 and Figure 31).

Repeat for sections that have not been calculated.

Figure 30: Screenshot of applying the “Transects by Distance” tool in QGIS

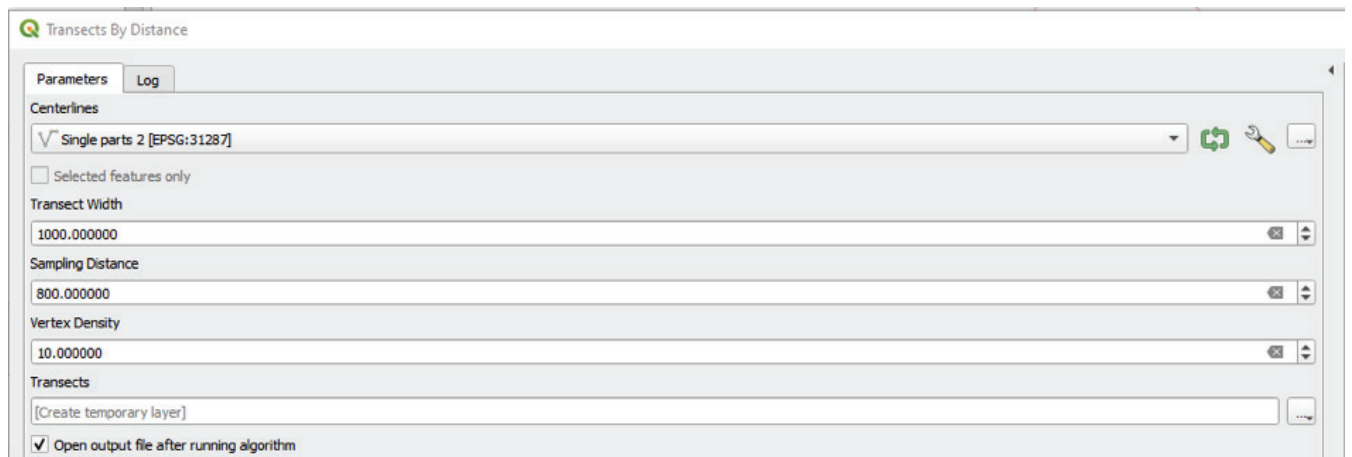
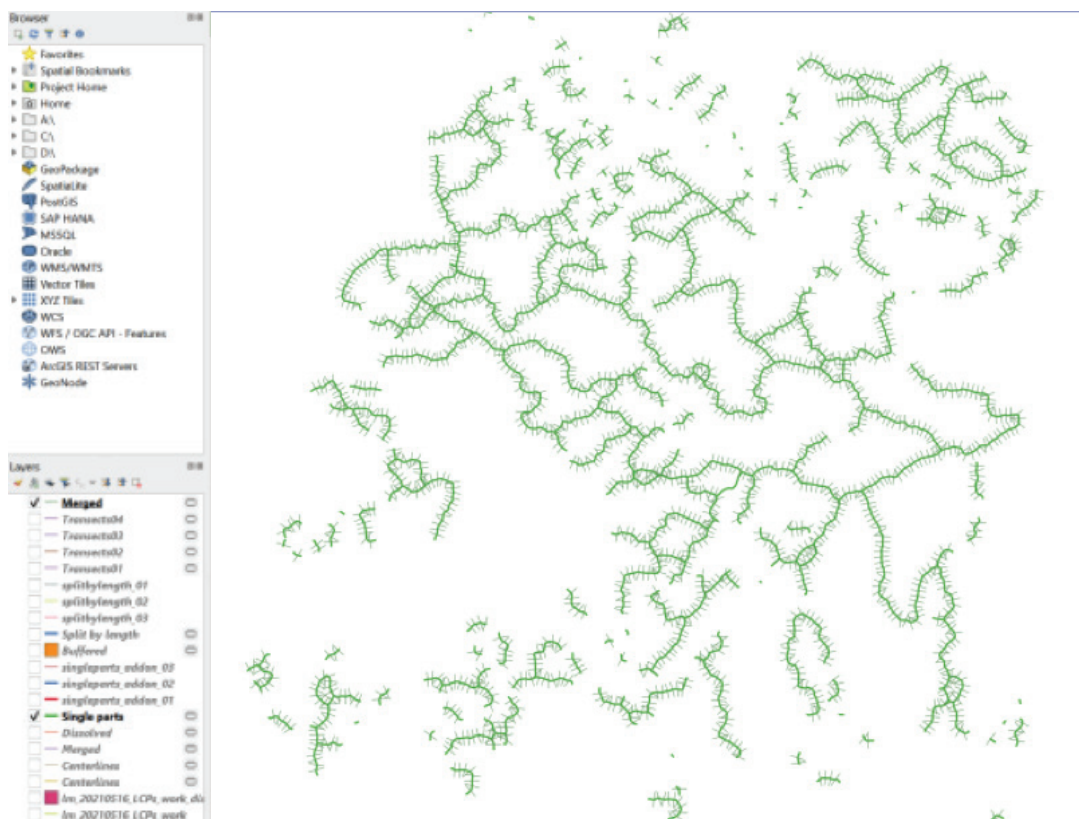


Figure 31: Result of the segmentation workflow in QGIS



Switch to ArcGIS

e) Conversion of the raster output of the corridor calculation to a polygon vector file using a threshold (here 10000) (Figure 32).

f) Combination of resulting polygons with transects using “Features to Polygons” tool - this result has to be cleaned subsequently.

2.6.8 Intersection of the corridor segments with the bottle-neck areas

In this process step the corridor segments created in 2.6.7 are combined with the result of the pinchpoint mapper calculation (Figure 33). All steps are executed using ArcGIS:

a) Filling of the gaps in the pinchpoint mapper result using the raster calculator, in this example using the expression:

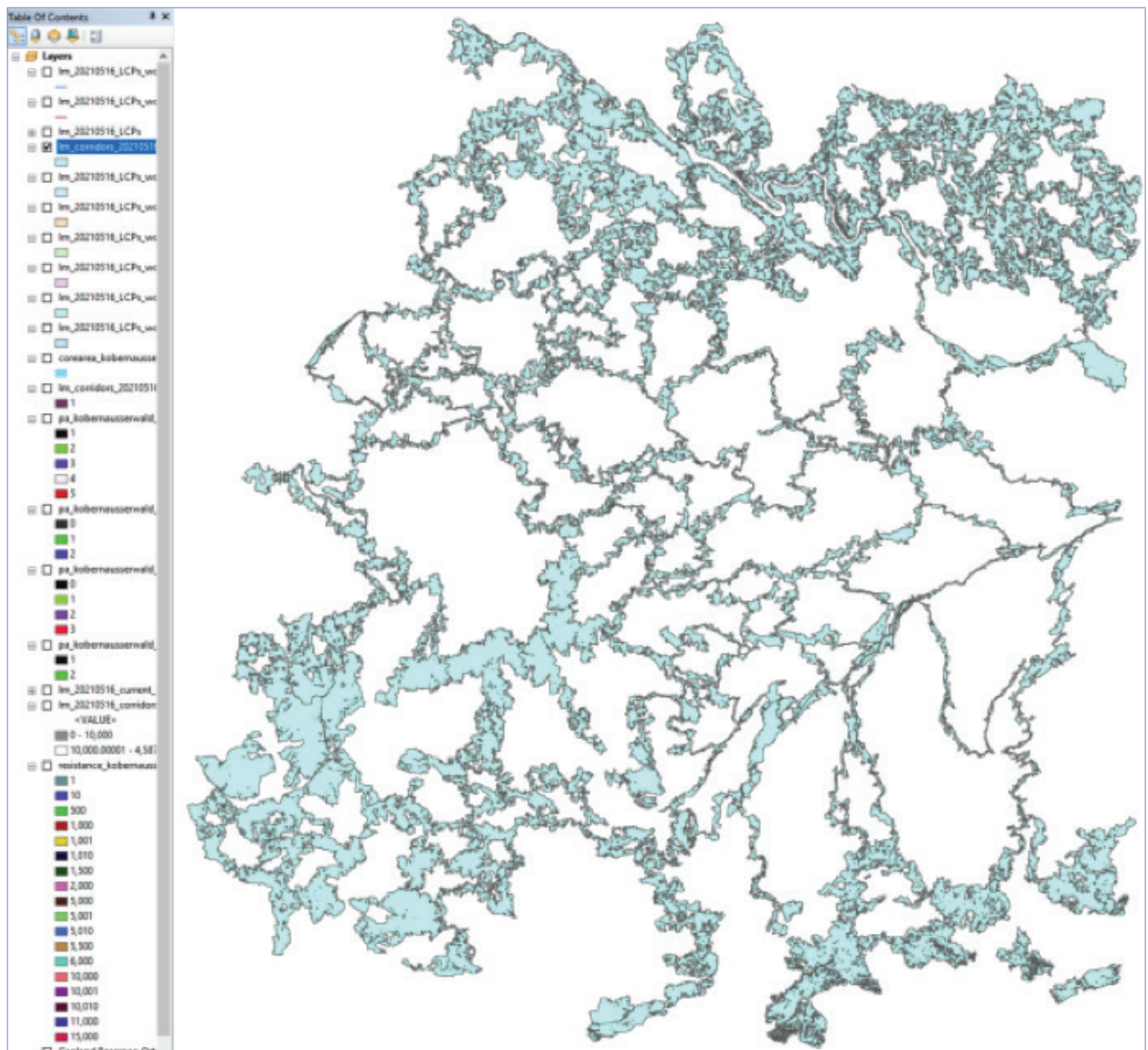


Figure 32: Results of the conversion of calculated corridors



CHAPTER 3

Monitoring of functional connectivity



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The second major step in a comprehensive monitoring of landscape connectivity represents the monitoring of functional connectivity, thus the assessment if species (or species groups) are able to reach their core areas and use identified corridors between them. Be aware that much of the monitoring work is in progress or has already been carried out to fulfil the requirements of different frameworks and directives. However, a homogeneous approach to monitor the functional connectivity is missing specially to integrate the obtained information into larger databases and to create a benefit by combining information from different sources.

Thus, one superordinate aim of the concept of monitoring functional connectivity is, besides collecting information on indicator species, to propose a technical backbone that allows on the one hand an efficient use in the field and on the other hand an easy data integration into larger data collections.

A focus of the monitoring should be laid on over- and underpasses and other bottleneck situation of relevant corridors to assess their permeability. This should provide useful information for the further implementation of such mitigation measures to further increase the connectivity of core areas or to better supplement new infrastructure projects that reduce the connectivity of the landscape per se.

The monitoring of functional connectivity follows different steps. At the beginning, **suitable indicators** need to be selected. Such suitable indicators might be e.g. animal species, which indicate a certain condition of the habitat through the characteristics of their occurrence (e.g. presence/absence, frequency, vitality) in this living environment. Animal groups selected as indicators include a particularly large number of species whose habitat requirements are well known and whose occurrence can be correlated with specific habitat characteristics. Good indicators (or indicator groups) are

characterized by the fact that they are relatively easy to record and to evaluate and allow statements to be made about factors and/or cumulative effects that are otherwise difficult to measure.

In order to determine suitable indicator species or groups, the surrounding and adjoining habitats of bottleneck areas, which are connected by green bridges or crossing aids must be selected initially.

A list of habitat types (according to the EUNIS-habitat classification) is listed in the SaveGREEN library (see <https://www.interreg-danube.eu/approved-projects/savegreen/outputs>) for green bridges, underpasses and corridors. These tables also show a list of relevant animal groups for the subsequent monitoring and the assigned monitoring methods proposed.

These EUNIS habitat types are:

- » Inland surface waters (C, C2, C3),
- » Grassland and lands dominated by forbs, mosses or lichens (E, E2),
- » Regularly or recently cultivated agricultural, horticultural and domestic habitats (I),
- » Woodland, forest and other wooded land (G, G5),
- » Constructed, industrial and other artificial habitats (J),
- » Habitat complexes (X),
- » Inland unvegetated or sparsely vegetated habitats (H),
- » Mires, bogs and fens (D).

For the selection of the indicator groups, also with regard to the study of ASFINAG (2020), Austria's managing body of motorways and expressways, on monitoring crossing aids two questions are central:

- » Which animal groups are suitable as an indicator groups in general and for which life stage of a species reliable statements can be made? (Habitat corridor, habitat use).
- » Which survey method is the most efficient for each animal group?

Different animal groups show a different action radius, which refers to the migration performance of the respective species. It includes both the change between sub-habitats (e.g. for feeding or paring) and the colonization of new habitats (dispersal tendency). The radius of action is therefore divided into three categories: large, medium and small.

Species with a **large action radius** apply to those already addressed within the framework of the Alpine-Carpathian Corridor (AKK) and other trans-regional corridors. According to the listing of AKK target species, this concerns large mammals such as red deer, wild boar, roe deer and subsequently carnivore species, such as brown bear, lynx and wolf. Furthermore, this includes fish species, which use the habitats of tributary streams in the mountain regions in breeding season (e.g. small barbs, huchen, European grayling) and therefore have to migrate. Since capable of flying the group of birds and bats is also classified as dispersers in terms of migratory behavior. Finally, also medium-sized mammals, that are very mobile, are also belong to the species with a large radius of action (esp. brown hare, red fox, marten and otter).

Species with a **medium action radius** also use crossing aids of the local environment, but are less mobile. This group includes small mammals such as dormice, mice, gopher, hamster, hedgehog and reptiles as well as several amphibian species (e.g. common toad).

The group of species that have a **small action radius** is basically more heterogeneous. This group includes small animals such as certain amphibian species (e.g. group of salamanders including newts) and reptiles (e.g. lizards),

but above all ground-based and aquatic invertebrate species.

For this study, large and medium-sized mammals were selected representing animal groups with a large radius of action. Since birds are not dependent on crossing aids and bats are very complex to survey, monitoring was only recommended if corresponding species are present and particularly relevant in terms of nature conservation.

Small mammals and reptiles were selected among vertebrates with small to medium action radius. For insects, ground beetles (small to medium radius of action) were selected. As small area colonizers, they provide good information about soil moisture, soil conditions, and succession stages (woody plant succession). At the same time, there is sufficient knowledge about habitat requirements and dispersal tendencies of this animal group (ASFINAG 2020).

There are **minimum requirements** for the monitoring for the following defined groups:

- » **Large carnivores,**
- » **Large sized mammals,**
- » **Medium sized mammals**

These indicator species groups are monitored based on two approaches: (1) using photo traps, and (2) field monitoring to record direct observation or any other activity signs, such as tracks, droppings or wallows.

The monitoring by **photo traps and of indications of species presence** (remnants of feeding, droppings, hair, resting sites, etc.) as well as **animal tracks** (in snow, mud, sand, etc.) should be carried out in **parallel** to create supplemental information on the use of the corridor by the species. If photo traps are not available or not in place in the required number, the focus can be laid on the acquisition of activity signs (indications of presence and tracks).

3.1 Timeline

The surveys ideally should cover the whole year or at least the relevant vegetation period (which is the portion of the year in which local conditions permit normal plant growth), in order to reflect possible seasonal differences. As the monitoring should be conducted as synchronously as possible, narrow time windows were set in which all monitoring areas should be surveyed at the same time.

For monitoring of mammals, which are the minimum requirements in course of the SaveGREEN project, the monitoring period is scheduled ideally for the duration of one year. If this is not possible, monitoring should be conducted at least when migration routes are frequented by the target species.

The table „Timeline” in the SaveGreen online library provides an overview of the frequency of monitoring for the respective monitoring methodologies. The timing and time span of the particular methods are described in chapter 3.2.

The optimal duration and frequency of monitoring is throughout the whole year with monthly visitations. In case of limited resources it is important **to record at least all species-specific migration movements** e.g.: changes from winter to summer habitats and back, mating sites, breeding sites, sites for feeding. During periods when such migrations do not occur and thus the likelihood of detection is low, monitoring may not be necessary.

3.2 Methodology for indicator species

In the following, a rough overview of the most important recording methods of common indicator species will be given. Therefore, these

explanations do not claim to be complete and are intended to be a first basis for decision-making and a starting point for more in-depth research of the species of interest. Based on an existing national monitoring methodology (ASFINAC, 2018) of the Austrian freeway network operator ASFINAC, the approach was adapted to the needs of the project and comprehensively supplemented to meet the different requirements of the SaveGREEN pilot areas.

3.2.1 Large and medium sized mammals, including large carnivores

The survey of large and medium-sized mammals is basically carried out using camera traps throughout the year (i.e. continuous recording). Battery replacement and exchange of the storage medium is necessary in due time (also see section 3.3 below, and the SaveGREEN library „Timeline“).

In addition, evidence of species occurrences, e.g. animal tracks or droppings, should be observed throughout the year. Alternatively, other animal signs of presence can be monitored (i.e. browsed vegetation,

antlers, etc.). The monitoring measures are facilitated by using the QField application. Within SaveGREEN a data package has been developed that enables a consistent field monitoring approach throughout the different pilot areas and also supports an efficient data integration of the collected information into a comprehensive database – further details can be found in see SaveGREEN library (see <https://www.interreg-danube.eu/approved-projects/savegreen/outputs>). The minimum frequency for the monitoring of large and medium sized mammals are three visits in winter and three visits in summer season to detect animal activity signs year-round and tracks in the snow in winter. Ideally, further monitoring will also take place in spring and autumn to take into account the activity maxima of other animals, e.g. the brown bear, which is a key species for the analysis of connectivity. These activities can be aligned with the photo trap monitoring as batteries and data storage in photo traps normally need a replacement every one to two months – such maintenance visits can be used to collect other species data as well (Reimoser et al. 2010, Richtlinien und Vorschriften für das Straßenwesen 2009).



3.2.2 Small mammals

Small mammals are also surveyed using camera traps. In contrast to the larger species, the camera traps are aligned close to the ground. In order to increase the probability of detecting smaller species, a strip of grass should be mowed regularly in front of the camera traps. In addition, the recording intervals are adapted to the activity times of small mammals.

We recommend continuous recording from June to August. In addition, evidence of animal tracks and signs throughout the year as well as droppings can be observed. There is also the opportunity of using animal track trap that can be laid out from March until November, depending on target species. These simple



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soil/sand traps allow to capture the footprints and should be applied for 14-days and checked for tracks regularly. Additionally, live traps (box traps) can be used for evidence. They need to be laid out for four consecutive days or nights in each case in the time from August to October (Williams et al. 2018, Richtlinien und Vorschriften für das Straßenwesen 2009).

3.2.3 Amphibians and reptiles

The survey of amphibians and reptiles is only recommended if the green bridge, crossing aid or corridor is of high importance in terms of connecting habitats and therefore the occurrence within the monitoring area can be assumed.

Visual observation, sampling and identification of road-killed individuals are the most efficient and proven monitoring methods for amphibians and reptiles. It should be noted that a higher number of road killed animals in the vicinity of crossing aids (e.g. amphibian tunnels, overpasses, etc.) means that these structures are not accepted as desired. For the purpose of monitoring, surveys are conducted

once a month for amphibians between March and October. For reptiles, surveys should be performed once a month from late February/ March to October.

In addition and for a more in depth analysis, artificial hiding places for amphibians and reptiles can be laid out. For every 200 m² of crossing area, one artificial hiding place is sufficient, preferably in the central area of the crossing. The inspections are to be carried out monthly, within the same period as the collection of the observation data for both taxonomic groups between March-October.

Furthermore amphibians and small reptiles can be recorded using appropriate fences and pitfall traps. Therefore, a trap fence has to be erected in the middle of the crossing, if possible over the entire width of the crossing. The period and duration of the survey are to be determined in consideration of the species present, but must be conducted at least two times with a duration of 14 days each (Richtlinien und Vorschriften für das Straßenwesen, 2015).

Moreover, vocalizing amphibians (e.g. frogs and toads) can be monitored using acoustic detectors, mainly to identify breeding areas



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of frog species. These methods can be used well in spring and early summer (March-June). The equipment for sound recording must be relocated twice a month, allowing 48 hours for each recording.

Amphibians and reptiles can additionally be recorded by analysing road kills, since paved road often function as ecological traps. Amphibians and reptiles use roads as a warming zone in the cold periods and feeding zone at sunset and sunrise in summer. The length of the sampling section depends on the size of the crossing area, however should stretch over a minimum of 100 meters on both sides of the road.

Amphibians and reptiles could also be surveyed using camera traps. These camera traps are aligned inside the amphibian tunnels and close to the ground. Both species groups can use combined underpasses for migration between different habitats.

In aquatic habitats electrofishing surveys and samples with scoop nets can give a lot of information about the occurrence and habitat usage of amphibian species and several aquatic reptiles. Both methods



can be conducted in parallel with fish and macroinvertebrate surveys (Hachtel et al. 2009, Richtlinien und Vorschriften für das Straßenwesen 2019).

3.2.4 Birds

Bird surveys are recommended only if the green bridge, crossing aid or corridor is of high importance to bird habitat connectivity and, accordingly, is likely to be used by birds.

Identification of road-killed individuals could be used to identify bird danger zones and to develop a list of fauna living in the pilot area.

Visual observation is the most efficient and proven monitoring method for birds. Field mapping should cover at least 10 days and is recommended from April until October, depending on the occurrence of the respective species.

Additionally animal tracks and signs can be recorded in winter. This is especially suitable for game birds and several aquatic birds (e.g. great egret, grey heron). Inspection is recommended

after 3 days of closed snow cover and can be conducted from November through March and supplemented by bird observations in parallel.

In addition, birds can be recorded well using different types of acoustic detectors throughout the season, but ideally the beginning of the breeding season until the end of autumn, when the intensive migration periods of small singing birds is finished (Bibby et al. 1995, Richtlinien und Vorschriften für das Straßenwesen 2007).

3.2.5 Bats

The survey of bats is recommended only if the green bridge, crossing aid or corridor is of high importance with regard to the connectivity of bat habitats and therefore a corresponding frequency of crossing animals can be expected.

Following methods can be applied from April to October:

Nets: net trapping is a well-suited method for detecting bat adoption, especially on green bridges and corridors.

Automatic call recording using Batcorders: Batcorder recordings are a well-suited method to detect bat occurrence, especially close to underpasses.

Twilight observation with hand-held active bat detectors: Add-on method to net trapping and batcorder (Berthinussen & Altringham 2015, Richtlinien und Vorschriften für das Straßenwesen 2015).

3.2.6 Fishes

Since fishes represent the highest trophic level in aquatic ecosystems, monitoring datasets on fishes allow well-founded statement on the changes of water quality of surface waters. In EU countries fishes are surveyed in course of the Water Framework Directive (WFD), which was introduced aiming to provide a standardised approach for water resource



management throughout Europe and promoting the protection and enhancement of healthy aquatic ecosystems. The directive, transposed into law in all EU countries, obliged EU Member States to protect water bodies of good or high ecological status and to restore all water bodies that are degraded, in order to achieve at least good ecological status by 2015, and latest by 2027. In the frame of WFD all EU countries developed their own monitoring process to survey the fish fauna of different water bodies.

Since numerous motorways, expressways and roads cross streams and standing water habitats in the Carpathian region the monitoring of fishes is important to understand the effects of different types of underpasses on fish fauna composition at temporal and regional scales.

The ideal method to survey fishes in different aquatic habitat types is electrofishing. This method can also be used simultaneously for sampling crayfish (e.g. *Astacus astacus*), tadpoles as well as larvae, juvenile and adult individuals of amphibians and semi-aquatic reptile species (*Natrix natrix*, *Natrix tessellata*).

Monitoring approach should aim at measuring multiple biotic (e.g. aquatic vegetation) and abiotic (types of sediment) environmental variables to allow assessment.

Sampling should be carried out in three sections of the waterbody. The length of these sections depends on the size of the stream: 150 m for small streams, rivers should be subdivided each 300 m. The size of the upstream and downstream sections to be monitored should be at least 100 m and no more than 1000 m measured from the centre of the relevant underpass. Surveys ought to be conducted twice a year, in spring as well as end of summer or early autumn.

3.2.7 Aquatic macroinvertebrates

Aquatic macroinvertebrates are in different trophic levels of aquatic ecosystems, enabling monitoring datasets of relevant species and taxonomic groups allows to draw conclusions on changes of water quality of surface waters. The technical background of sampling aquatic macroinvertebrates is specified by the EU Water Framework Directive (WFD) and



national monitoring systems. The location of study sites can be chosen according to the monitoring of fishes.

To properly collect macroinvertebrates various methods of kick and sweep sampling techniques (AQEM Consortium 2002, Bojana et al. 2017) have become established using a hand net (500 μ m mesh size).

3.2.8 Pollinators (including butterflies)

The sampling of pollinators is only recommended in exceptional cases and only if there is a high planning relevance for specific species. Surveys are practical primarily on corridors and green bridges; occasional use of underpasses for dispersal is barely detectable.

Wild bees are surveyed by landing net (visual capture), sampling of suitable nest sites and flowers. Therefore five inspections are recommended between March and September. Butterflies are recorded by visual observation of the imagines in sunny, warm and windless weather. Recommended are

4-5 surveys between April and August. The use of green bridges and corridors depends on the availability of available flowering plants. Successful crossing can only be proven in exceptional cases (Abraham 1991, Richtlinien und Vorschriften für das Straßenwesen 2015).

3.2.9 Ground beetles

Since ground beetles are ideal indicator species for habitat connectivity due to their specialized life history, surveys in this regard are recommended in nearly all habitats. Their high suitability as bioindicators results from their particular use of ecological niches related to soil moisture, soil properties, climate, and habitat types.

For the sampling of ground beetles, the same survey methods can be used for bridges, underpasses and corridors. To guarantee a standardised methodology over the entire survey period, six barber traps (Barber 1931) per habitat type are buried on the green bridge, underpass or corridor. The trap liquid used is a mixture of alcohol, distilled water and vinegar essence in a ratio of 3:1:0.75 with a little dish soap. These traps are buried in the soil surface and changed every 14



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days. These surveys can be carried out from April to September. As a nonlethal alternative, in-person observation can be chosen once a month during the same time period (Rietze 2002, Richtlinien und Vorschriften für das Straßenwesen 2015).

3.2.10 Terrestrial spiders

Spiders are a ground- and shrub-bound group of animals with a small radius of action. They have a high suitability as indicators for the habitats in the area of the wildlife crossings and can be sampled alternatively to the ground beetle survey.

For the sampling of spiders, the same survey methods can be used for bridges, underpasses and corridors. According to standardised methods in the field of road and railroad engineering (Richtlinien und Vorschriften für das Straßenwesen, 2015), the minimum requirements for sampling are 3 barber traps to be used per habitat type, therefore 6 barber traps are to be expected per crossing (e.g. adjacent meadow areas with woody stands).

The monitoring should be conducted from April to September. As a nonlethal



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alternative, in-person observation can be chosen once a month during the same time period (Richtlinien und Vorschriften für das Straßenwesen 2015).

3.2.11 Terrestrial molluscs

Molluscs are a ground- and shrub-bound group of animals with a small radius of action. Due to the low dispersal rate and often high degree of specialisation to a particular habitat and site, the sampling of molluscs is particularly recommended at locations with high potential for this group.

For bridges, underpasses, verges of roads, ditches, culverts and corridors the same survey methods can be used.

In this regard, hand collections are usually conducted during warm and humid weather on vegetation, on the ground, and under structures (dead wood, artificial hiding places, natural or human organic debris). In addition, substrate samples should be collected for detection of small and micro snails in the area of the wildlife crossing.

In this regard, the survey should include at least 5 visits: 2 to 3 field observations from March to July, and another 1 to 2 visits between September and November (Richtlinien und Vorschriften für das Straßenwesen 2015).

3.3 Positioning of camera traps for large, medium and small mammals

The aim of the modelling of structural connectivity was to define the most suitable migration corridors of target species and to identify bottleneck situations that need special attention within the pilot areas to maintain the connectivity between core areas. Thus, the results of the analysis of structural connectivity should be considered for the monitoring of the functional connectivity especially with regard to the data collected by photo traps and field monitoring using the QField application. For the determination of appropriate monitoring sites, the bottlenecks identified by the modelling of structural connectivity provide important locations to install photo traps. Thus, the results of the structural connectivity modelling serve as baseline for the set-up of the monitoring. This baseline should be supplemented with expert knowledge. In the context of SaveGREEN this applied to the evaluation of the very heterogeneous pilot areas (major differences concerning size, environmental conditions as well as relevant target species). The knowledge of local experts is thus key for the final positioning of photo traps and determination of focus areas for field monitoring. Especially in very large areas, area-wide monitoring is hardly feasible and therefore decisions have to be made where monitoring should ideally take place.

The locations and number of phototraps should be chosen so that at least 10 sites can be surveyed. Monitoring sites should therefore be established in the following sections of the corridor:

- » Potential source and target areas of umbrella species.
- » Areas of the corridor where the model shows high connectivity

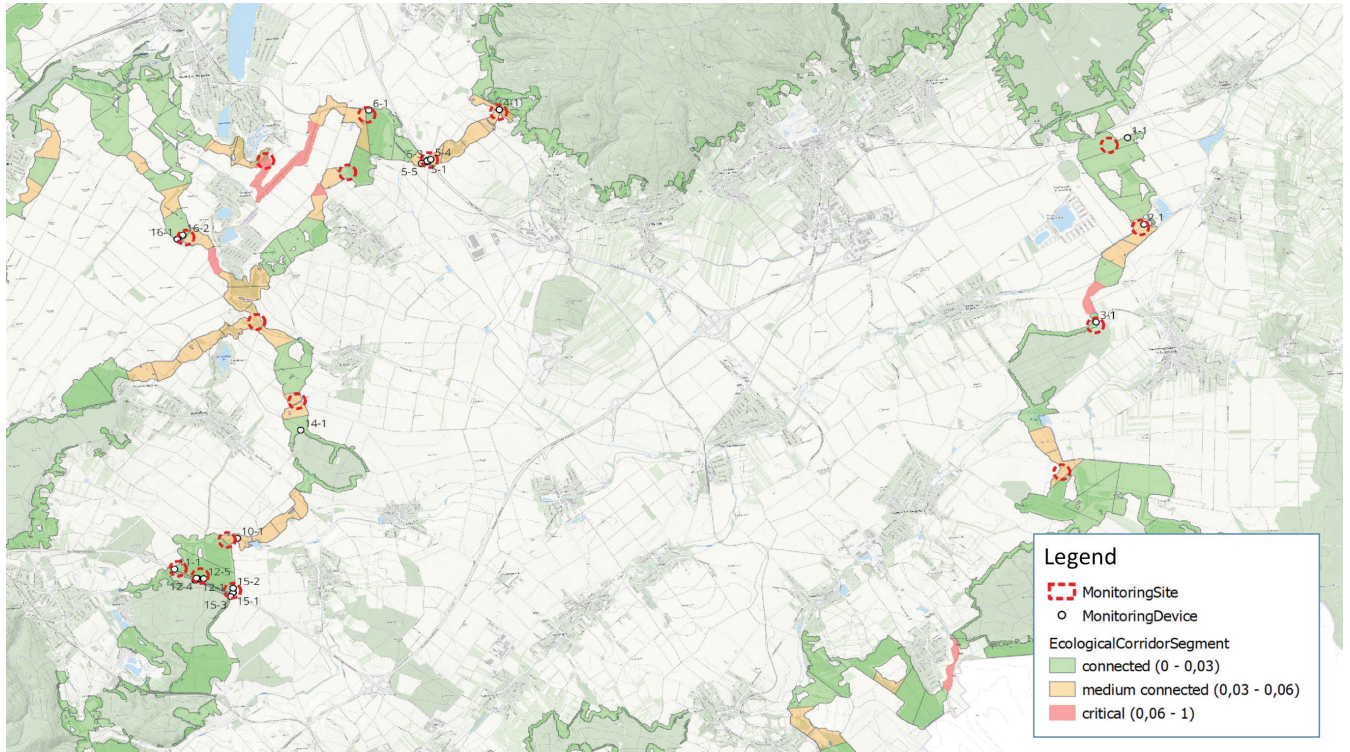


Figure 34: Overview of established monitoring sites and device locations within the pilot area Pötsching (AT)

- » Areas of the corridor where the model shows an impact/disruption of connectivity
- » Bottleneck areas of the corridor (intersections of highways by underpasses and overpasses, bottlenecks due to settlements, etc.)

An example of established monitoring sites in the PA Kobernausser Forest in Austria is given in Figure 34. All of the above criteria for selecting monitoring sites are met in this pilot area.

The positioning of monitoring equipment at green bridges, overpasses, and underpasses should ensure observation of the entire entrance and exit area. For this purpose, the camera traps are placed opposite to each other on both entrances and should be no more than 40 meters apart. When aligned, the maximum observation distance of a camera is 20 meters. However, the maximum distance also depends on the location and the type of photo trap. Additional photo traps should also be placed in the feeder

area of overpasses, underpasses, and corridor bottlenecks to record animals that do not end up crossing these structures. Depending on the size of the corridor, one or two transects should be selected in its center to observe all animal movements (Figure 35).

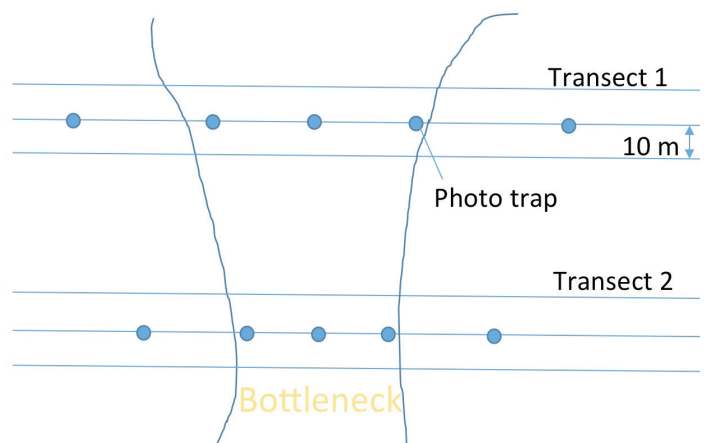


Figure 35. Location of transects and photo traps in the bottleneck situation of a migration corridor. The distance between the photo traps doubles outside the corridor.

In addition to the coverage of green bridges, overpasses, and underpasses, the corridors themselves should be monitored over larger sections as well. When bottleneck situations occur along the corridors and thus migration pressure is high in these sections, wildlife cameras in the immediate vicinity are placed closer to the corridor axis to allow for more comprehensive monitoring, which means that the spacing of the devices increases with distance from the corridor axis (Figure 35). Phototraps should also be set up in the vicinity of retreat and hiding places, e.g. landscape elements or field copses

to affect physiology, behaviour and reproduction of a range of animal taxa. At the same time there is a significant gap in knowledge on the impact of these pollutants (Newport J. 2014). Wildlife crossing structures that pass over and under transportation infrastructure have been proposed as a solution to road-related habitat fragmentation, wildlife collisions, and road kills. To assure the efficacy of these crossing structures, road and traffic related negative impacts that could cause avoidance of these structures by wildlife, such as noise and light, need to be considered (Shilling F. 2018).

Therefore, monitoring the influence of light and noise on migration corridors is also of major importance. In SaveGREEN, the assessment of the influence of light and noise was recorded independently of other measures of monitoring in the pilot areas. Furthermore, the recording of light and noise was voluntary and optional for the pilot areas in SaveGREEN as the dataloggers for these measurements have been just recently developed. However, the deployed loggers represent a cost-efficient option to record noise and light. They measure light in the unit lux and noise in decibels in a time interval of at least 15 minutes. A battery life of 45 days is targeted to ensure adequate monitoring duration.

3.4 Methodology of functional monitoring: sources of interference - light and noise

Wildlife is affected by light and noise pollution. Both factors have the potential

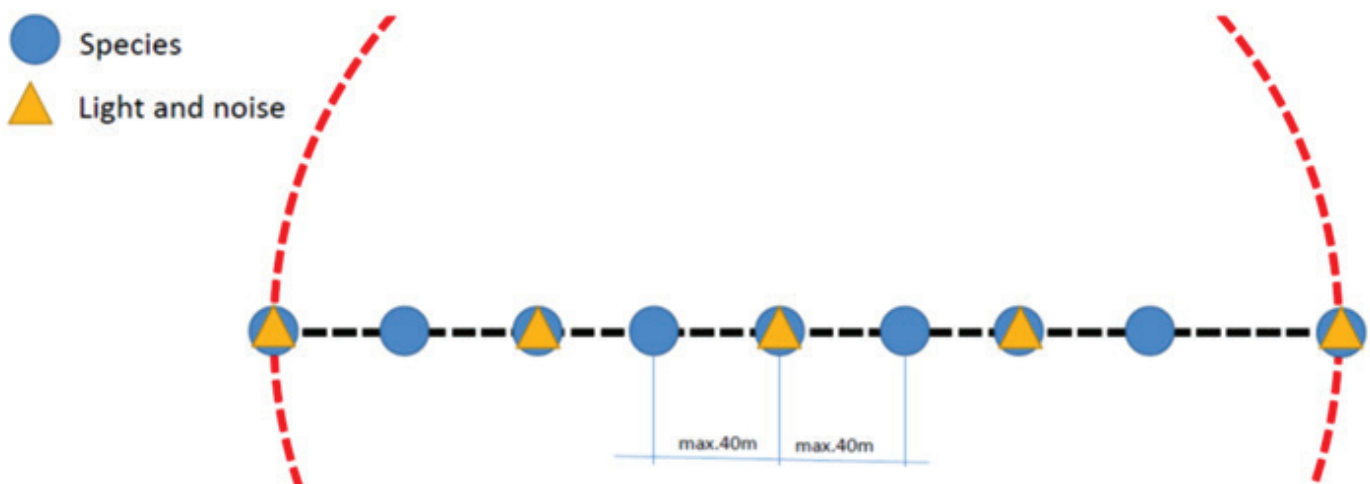


Figure 36. Number and positioning of sensors in combination with camera traps when set up at a distance of 40 meters

In total 40 sensors have been developed whereof 20 will be used in Austria (for pilot areas Pöttlaching and Kobernausser forest) for initial testing, while another 20 sensors could be borrowed from the partners after a test phase of the software.

Light and noise should ideally be measured close to residential areas as well as industry and transport. The installation is proposed especially along gray infrastructure and at green bridges and underpasses, where light and noise are present and can affect the function of these crossing structures for migration.

The monitoring concept provides for wildlife cameras every 40 meters. Additional light

and noise measurements are planned at every second monitoring device (Figure 36). The sensors are installed on site and set up with the QField application, which is also used to monitor other data in the field. Light and noise are recorded close to the emission sites where the measuring points will be set up in higher numbers. As the distance from the emission sites increases, the density of measuring devices will be reduced.

However, measurements should also be taken in areas with no presumed light and noise pollution to have a baseline for animal occurrence without disturbance.

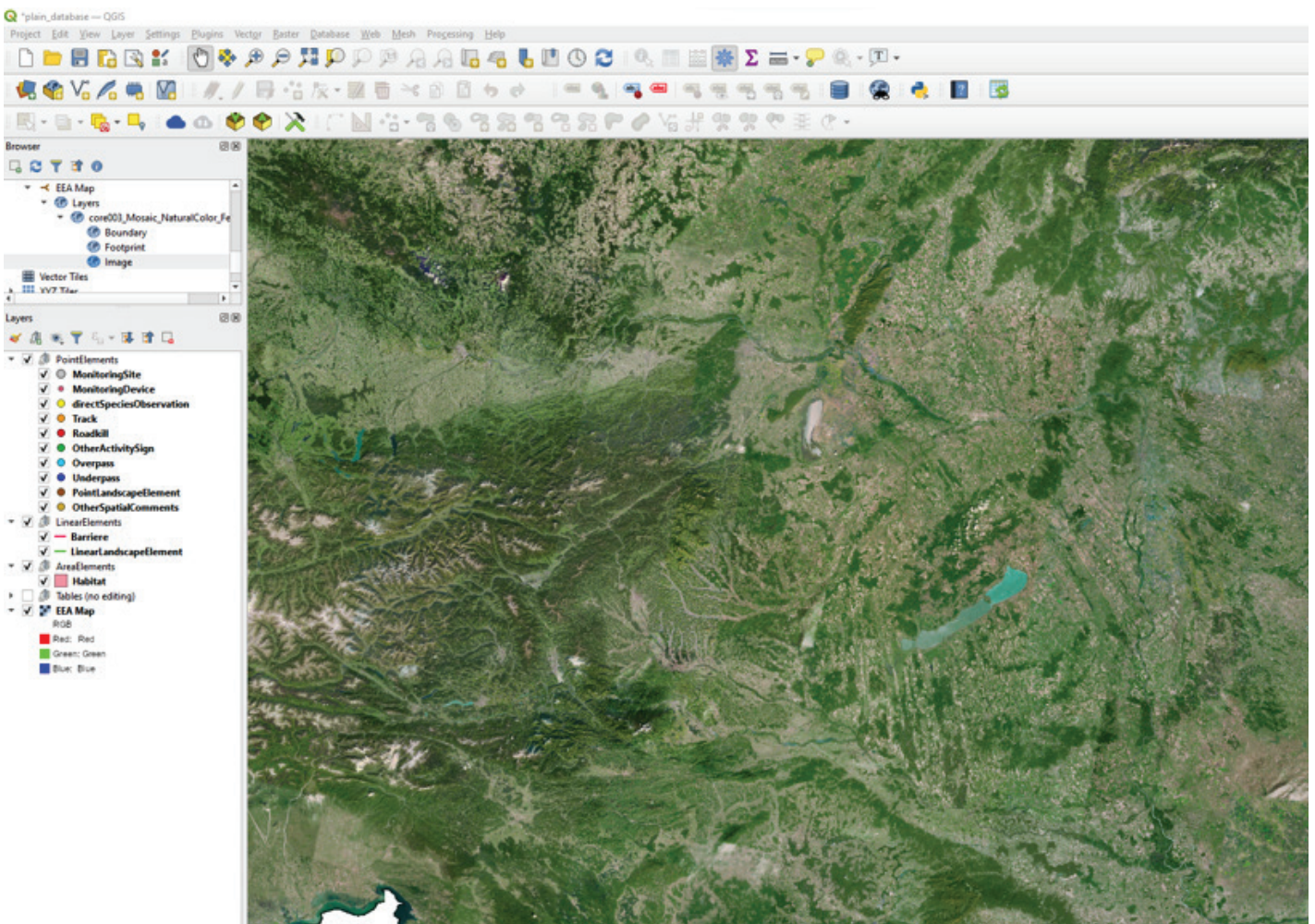


Figure 37: SaveGREEN data model in QGIS providing the basis for the QField package

3.5 Methodology of functional monitoring: landscape inventory and pilot area-wide evidence of species occurrence

3.5.1 Field mapping application and generic data model

To survey the landscape inventory and to provide an overview of species occurrence in the pilot areas, a customized QField-project (see application Qfield: <https://qfield.org/>), has been configured and made available to all pilot areas in the course of the Functional Monitoring Application Toolbox (FM-AT).

QField is an open-source mobile GIS application developed by OPENGIS.ch, an open source software provider. QField enables users to set up a project in the desktop application QGIS (Figure 37) that can be then exported using the QField plugin. The created data package can then be deployed to a mobile device using the

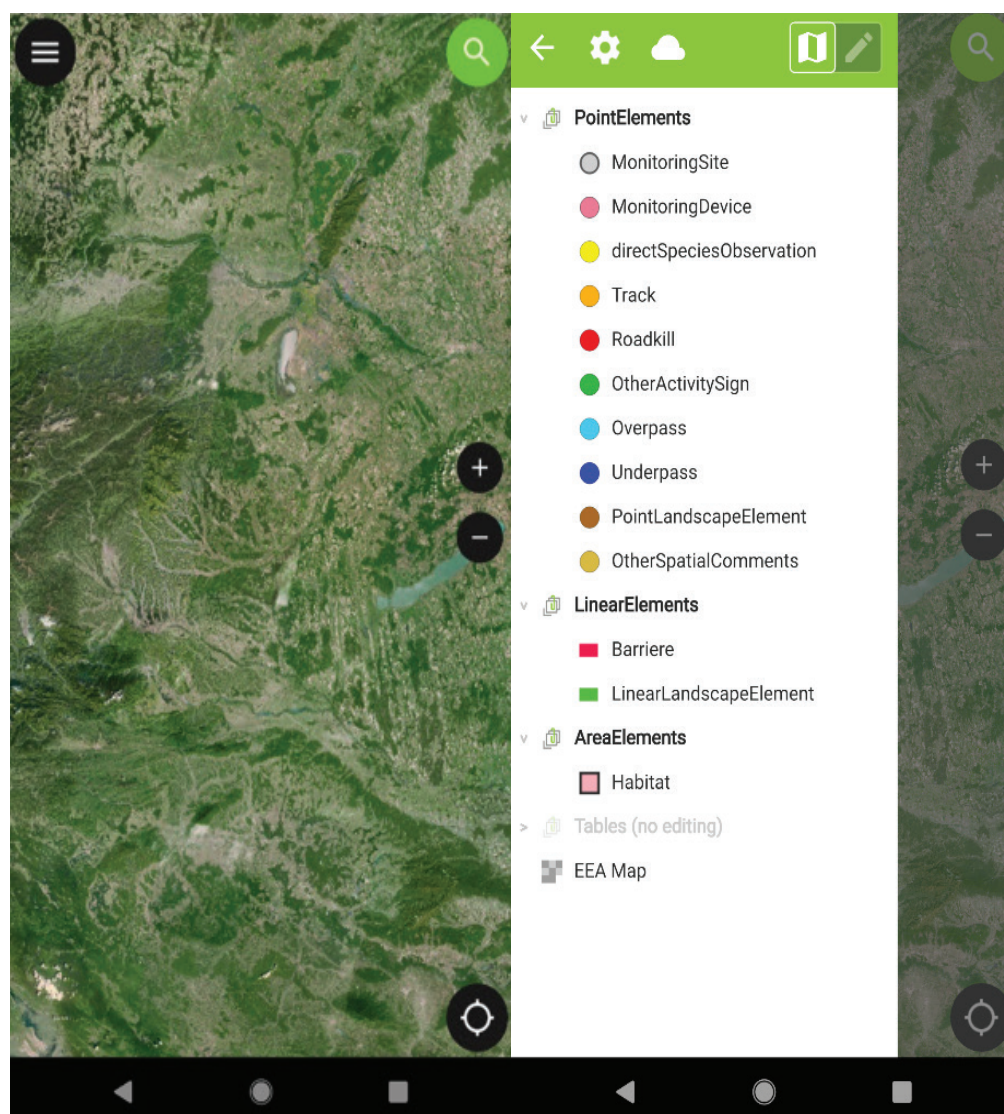


Figure 38: SaveGREEN data model performed in QField application for surveying the landscape inventory and area-wide mapping of evidence for species occurrence (tracks, other activity signs, direct observations, etc.). The left image shows the map view of the project used to digitise features (basemap by EEA from <https://discomap.eea.europa.eu/Index/Services.aspx?agsID=61&fID=6657/>), The right image shows the layer overview in QField.

installed QField application (available for Android or iOS). Subsequently the QField project can be used in the field to record data and integrate into the layers and maps prepared.

To fulfil the different needs of the pilot areas, the so called “generic data model” has been developed in collaboration with regionally active project partners. The data model includes all objects (i.e. different layers and tables to store information on species occurrence and landscape elements) that should be mapped within the pilot areas. All layers and tables were made available in form of a geodatabase stored in the geopackage format (also an open-source file format). Furthermore, individual forms for the characterisation of these objects were developed to facilitate and support fieldwork and to guarantee easy handling of the QField application in the field.

After installing the QField application on a mobile device, the data package created in the QGIS desktop application has to be uploaded to the device. The data set (geodatabase, forms, map styles, and in situ data collected specifically for the pilot area) is thus ready for fieldwork to be conducted. (see Figure 38).

Templates for the relevant QGIS and QField projects (without the pilot area specific in-situ data) are available here:

<https://ccibis.priestoroveplanovanie.sk/documents/383>

For the exchange between QGIS and QField (i.e. creating packages in QGIS for QField and importing QField data back to QGIS) the QField plugin (see <https://qfield.org/docs/de/synchronise/qfieldsync.html>) is needed in QGIS.

3.5.2 Importance of pilot area wide information to obtain information on the continuum of the ecological corridor

Field mapping data as additional and area wide information is required to determine the continuum and functionality of corridors and to identify sections of the ecological corridor where permeability is limited.

In large pilot areas with a size of more than 400 square kilometres, the minimum requirement is to map all objects defined in the generic model within a radius of 500 meters from any monitoring site. It must be ensured that through a correct selection of the spatial location and number of monitoring sites the generated information is sufficient to enable the assessment of the functionality of the corridor.

For pilot areas smaller than 400 square kilometres, it is recommended to map the entire area of the ecological corridor. Mapping should be based on the central axis of the main ecological corridor, which was identified by the GIS model as part of the structural connectivity model. To reach the various monitoring sites and avoid problems with property owners, public paths and the road network should be used to conduct field work. For the survey regarding the ecological corridor, all landscape elements relevant to wildlife ecology are located at a distance of 400 meters on both sides of the corridor axis and all objects defined in the generic model should be mapped by using the QField application.

The data collected in the SaveGREEN pilot areas will be synchronised with the Carpathian Countries Integrated Biodiversity Information System (CCIBIS, see <http://ccibis.org/>). For one, the data will provide the opportunity to review the maps of final results for future decision making and transboundary assessment to support further corridor planning and protection. Secondly, the data will be available for download to support monitoring activities and scientific work in the field.

3.6 Evaluation methods for the data obtained from monitoring of functional connectivity

3.6.1 Stationary monitoring devices

As described in chapter 3.3, stationary monitoring devices play a crucial role in order to draw conclusions on the actual acceptance of the defined migration corridors of target species and the identified bottleneck situations from the structural monitoring. This not only allows conclusions to be drawn about the functionality of the corridor and migratory species on site, but also provides valuable feedback for the preceding data-driven approach.

In SaveGREEN especially the following stationary monitoring devices have been used in the field:

- » Camera traps
- » Light sensors
- » Sound sensors

For the purposes of illustration, only the results from the monitoring by camera traps will be presented in the following.

Camera traps are a common method to track the activity of wild animals in the field. These cameras are automatically triggered by a change in some activity in their vicinity, like the presence of an animal. Typically they are equipped with a motion sensor, usually using an infrared light beam to record activity day and night.

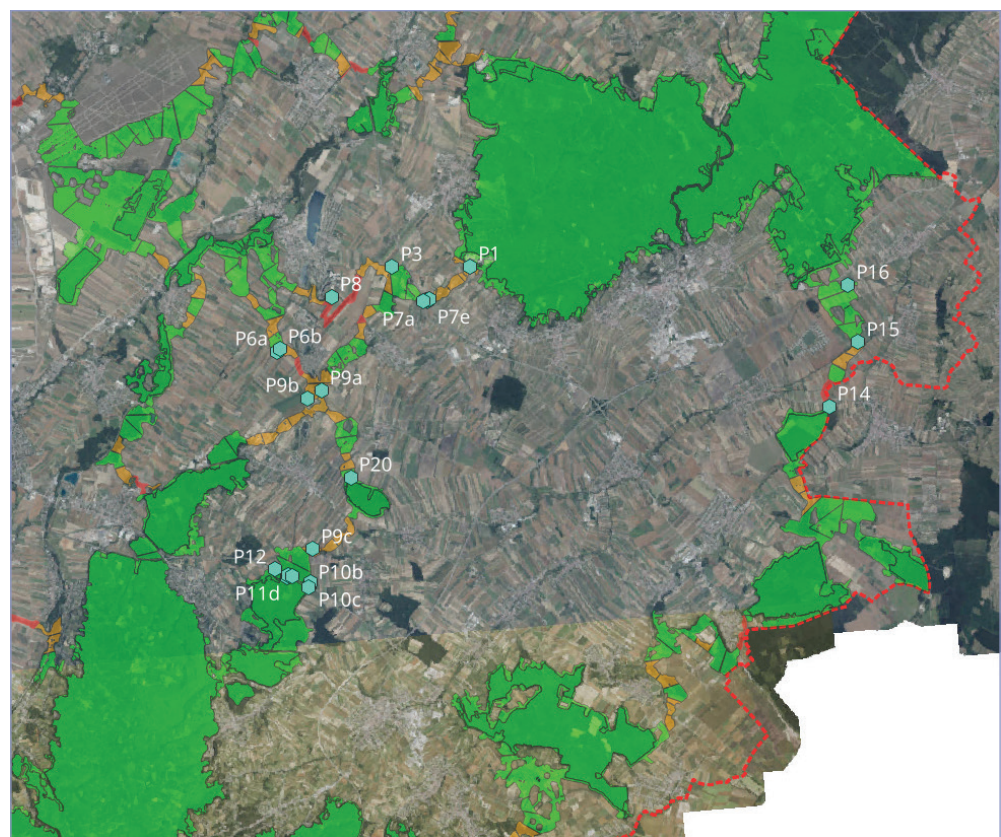


Figure 39: Location of camera traps within pilot area Pöttsching (AT)

The images are delivered as colour photos, which contain date, time and temperature as directly readable information. The chosen monitoring sites are pre-defined and therefore, the records can be located spatially (Figure 39).

After a manual or semi-automatic identification run of the recorded images, the following information can be obtained among other things:

- » Category of Activity (Animal/Human activities)
- » Species (Figure 40)
- » Abundance of animals (Figure 40)
- » Direction of movement

The evaluation of the different parameters allows an illustration of various aspects, depending on the specific question, e.g. activity peaks or potential avoidance behaviour (Figure 41), be it for the individual site or the entire study area.

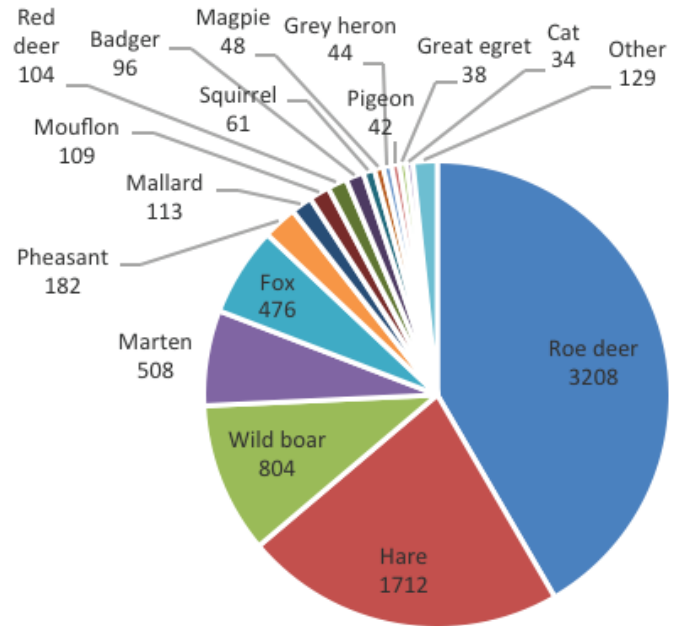


Figure 40: Frequency and species derived from the recorded images in the pilot area Pötttsching (AT)

This way, the monitoring sites and the associated results can also be presented individually and spatially explicit for specific landscape sections, thus allowing the

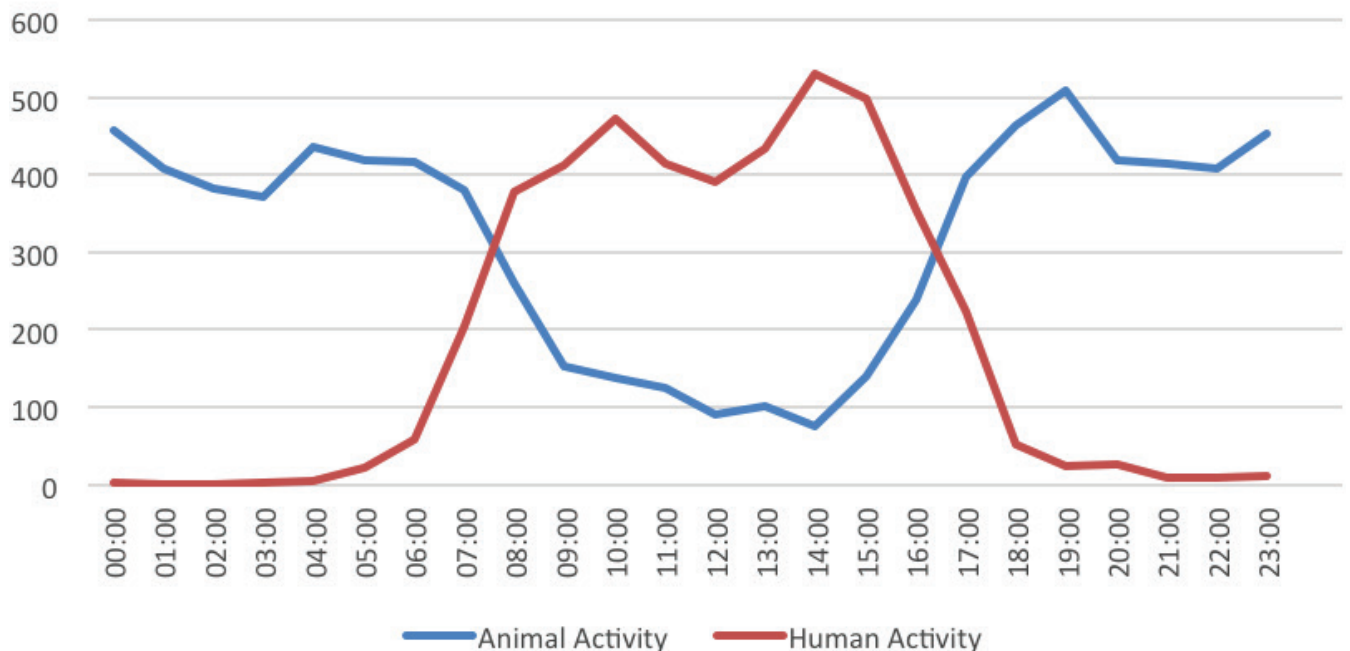


Figure 41: Diurnal activity patterns of humans and animals in pilot area Pötttsching (AT)

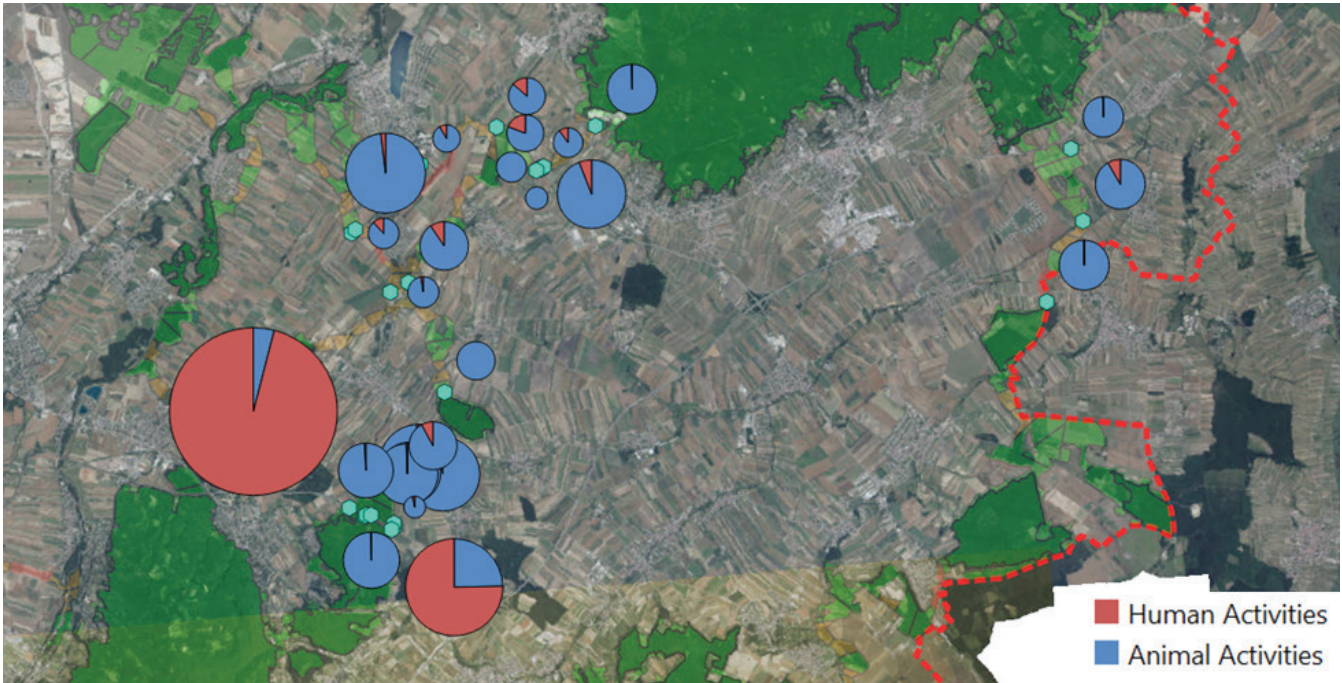


Figure 42: Spatially explicit illustration of human and animal activities within the pilot region Pötsching (AT)

interpretation of the functionality of corridors or neuralgic areas along the corridor (Figure 42) by common methods of geoinformatics and interpretation of monitoring results.

These spatial representations can be adjusted to individual species or species groups according to interest or problem definition (Figure 43).

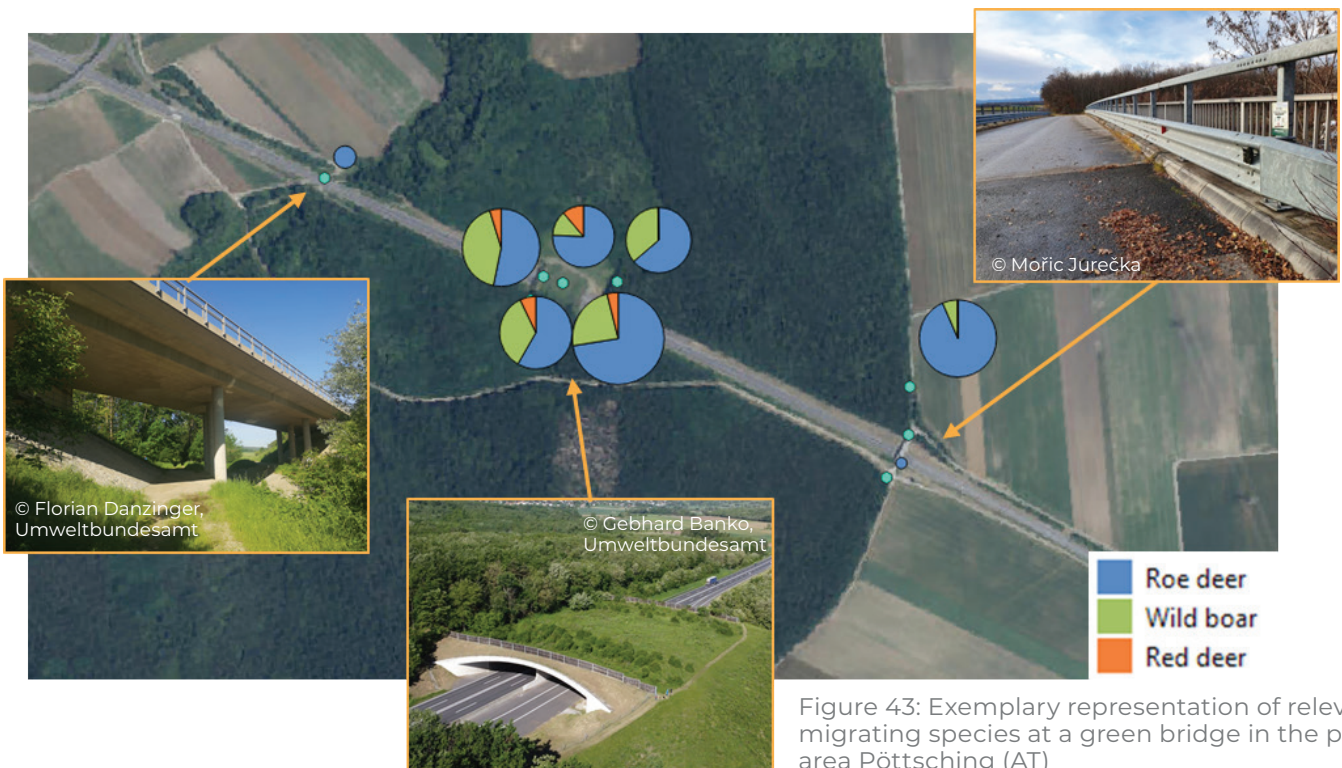


Figure 43: Exemplary representation of relevant migrating species at a green bridge in the pilot area Pötsching (AT)

3.6.2 Field mapping

In order to complement stationary monitoring devices beyond their fixed locations, different field monitoring methods can be used to cover inaccessible places or areas that are difficult to record. These include among others the monitoring and recording of

- » Direct species observations
- » Tracks
- » Other activity signs
- » Roadkills
- » Over- & Underpasses

» Landscape elements (linear/punctiform)

» Barriers

Compared to monitoring using stationary devices, field mapping methods can also be used over larger areas in the open landscape and between stationary sites. In addition, this allows even more specific questions to be identified, but with significantly higher effort and costs per data point obtained.

The results can be presented cumulatively, per factor or for each species spatially explicit in the study region. One option to visualize activity hotspots are so called heatmaps, which can be created with simple operations of a geographic information system (Figure 44).

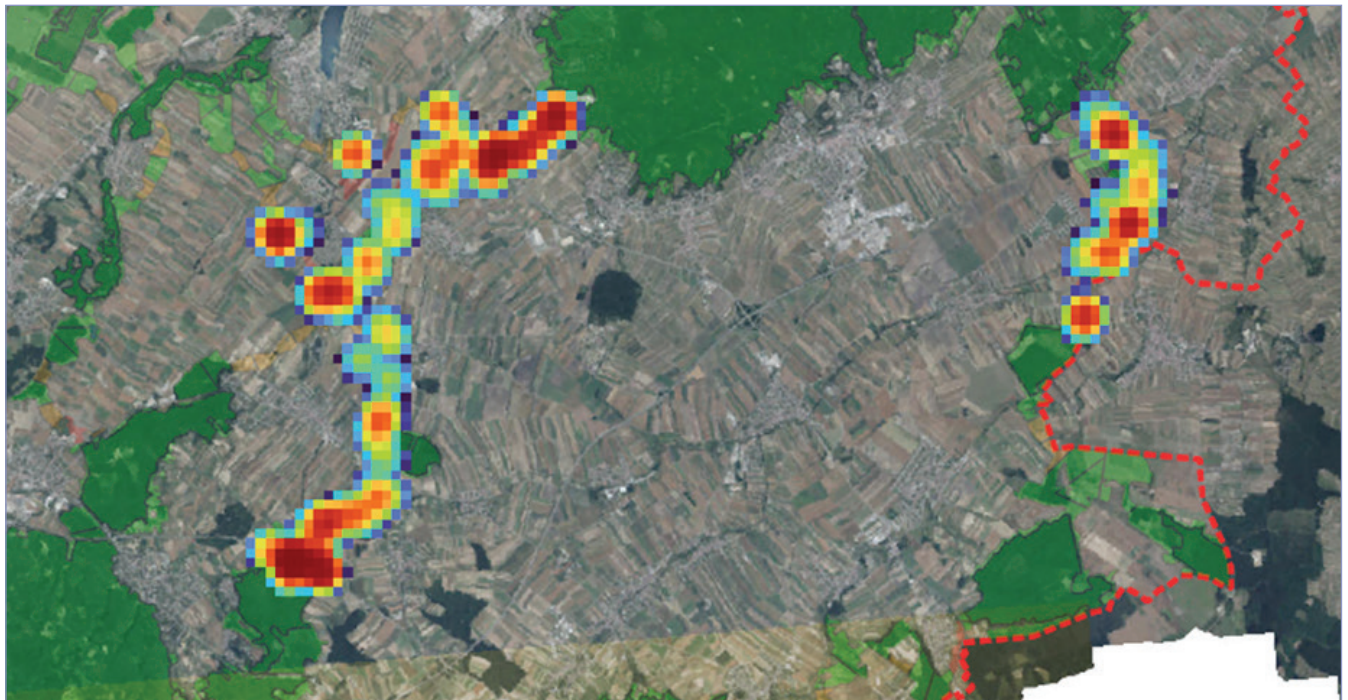


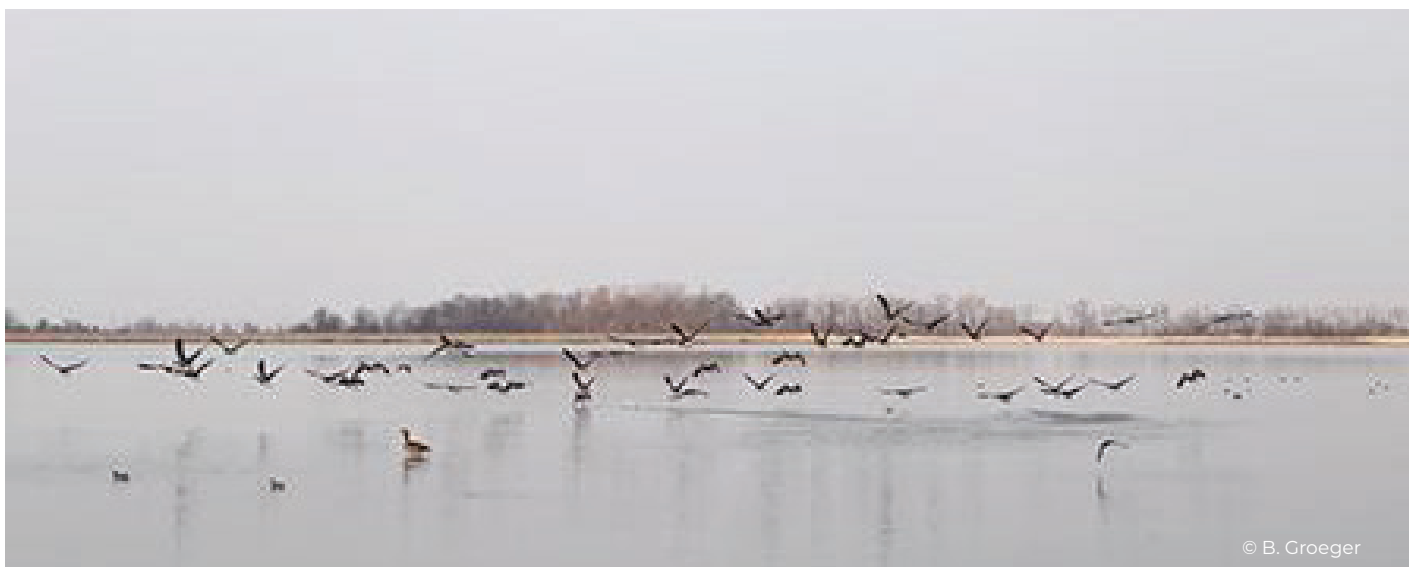
Figure 44: Heatmap of all recorded species activities in the pilot area Pöttching (AT)

An aerial photograph of a rural landscape. In the foreground, there is a road with a white truck and a concrete bridge structure. The middle ground shows large agricultural fields with distinct furrows. In the background, there are rolling hills and a line of wind turbines under a clear sky. The image is overlaid with a semi-transparent dark rectangle containing the chapter title.

CHAPTER 4

Lessons learned & recommendations

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In spring 2022 a survey among the project partners working in the pilot areas was conducted on the experiences regarding the existing monitoring methodology. The following difficulties were reported several times: **a sufficient number of cameras is not available**. On the one hand, this was due to the fact that insufficient funds were available and thus a sufficient number of cameras could not be purchased. This is particularly important when the area under investigation is very large, as it was the case for pilot areas in Bulgaria or Romania. In the Czech Republic, the cameras were therefore not installed at both entrances but centrally in the middle of the green bridges to solve this situation. This solution should also provide a sufficiently good indication of the use of the corridor.

Another difficulty was the **theft of the cameras**, as reported by several partners. There were situations where the cameras could be all set up properly according to the methodology, but the cameras and their information was lost due to the theft of one or more cameras. This situation was mitigated by hiding the cameras and avoiding installation at open places to reduce the visibility of the cameras. Since animal tracks were also collected during monitoring and information on migration routes was thus available, the lack of cameras or the loss due to theft could be partially compensated.

One difficulty encountered in Austria was the **acceptance of monitoring by stakeholders**,

especially by landowners and local hunters. In order to carry out the monitoring, including the installation of the cameras, permissions had to be obtained from the landowners and users (e.g. hunters). However, some important landowners and hunters did not want to give their permission for the monitoring or were only prepared to do so after a time-consuming period of persuasion.

Lessons learnt after this process were:

- » to engage with smaller supportive groups to reach more stakeholders later,
- » to be aware of the hierarchical structure of associations,
- » to prepare arguments to encounter important stakeholders' concerns,
- » to not underestimate the time needed for engaging with stakeholders.

In general, the **feedback on the monitoring** methodology for functional monitoring was positive. As the pilot areas are very heterogeneous, there were always sites where adjusted monitoring solutions had to be found. As local experts carried out the work on site, they adapted the present methodology to the local circumstances. In this way, satisfactory solutions emerged that provided valuable information on wildlife corridors.

References



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Abraham R. (1991): Fang und Präparation wirbelloser Tiere. Springer Spektrum Verlag

Andersson, E. and Bodin, O. (2009): Practical tool for landscape planning? An empirical investigation of network based models of habitat fragmentation. *Ecography* 32: 123-132.

AQEM Consortium (2002): Manual for the application of the AQEM system: A comprehensive method to assess European streams using benthic macroinvertebrates, developed for the purpose of the Water Framework. Essen: University Duisburg-Essen, Germany, 198 p.

ASFINAG – Autobahnen- und Schnellstraßen-Finanzierungs-Aktiengesellschaft (2020): Monitoring an 18 Grünquerungen im Jahre 2018. Forschungsbericht. Wien.

Barber, H. S. (1931): Traps for cave-inhabiting insects. - *J. Elisha. Mitchell Sci. Soc.* 46: 259-266.

Berthinussen, A. and Altringham, J. (2015): Development of a cost-effective method for monitoring the effectiveness of mitigation for bats crossing linear transport infrastructure. Defra contract report WC1060

Bibby C. J., Burgess N. D. & Hill D. A. (1995): Methoden der Feldornithologie: Bestandserfassung in der Praxis. – Neumann, Radebeul, 270 pp.

Brooks, C.P. (2003): A scalar analysis of landscape connectivity. *Oikos* 102: 433-439.

Bojana P. Tubić^{1,*}, Nataša Z. Popović¹, Maja J. Raković, A.S. Petrović, V.M. Simić, .M.M. Paunović (2017): Comparison of the effectiveness of kick and sweep hand net and Surber net sampling techniques used for collecting aquatic macroinvertebrate samples. *Arch Biol Sci.* 69(2): 233-238.

Di Febbraro, M.; Sallustio, L.; Vizzarri, M.; De Rosa, D.; De Lisio, L.; Loy, A.; Eichelberger, B.; Marchetti, M. (2018): Expert-based and correlative models to map habitat quality: Which gives better support to conservation planning? *Glob. Ecol. Conserv.*, 16, e00513. <https://doi.org/10.1016/j.gecco.2018.e00513>

Dutta, T., Sharma, S., McRae, B. H., Roy, P. S., & DeFries, R. (2016): Connecting the dots: mapping habitat connectivity for tigers in central India. *Regional Environmental Change*, 16(1), 53-67. 10.1007/s10113-015-0877-z

European Environment Agency (EEA). (2014): EU-DEM statistical validation.

Haberl, H., Wiedenhofer, D., Schug, F., Frantz, D., Virág, D., Plutzer, C., Gruhler, K., Lederer, J., Schiller, G., Fishman, T., Lanau, M., Gattringer, A., Kemper, T., Liu, G., Tanikawa, H., van der Linden, S., Hostert, P., (2021): High-resolution maps of material stocks in buildings and infrastructures in Austria and Germany. *Environ. Sci. Technol.* <https://doi.org/10.1021/acs.est.0c05642>

Hachtel M., Schlüpmann M., Thiesmeier B. & K.Weddeling (2009): Methoden der Feldherpetologie. Supplement der Zeitschrift für Feldherpetologie 15; 424 S.

Hlaváč, V., Anděl, P., Matoušová, J., Dostál, I., Strnad, M., Immerová, B., Kadlečík, J., Meyer, H., Moť, R., Pavelko, A., Hahn, E., Georgiadis, L. (2019): Wildlife and Traffic in the Carpathians. Guidelines how to minimize impact of transport infrastructure development on nature in the Carpathian countries. Danube Transnational Programme TRANSGREEN Project, The State Nature Conservancy of the Slovak Republic, Banská Bystrica. 228 pp.

Kadoya, T. (2009): Assessing functional connectivity using empirical data. *Population Ecology* 51: 5-15.

Kindlmann, P. and F. Burel. (2008): Connectivity measures: a review. *Landscape Ecology* 23: 879-890.

Littlefield, C. E., McRae, B. H., Michalak, J. L., Lawler, J. J., & Carroll, C. (2017): Connecting today's climates to future climate analogs to facilitate movement of species under climate change. *Conservation Biology*, 31(6), 1397-1408.

Malinowski, R., Lewiński, S., Rybicki, M., Gromny, E., Jenerowicz, M., Krupiński, M., Nowakowski, A., Wojtkowski, C., Krupiński, M., Krätzschar, E., Schauer, P. (2020): Automated Production of a Land Cover/Use Map of Europe Based on Sentinel-2 Imagery. <https://doi.org/10.3390/rs12213523>

McRae BH. (2012): Pinchpoint Mapper Connectivity Analysis Software. The Nature Conservancy, Seattle, WA. Available from <https://linkagemapper.org>

Mönkkönen, M. and P. Reunanen. (1999): On critical thresholds in landscape connectivity: a management perspective. *Oikos* 84(2): 302-305.

Newport J., Shorthouse D. J. & A. D. Manning (2014): The effects of light and noise from urban development on biodiversity: Implications for protected areas in Australia. <https://doi.org/10.1111/emr.12120>

Phillips, S. J., Anderson, R. P., & Schapire, R. E. (2006): Maximum entropy modeling of species geographic distributions. *Ecological modelling*, 190(3-4), 231-259. <https://doi.org/10.1016/j.ecolmodel.2005.03.026>

Reimoser, F., Pfeifer, M. & Leitner, H. (2010): Entwicklung methodischer Standards für die Erfolgskontrolle von Wildquerungshilfen. Projektbericht. (Bundesministerium für Verkehr Innovation und Technologie, Hrsg.)

Richtlinien und Vorschriften für das Straßenwesen (RVS) 04.03.13 (2007): Vogelschutz an Verkehrswegen. Verbindlich erklärt am 18.12.2006. Herausgegeben vom Bundesministerium für Verkehr, Innovation und Technologie, BMVIT-300.041/0061-II/ST-ALG/2006 und der Österreichischen Forschungsgesellschaft für Straße – Schiene – Verkehr.

Richtlinien und Vorschriften für das Straßenwesen (RVS) 04.03.14 (2009): Schutz wildlebender Säugetiere (ausgenommen Fledermäuse) an Verkehrswegen. Verbindlich erklärt am 20.11.2009. Herausgegeben vom Bundesministerium für Verkehr, Innovation und Technologie, BMVIT-300.041/0064-II/ST-ALG/2009 und der Österreichischen Forschungsgesellschaft für Straße – Schiene – Verkehr.

Richtlinien und Vorschriften für das Straßenwesen (RVS) 04.03.15 (2015): Artenschutz an Verkehrswegen. Verbindlich erklärt am 01.10.2015. Herausgegeben vom Bundesministerium für Verkehr, Innovation und Technologie und der Österreichischen Forschungsgesellschaft für Straße – Schiene – Verkehr.

Richtlinien und Vorschriften für das Straßenwesen (RVS) 04.03.11 (2019): Amphibienschutz an Verkehrswegen. Verbindlich erklärt am 01.02.2019. Herausgegeben vom Bundesministerium für Verkehr, Innovation und Technologie, BMVIT -300.041/0005-IV/IVVS-ALG/2019 und der Österreichischen Forschungsgesellschaft für Straße – Schiene – Verkehr.

Serfling C. (2014): Methoden der Reptilienerfassung. https://www.thueringen.de/imperia/md/content/tlug/abt1/v-referate/2014/16_2014/3_serfling_methoden_reptilienerfassung.pdf

Shilling F., Collins A. & A. Louderback-Valenzuela (2018): Wildlife-Crossing Mitigation Effectiveness with Traffic Noise and Light. <https://escholarship.org/uc/item/8893d8zw>

Strahler A. N. (1957): Quantitative analysis of watershed geomorphology. *Am Geophys Union Trans* 38:913–920. doi: <https://doi.org/10.1029/TR038i006p00913>

Wansink, D., Tukker, A., Weiperth, A. P. M., & Gál, B. (2013): Cost-effective maintenance to support the ecological functions of roads. Harmony procedures for the design of roads in harmony with wildlife. CEDR call. https://3e370274-79bf-479a-be0a-690637f02a27.filesusr.com/ugd/1cba1b_9967e0fbcac44f5aa689f1114653b587.pdf

Williams, B. M., Baker, P. J., Thomas, E., Wilson, G., Judge, J., & Yarnell, R. W. (2018): Reduced occupancy of hedgehogs (*Erinaceus europaeus*) in rural England and Wales: The influence of habitat and an asymmetric intra-guild predator. *Scientific Reports*, 8(1), 1-10.



PILOT AREAS:

Austria

- 1 Kobernausser forest
- 2 Pötsching (Alpine-Carpathian Corridor)

Czech Republic/Slovakia

- 3 Beskydy-Kysuce CZ-SK cross-border area

Hungary/Slovakia

- 4 Novohrad-Nógrád SK-HU cross-border area

Ukraine

- 5 Zakarpattia region

Romania

- 6 Mureş valley (Arad-Deva)
- 7 Mureş Valley (Târgu Mureş – Târgu Neamţ)

Bulgaria

- 8 Rila-Verila-Kraishte corridor



Project partners:

Austria: WWF Central and Eastern Europe (Lead Partner), Environment Agency Austria

Bulgaria: Black Sea NGO Network, Bulgarian Biodiversity Foundation

Czech Republic: Friends of the Earth Czech Republic – Carnivore Conservation Programme, Transport Research Centre Czech Republic

Hungary: CEEweb for Biodiversity, Hungarian University for Agriculture and Life Sciences

Romania: Zarand Association, EPC Environmental Consultancy Ltd., WWF Romania

Slovakia: Slovak University of Technology in Bratislava – SPECTRA Centre of Excellence of EU

Associated Strategic Partners:

Austria: Ministry for Climate Action, Environment, Energy, Mobility, Innovation, and Technology

Bulgaria: Ministry of Agriculture, Food and Forestry – Executive Forest Agency, Southwestern State Enterprise SE – Blagoevgrad

Czech Republic: Ministry of the Environment, Nature Conservation Agency

France: Infrastructure and Ecology Network Europe (IENE)

Germany: Bavarian State Ministry of the Environment and Consumer Protection

Greece: Egnatia ODOS S.A.

Hungary: National Infrastructure Developing Private Company Ltd. (NIF Ltd.), Ministry of Agriculture, Danube-Ipoly National Park Directorate

Romania: Ministry of Environment, Waters and Forests, Ministry of Public Works, Development and Administration, Ministry of Transport, Infrastructure and Communications

Slovakia: State Nature Conservancy, Ministry of Environment, Ministry of Transport and Construction, National Motorway Company

Ukraine: M.P. Shulgin State Road Research Institute State Enterprise – DerzhdorNDI SE, Department of Ecology and Nature Resources of Zakarpattia Oblast Administration

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