

BioREGIO Carpathians

Advanced tools and methodologies adopted GIS Model Design for deriving ecological corridors

European Academy of Bolzano

Favilli, F., Hoffmann, C., Ravazzoli, E., and Streifeneder, T.

Institute for Regional Development and Location Management

Viale Druso 1

39100 Bolzano/Bozen

Tel. 0471-055328

filippo.favilli@eurac.edu

Bolzano/Bozen, 25.11.2013

Jointly for our common future

Contents

1	Introduction.....	1
2	Definitions.....	3
3	Conceptual steps for building the model:.....	6
3.1	Pre-modelling:.....	8
3.2	Collection of available data.....	9
3.2.1	Free data sets:.....	11
3.2.2	Data from Project Partners.....	12
3.2.3	The Role of external partners active in the CC area for data acquisition.....	14
3.3	Choosing habitat factors.....	14
3.3.1	Land cover.....	15
3.3.2	Topographic variables.....	16
3.3.3	Human disturbance.....	16
4	Technical Steps:.....	20
4.1	First step: Application of the Corridor Designer – creation of a Habitat Suitability Model.....	20
4.1.1	Calculation of suitability score of factors’ classes.....	20
4.1.2	Assigning weights to each factor for each umbrella species.....	21
4.1.3	Calculation of pixels’ Suitability value with CorridorDesign.....	21
4.1.4	Habitat suitability is limited by its worst factor.....	21
4.1.5	Creating a habitat suitability model.....	22
4.2	First sub-step: Adding a Critical Species’ Specific factor.....	24
4.2.1	Required Procedure:.....	25
4.3	Second Step: Linkage Mapper- model design – identification of least-cost paths.....	26
4.4	Virtual Model Validation.....	28
4.5	Web-GIS.....	29
4.6	Lessons learned.....	29
4.7	Essential References:.....	30
5	ANNEX – Umbrella Species.....	34
5.1	Define habitat patch (core area).....	34
5.2	EUROPEAN LYNX (<i>Lynx lynx</i> , L., 1758).....	35
5.2.1	First step: Application of the CorridorDesigner GIS Habitat Suitability Model.....	35
5.2.2	Second Step: Adding a Critical Species’ Specific factor.....	36
5.2.3	Third Step: Linkage model design – identification of least-cost paths.....	37
5.3	BROWN BEAR (<i>Ursus arctos</i> , L. 1758).....	37
5.3.1	First step: Application of the CorridorDesigner GIS Habitat Suitability Model.....	37
5.3.2	Second Step: Adding a Critical Species’ Specific factor.....	39
5.3.3	Third Step: Linkage model design – identification of least-cost paths.....	39

5.4	GREY WOLF (<i>Canis lupus</i> , L., 1758).....	40
5.4.1	First step: Application of the CorridorDesigner GIS Habitat Suitability Model.....	40
5.4.2	Second Step: Adding a Critical Species' Specific factor	41
5.4.3	Third Step: Linkage model design – identification of least-cost paths	43
5.5	CHAMOIS (<i>Rupicapra rupicapra</i> L. 1758).....	45
5.5.1	First step: Application of the CorridorDesigner GIS Habitat Suitability Model.....	45
5.5.2	Second Step: Adding a Critical Species' Specific factor	46
5.5.3	Third Step: Linkage model design – identification of least-cost paths	47
5.6	EUROPEAN OTTER (<i>Lutra lutra</i> , L., 1758)	47
5.6.1	First step: Application of the CorridorDesigner GIS Habitat Suitability Model.....	47
5.6.2	Second Step: Adding a Critical Species' Specific factor	48
5.6.3	Third Step: Linkage model design – identification of least-cost paths	49
5.7	WESTERN CAPERCAILLIE (<i>Tetrao urogallus</i> , L., 1758)	50
5.7.1	First step: Application of the CorridorDesigner GIS Habitat Suitability Model.....	50
5.7.2	Second Step: Adding a Critical Species' Specific factor	51
5.7.3	Third Step: Linkage model design – identification of least-cost paths	51
5.8	EUROPEAN HARE (<i>Lepus europaeus</i> , Pallas, 1759)	53
5.8.1	First step: Application of the CorridorDesigner GIS Habitat Suitability Model.....	53
5.8.2	Second Step: Adding a Critical Species' Specific factor	54
5.8.3	Third Step: Linkage model design – identification of least-cost paths	54

Tables

Table 1: Overview on data sources.....	11
Table 2: Corine Land Cover Classes	15
Table 4: LAND COVER WEIGHT: 40% (<i>European Lynx</i>).....	35
Table 5: TOPOGRAPHIC POSITION WEIGHT: 20% (<i>European Lynx</i>)	35
Table 6: ELEVATION WEIGHT: 10% (<i>European Lynx</i>).....	35
Table 7: DISTANCE TO HUMAN IMPACT FACILITIES WEIGHT: 15% (<i>European Lynx</i>).....	35
Table 8: DISTANCE TO ROADS WEIGHT: 15% (<i>European Lynx</i>)	36
Table 9: CORE AREA SIZE (<i>European Lynx</i>).....	36
Table 10: LAND COVER WEIGHT: 30% (<i>Brown Bear</i>).....	37
Table 11: TOPOGRAPHIC POSITION WEIGHT: 30% (<i>Brown Bear</i>).....	38
Table 12: DISTANCE TO HUMAN IMPACT FACILITIES WEIGHT: 10% (<i>Brown Bear</i>).....	38
Table 13: ELEVATION WEIGHT: 10% (<i>Brown Bear</i>)	38
Table 14: DISTANCE TO ROADS WEIGHT: 20% (<i>Brown Bear</i>)	39
Table 15: CORE AREA SIZE (<i>Brown Bear</i>).....	39
Table 16: LAND COVER WEIGHT: 30% (<i>Grey Wolf</i>).....	40
Table 17: TOPOGRAPHIC POSITION WEIGHT: 10% (<i>Grey Wolf</i>)	40
Table 18: DISTANCE TO HUMAN IMPACT FACILITIES WEIGHT: 20% (<i>Grey Wolf</i>).....	40
Table 19: ELEVATION WEIGHT: 20% (<i>Grey Wolf</i>)	41
Table 20: DISTANCE TO ROADS WEIGHT: 20% (<i>Grey Wolf</i>)	41
Table 21: Food availability (<i>Grey Wolf</i>)	41
Table 22: LAND COVER WEIGHT: 30% (<i>Red Deer</i>).....	42
Table 23: TOPOGRAPHIC POSITION WEIGHT: 20% (<i>Red Deer</i>)	42
Table 24: DISTANCE TO HUMAN IMPACT FACILITIES WEIGHT: 20% (<i>Red Deer</i>)	42
Table 25: ELEVATION WEIGHT: 15% (<i>Red Deer</i>).....	42
Table 26: DISTANCE TO ROADS WEIGHT: 15% (<i>Red Deer</i>).....	43
Table 27: Summary of home ranges of individual wolves and packs in Europe (radio-tracking).....	44
Table 28: LAND COVER WEIGHT: 50% (<i>Chamois</i>).....	45
Table 29: TOPOGRAPHIC POSITION WEIGHT: 20% (<i>Chamois</i>)	45
Table 30: DISTANCE TO HUMAN IMPACT FACILITIES WEIGHT: 10% (<i>Chamois</i>).....	45
Table 31: ELEVATION WEIGHT: 15% (<i>Chamois</i>).....	46
Table 32: DISTANCE TO ROADS WEIGHT: 5% (<i>Chamois</i>)	46
Table 33: SNOW COVER (<i>Chamois</i>).....	46
Table 34: LAND COVER WEIGHT: 40% (<i>European Otter</i>)	47
Table 35: TOPOGRAPHIC POSITION WEIGHT: 20% (<i>European Otter</i>).....	47

Table 36: DISTANCE TO HUMAN IMPACT FACILITIES WEIGHT: 5% (<i>European Otter</i>)	48
Table 37: ELEVATION WEIGHT: 15% (<i>European Otter</i>)	48
Table 38: DISTANCE TO ROADS WEIGHT: 20% (<i>European Otter</i>).....	48
Table 39: DISTANCE TO WATER (<i>European Otter</i>)	48
Table 40: LAND COVER WEIGHT: 40% (<i>Wester Capercaillie</i>).....	50
Table 41: TOPOGRAPHIC POSITION WEIGHT: 20% (<i>Wester Capercaillie</i>).....	50
Table 42: DISTANCE TO HUMAN IMPACT FACILITIES WEIGHT: 5% (<i>Wester Capercaillie</i>).....	50
Table 43: ELEVATION WEIGHT: 15% (<i>Wester Capercaillie</i>).....	51
Table 44: DISTANCE TO ROADS WEIGHT: 20% (<i>Wester Capercaillie</i>).....	51
Table 45: FOREST AGE (<i>Wester Capercaillie</i>).....	51
Table 46: LAND COVER WEIGHT: 40% (<i>European Hare</i>)	53
Table 47: TOPOGRAPHIC POSITION WEIGHT: 20% (<i>European Hare</i>).....	53
Table 48: DISTANCE TO HUMAN IMPACT FACILITIES WEIGHT: 5% (<i>European Hare</i>)	53
Table 49: ELEVATION WEIGHT: 15% (<i>European Hare</i>).....	54
Table 50: DISTANCE TO ROADS WEIGHT: 20% (<i>European Hare</i>).....	54
Table 51: ENVIRONMENTAL DIVERSITY (<i>European Hare</i>)	54

Figures

Figure 1: Explanation of the steps for developing a species-specific habitat suitability map.....	5
Figure 2: Spatial analyst > Reclassification > Reclassify	17
Figure 3: Euclidean Distance.....	18
Figure 4: Reclassification of the suitability model (distance to road).	19
Figure 5: The creation of a habitat suitability model.....	23
Figure 6: The creation of a habitat patch map.....	25
Figure 7: The creation of a habitat patch map.....	28

Acknowledgement

The EURAC Team wants to thank all the partners from BioREGIO Carpathians for their contribution and the organization of site visits to support and evaluate the developed ecological connectivity model created in work package 5 of the SEE project BioREGIO.

1 Introduction

Everyone in the world depends on the Earth's ecosystems and on the services they provide. These services range from food and water to disease management, climate regulation, spiritual fulfillment, and aesthetic enjoyment. Unfortunately, man-induced changes in the landscape have resulted in the degradation of more than 60% of ecosystem services. The consequences of human induced fragmentation of native fauna and flora are extensive (MEA 2005, Hilty et al. 2006). Natural habitats are being lost at an incredible rate due to anthropic pressures, and what remains is becoming increasingly fragmented. Increased fragmentation dramatically alters species and landscape relationships and usually increases the risk of extinction.

Taking in consideration the increasing impact of human activities and the modernization of many infrastructures that may cause even more fragmentation, always more researchers, institutions and universities are trying to define the best approach to highlight the threats and to identify the possible solutions to the increasing fragmentation.

One of the approaches that it is always more used is the GIS-suitability model approach. Suitability modelling on ArcGIS is based on the visual identification of the main areas of wildlife occurrence and movements. The model is built on the ecological preferences and requisites of each considered species, giving percentage habitat suitability values (between 0 and 100%; 0: no habitat; 100: best habitat) to the different environmental features hosting the different activities of a species (hunting, breeding, resting and dispersing). This kind of approach is not predictive but probabilistic. This approach is focused on wildlife species and on the potential threats they may encounter during their daily movements. The basic assumption is that the identification of the most probable paths for wildlife dispersal enables the formulation of recommendations to overcome future threats due to the expansion of human infrastructures. In an environment such as the Carpathians, having still a high degree of wilderness, this approach is more valuable. The Carpathians landscape is still highly permeable but foreseen planned infrastructures may become barriers to the ecological connectivity, in case the ecological network is not identified.

The first step of the suitability model identifies the *potential* areas where a certain species could be found and the *potential* core areas according to certain species-specific characteristics (i.e., size of the core area, prey abundance, etc.). In the second step, the suitability model selects only the *most probable* least-cost paths the species may use to move from one core area to another. The suitability model allows the identification of most probable paths and landscape corridors. It highlights human infrastructures (mainly motorways or settlements) that may block wildlife movements. The identification of *potential barriers for connectivity* allows the formulation of specific recommendations to overcome them. In the BioREGIO project, 7 species have been used, considered as highly characteristic of the Carpathians environment. After a first selection from the literature and long discussions with the partners, the choice fell on the following ones:

- Eurasian Lynx (*Lynx lynx* L.)
- Brown Bear (*Ursus arctos* L.)
- Grey Wolf (*Canis lupus* L.)
- European Otter (*Lutra lutra* L.)
- Chamois (*Rupicapra rupicapra* sp. L.)
- European Hare (*Lepus europaeus* P.)
- Western Capercaillie (*Tetrao Urogallus* L.)

The species are considered as umbrella species because they cover the ecological niche of many other species as an “umbrella”. The species were selected because, although they occupy different ecological niches, they partially overlap, allowing the identification of the most valuable areas for connectivity based also on prey-predators relationships. The reaction of the species to the human barriers is also different and this enables us to identify those barriers harming more than one species and therefore to formulate the most appropriate recommendations for a *win-win* situation. Humans should be able to build their connectivity ways (motorways) and wildlife species to move freely in their habitats, in a healthy environment.

The results of the model application to the study area are then projected on an open GIS platform on the web (Web-GIS). The aim of a Web-GIS application is to allow everybody to see the results of the connectivity analysis without having the GIS installed on their computers.

The Web-GIS is a visualization tool that may be useful for both experts and administrators to define the areas to be preserved and those where a deeper analyses is needed in order to overcome potential (or foreseen) barriers.

2 Definitions

Ecological Connectivity: is a term referring to the facility with which organisms move between particular landscape elements. It is important to define the most important patches of land, the number of connections between patches and the maximum number of potential connections.

The concept of connectivity is usually expressed using a common terminology in conservation science. The following definitions are used to clarify what is meant by a certain term in this particular approach.

Buffer zone: Safety zone to protect the network from potentially damaging external influences

Corridors (ecological network): Stripes of habitats allowing individual animals access to a larger area of habitat. Facilitating seasonal migration and permitting genetic exchange. Corridors give the opportunities for animals' movements through the landscape and to move away from a habitat that is degrading or from an area that is under threat. They secure the integrity of physical environmental processes that are vital to the requirements of certain species. A typical corridor is structured in zones called core area, stepping stones, least-cost paths and buffer zones

Core Area: a habitat patch having the ecological requisites to support breeding by an umbrella species. In GIS it is expressed by a group of contiguous pixels with high habitat suitability (low energy cost) that could fulfill the ecological needs of a certain species. Protected areas usually overlap with these main presence areas. Outside of protected areas, they have high importance to conserve biodiversity being the main shelter zones for wildlife protection.

Cost (resistance): a pixel attribute that quantitatively represents the difficulty of moving through the landscape *for a particular umbrella species*. A lower level of resistance corresponds to higher suitability. The suitability model assumes that pixel resistance is the opposite of the pixel's habitat suitability (resistance = 100 minus suitability).

Cost-weighted distance (cwd): a distance between favourable land cover structures that reflects the difficulty of moving between them. The calculation of the cwd takes into account the environmental feature encountered in the identified least-cost paths.

Habitat Factor: a model's attribute such as land cover, elevation, topographic position, slope, or distance to roads, considered for the calculation of the Habitat Suitability Model. Each of the considered factors has a different impact on the dispersal of the umbrella species, depending on the ecological requirements.

Habitat Factor's Weight: Each habitat factor has a *weight* inside of the suitability model, representing that factor's relative importance to the habitat suitability for a certain species.

Habitat Factor Classes: Within each habitat factor, several *classes are differentiated*. Every class is *valuated according to its suitability towards the ecological preferences of each umbrella species*.

For example the factor “land cover” considers classes like grassland, forest, agricultural and urban areas, or the factor “topographic position” consist of classes like ridge top, canyon bottom, & steep slope.

Geometric Mean: Calculated for each pixel to derive a suitability value. Therefore, each habitat factor class is potentiated with the habitat factor’s weight. The product out of the weighted habitat factor classes returns in the optimal case (every factor class is 100% suitable) a pixel value of 1 or 100%. On the other hand, if only one habitat factor class is 0 (highest resistance), the pixel value will be 0, even if all the other habitat factors would be 100% suitable.

Habitat suitability (permeability): The ability of a pixel or a group of homogenous pixels to support survival and reproduction of a priority species. Our model calculates the percentage of suitability of a pixel as the product of the factor classes potentiated with the factor’s weight. We assume that pixel resistance (= cost) is the complement of pixel suitability, following the formula: Pixel resistance=100-Pixel Suitability. Permeability and resistance are complements such that permeability + resistance = 100. Thus, perfectly permeable landscape has zero resistance

Least-cost modelling: a modelling approach that attempts to identify the paths between core areas in the landscape providing the minimum resistance. The identified least-cost paths are drowned in the landscape that provides higher suitability but have to be selected according to each species’ ecological preferences and reaction to encountered barriers

Linkage design: Identification of landscape structures (core areas and least-cost paths) that should be maintained or restored to enhance wildlife connectivity.

Pixel/cell: The smallest unit of area in a raster GIS map – the Corine Land Cover has usually pixel size of 100X100 m. Each pixel is associated with factors, such as vegetation cover, topographic position, elevation and distance from roads. A pixel is a physical element represented as a small unit in a raster image. A raster image is laid out as a series of pixels organized in columns and rows. In the image each pixel has a numeric code representing a value (es: in the land use image each pixel is associated with specific value of forest, urban, crop). Moreover, each pixel has a position in the raster image, which represent its geographical location on the earth surface, and a resolution, which depends upon the size of the pixel. Smaller the size of pixel, higher will be the resolution and more clear will be the object, bigger the size of pixel, lower will be the resolution. The raster datasets used for project have a resolution of 100X100 m.

Resistance: Each cell in a resistance map is attributed with a value reflecting the energetic cost, difficulty, or mortality risk of moving across that cell. Resistance values are typically determined by cell characteristics, such as land cover or housing density, combined with species-specific landscape resistance models. As animals move away from specific core areas, cost-weighted distance analyses produce maps of total movement resistance accumulated.

Stepping-stones: small suitable patches between core areas that are not too distant one another, allowing individuals to moving, for sheltering and feeding and to rest

Umbrella species: Wildlife species that are representative of the investigated area and that can cover the spatial and ecological needs regarding the suitability and dispersal habits of most of the wildlife species in the Carpathians.

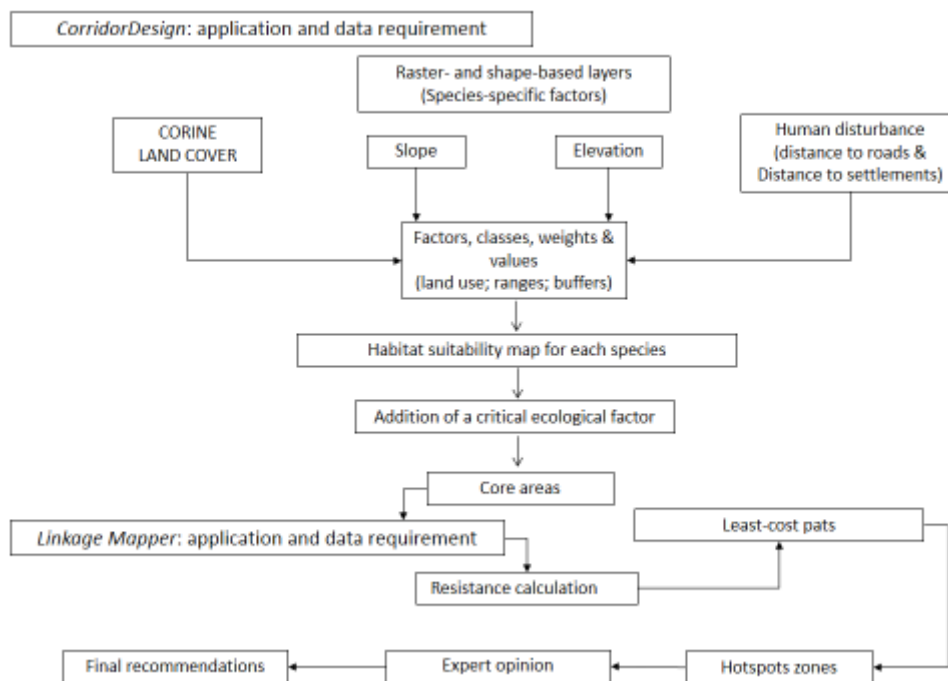


Figure 1: Explanation of the steps for developing a species-specific habitat suitability map

3 Conceptual steps for building the model:

Ecological networks provide for several functions in the maintenance of the health of the environment. They enable the conservation of the biodiversity at ecosystem and regional scale, putting an emphasis on the reinforcement of the ecological coherence and continuum and integrating biodiversity conservation into broad environmental management plans. Ecological networks may buffer critical areas from the effects of potentially damaging activities and helping in the restoration of degraded ecosystems. Ensuring the ecological continuum, without limiting the human development, can contribute to the promotion of the sustainable use of natural resources and to the raising of people's awareness towards a pacific coexistence and sharing of common spaces with wildlife species.

The extension of the Carpathians area and the diversification of the local situations, required a GIS methodology which enabled either a general overview of the habitat suitability and connectivity and a more detailed analysis of the sites where potential barriers were detected.

In order to explore the ecological connectivity and suitability our project adoptes a GIS approach. Among others important projects that have investigat the topic, the Econnect project is the one that aimed to enhancement of ecological connectivity across the Alpine range. ECONNECT had an holistic approach to provide an Alpine-wide overview on the areas important to ecological connectivity by referring to quantitative and qualitative information on selected sites (core areas) and the level of interconnectivity between them (corridors). For the scope of the project it was developed an internet-based GIS-analysis tool called "Joint ecological continuum analysis and mapping initiative (JECAMI)¹ having, at the alpine-wide analysis a 1km of spatial resolution. The GIS analyses were organized into three steps:

Step 1 – Analysis on the level of the landscape: The Continuum Suitability Index (CSI).

This step seeks to definea continuum suitability index from the interaction of ten different indicators calculated for the area of investigation. The indicators results range from 0 to 100 where 100 implies the best possible conditions for connectivity, allowing, then the identification of the main potential barriers for connectivity.

Step 2 – Analysis of distribution and migration of 6 key species: The Species Map Application (SMA). The SMA-Service detects barriers and/or corridors for a specific animal species. Local and real data of spatial distribution of a certain species can be uploaded and compared with the offered

¹ More information on the JECAMI: http://gis.nationalpark.ch/arcgisserver_app/secure/econ_jecami.htm

potential migration area calculated. The PAM-Service finally maps the most important areas of the pilot regions. These priority areas (PA) were identified by the previous continuum project.

Step3 – Analysis of species with a specific role in connecting aquatic and terrestrial habitats (Connectivity Analysis of Riverine Landscape – CARL)

In the BioREGIO project, the decision to use a combination of two free GIS tools and not the JECAMI was done for the following reasons: a) the species-approach to connectivity, focusing on the main potential core areas and the least-cost paths in a heterogeneous landscape at a regional scale – the use of umbrella species as indicators enables a comprehensive analysis of the ecological connectivity of the whole landscape; b) the difficulty in collecting local data needed for the calculation of the indicators; c) the JECAMI tool cannot be coupled with other GIS tools; d) data at a higher level of resolution are needed to deeply the knowledge of the landscape and be able to provide concrete guidelines (the CORINE LAND COVER having a 100 m of resolution enables a suitability evaluation of each landscape feature in the Habitat Suitability Model, although not detailed enough at local scale); e) This kind of approach, coupled with ground-data on human infrastructures, enables the identification of potential barriers, the localization of possible intervention zones and the development of recommendations.

The model applied into BioREGIO project is based on two main steps:

Step 1 consists in the design of the habitat suitability (Habitat Suitability Model) for the selected umbrella species followed by the identification of the core areas according to the addition of a critical ecological factor, essential for the survival of a certain species;

Step 2 identifies the most probable ecological paths the umbrella species choose for dispersal (Least Cost Paths). This together with substeps are in detail discussed later in the document.

After a careful literature review on GIS wildlife habitat modelling, we identified more appropriate GIS tools for our purposes. Among the available GIS habitat suitability models, we selected the ArcGIS 10.0 tool CorridorDesign and ArcGIS 10.0 tool Linkage Mapper. These tools are free of charge, relatively easy to apply and don't require the collection of empirical data on wildlife presence. Results from CorridorDesign can be applied in Linkage Mapper and in multiple study areas, as it enables rapid analyses of wildlife occurrence and ecological corridors.

CorridorDesign (<http://corridordesign.org/>) given a set of habitat factors (e.g. land cover, elevation, topography), produces a map of the general suitability of an area. By adding species-specific factors that concretely limits a species' dispersal, CorridorDesign allows the identification of the main core areas through the reduced extension of the general habitat suitability. The identified core areas can be used in Linkage Mapper (<https://code.google.com/p/linkage-mapper/>). Linkage Mapper is a GIS tool that uses GIS maps of core areas (from CorridorDesign) and resistances to identify the possible linkages between the core areas.

3.1 Pre-modelling:

In this phase the GIS tool is adapted to the investigated area, considering the most appropriate and significant umbrella species and including first considerations on main threats for connectivity.

The Carpathians are a region with a high degree of wilderness, especially in mountain areas. The current situation regarding ecological connectivity does not require urgent interventions to re-establish the ecological network. Preliminary studies have identified that the level of landscape fragmentation is still low but is endangered. The main needs for maintaining and (in few locations) restoring the ecological network in the Carpathians are related to the construction of new infrastructures (especially motorways and settlements' expansions) and to the local populations' attitude and economic interests toward large carnivores (i.e., Turnock, 2001; Salvadori, 2004; REC/EURAC, 2007; Ostapowicz and Kozak, 2010; Boltžiar, 2012). Current, realistic threats for connectivity are few and at the local level. Therefore, it is fundamental to identify the main areas of wildlife occurrence and their movements at regional scale in order to predict as precisely as possible the potential effects and impacts of the foreseen infrastructures and to use this acquired knowledge to enhance the environmental awareness of local people, stakeholders and of tourists.

Secondly, with the help of experts and partners, appropriate wildlife/umbrella species were selected to enhance connectivity based on ecological criteria like land cover selection, preferred range of altitude, effects of mountain slopes, distance from roads and from human habitat (settlements, enterprises). Since the selection of umbrella species follows the theory that their ecological requirements may cover other species' needs and dispersal habits, we selected wildlife species which may cover all the habitats and the possible interactions to the human presence. The Lynx and the Chamois are highly sensitive and specialist species, have a high level of human susceptibility, are bonded to restricted habitats and landscape features, which will disappear first, when connectivity gets lost.

The Wolf and the Bear are generalist and opportunistic species which have a bigger adaptation to different habitat types and to human activities.

The Otter is an aquatic species that need a structural and functional connectivity related to the presence of rivers and to the possibility of moving both along and between river catchments (lateral and longitudinal connectivity).

The Capercaillie and the Hare are prey species directly related to predators (Lynx / Wolf) and that are indicators of a healthy and diversified environment.

For each species it was essential to define the area requirements (home range and dispersal habits), the susceptibility to human disturbance, and the level of protection within the study area. For each species, a draft of a comprehensive ecological profile (see chapter 5) and dispersal characteristics was compiled.

Once the ecological profile was done, we started to collect available data to perform the selected Habitat Suitability Model and to define, with the help of experts, the suitability scores for each habitat factor.

3.2 Collection of available data

Three type of data were collected for the purpose of the project and precisely for the connectivity analysis: a) data gathered from questionnaires; b) qualitative information collected during the site visits and related to the pilot areas; b) geo-data, collected either through open-access databases or with the help of the project partners. While qualitative data were very essential for the analysis of socio-economic barriers, geo-data were necessary for the identification of the umbrella species' habitat suitability and connectivity as well as for the detection of physical barriers.

Geographical data, to be applied in GIS to create thematic maps, consist mainly of vector data (e.g. shapefile of road, rivers or settlement) and raster data (e.g. Corine land cover, Digital Elevation Model - DEM) as well as of orthophotos representing both the Carpathians and the pilot areas. The data, gather either through open-access databases or with the help of project partners, refers either to the whole study area (Carpathians rage) or to the Pilot Areas. Below is an explanation of the main types of geo-data collected and their relevance for the analysis:

Table 1: Types of data collected

Geographic Base line Data	CORINE Land Cover, DEM, and Classified Land Use satellite Images are crucial to visualise the landscape structure and to adapt the GIS analyses to the ecological preferences of the selected umbrella species.
Wildlife presence and distribution	Knowledge about known presence of selected umbrella species (and/or related species – like prey/predator relations) and of road kills is important for the validation of the results of the GIS model. Since every species selects its best habitat based on the availability of resources, breeding, rest and passage opportunities, the general species' ecology cannot justify local habitat selections, which are due to local characteristics and human presence. Punctual, reliable and recent data on animals' presence and distribution are therefore desirable. Nevertheless, this type of data, due to the difficulties in obtaining them, were often missing or incomplete.
Human Infrastructures	Shape files of human infrastructures (i.e., settlements, roads, planned roads, touristic infrastructures, railways etc.) provide useful information on the potential barriers hindering animals' dispersal. Coupling core areas and ecological corridors with information on potential barriers allows to perform detailed analyses on the basis of which elaborate specific recommendations.

Overall, the type of data collected for the project were not comprehensive of the whole study area and many partners experienced serious difficulties in gathering local data to create a substantive database. For instance, only few countries have submitted information concerning the wildlife presence and distribution, although at a low level of resolution, not covering the whole territory of investigation and mainly coming from hunting bags, occasional sighting and just few from empirical data (like radio tracking). More data on this aspect would have allowed a confirmation of the core areas and of the least-cost paths, and the definition of a more detailed strategy for the maintenance and/or restoration of important ecological corridors. In the table below there are detailed information concerning the data collection.

In general, data collection is a very delicate process in any project and acquiring “accurate” and “precise” data of high quality is a necessary requirement for producing good results. Together with it, concerns about harmonization, both spatial and semantic, could rise when the project involves more than one country, as in our case. The main problems related to data harmonization refer to:

- Understanding the different meanings of definitions across years and countries and their quantification (semantic harmonization);
- Different geo-data formats, coordinate reference systems, levels of resolution, geographical scales and administrative mutations or NUTS changes, and spatial (in-) consistencies between two spatial units (spatial harmonization).
- Data formats, missing values and data as well as inconsistent and outdated metadata;

In the case of our project, we have not had problems related to the semantic harmonization as agreements were found among the partners concerning the principal definitions and concepts such as “ecological connectivity”, “suitability”, “least cost path” etc..

More difficult was the process of spatial harmonization. Precisely, the main problems related to the use of different coordinate reference systems and projections and the level of data resolution. As concerning the coordinate system, the data received from the partners, in some cases, had different geographical projections and need to be adapted and adjusted to the common reference system used for this project. The spatial reference is ETRS-1989-LCC. This has no negative implication for the project. As concerning the resolution, we can refer precisely to the Corine Land Cover which has a resolution of 100x100 meter. No more precise data could be found at that scale so the choice was somehow forced. However, the use of a more resolute raster dataset would have created more detailed maps of the suitability and therefore contributed to the design of more “precise” ecological corridors. Additionally, the need to reclassify the Corine Land Cover from 44 classes into 6 classes reduced the set of information and thus the resolution of the data.

The main issues related to the conversion of data from raster format to vector format, precisely during the creation of species’s core areas, bring to the losing of many information related to each single cell.

3.2.1 Free data sets:

In order to identify the main themes and aspects related to the Carpathians territory, diverse datasets and sources were needed. The BioREGIO investigation was mainly focused on the detection and evaluation of possible barriers for connectivity, therefore, data concerning both the physical environment and the human habitat were necessary.

Table 2: Overview on data sources

GIS data	Source
Rivers, Lakes	Joint Research Center (JRC)
Roads	Joint Research Center (JRC)
Forests	Joint Research Center (JRC)
CORINE land cover (100X100m)	European Environmental Agency
Lakes	Joint Research Centre (JRC), EC
Rivers	Joint Research Centre (JRC), EC
NUTS2	EUROSTAT
GIS data	Source
NUTS3	EUROSTAT
Municipality Boundaries	Eurogeographics
large cities	ESRI
national borders	ESRI
landscape types	GISCO, EUROSTAT
elevation model	U.S. Geological Survey (USGS)
relief	U.S. Geological Survey (USGS)
nationally designated areas	European Environment Agency (EEA)
Wildlife species' distribution	IUCN
Habitats, orographic units	Carpates.org
Maps of proposed protected areas	Sopsr.sk
Tree Cover in Mountain Region	UNEP-WCMC

3.2.2 Data from Project Partners

Project partners were requested to integrate the free data sets with local data in order to gain a closer view for local connectivity and more realistic results. The idea behind was to apply also more detailed information than the generally and free available data for the whole Carpathians.

Some of the data were useful to confirm the results coming from the Habitat Suitability Model, especially those relating to the core areas of wildlife distribution (i.e., umbrella species in Slovakia, Hare in Hungary), or to the ecological requisites of forests to identify the probable core areas of Capercaillie. Other data have integrated the free data sets, like the road kills data, the extension and zoning of protected areas, hunting bags etc .

LP: - Lead Partner – NFA (National Forest Administration) ROMSILVA - Piatra Craiului National Park Administration

- Shape file of the habitat types distribution in the Carpathians

IPA PP1 and ERDF PP7: UNEP REGIONAL OFFICE FOR EUROPE - Interim Secretariat of the Carpathian Convention, UNEP Vienna - ISCC

- Jpeg image of the map of the borders of the pilot area Djerdap National Park (Serbia)
- Shape files of rivers and borders of the pilot area Iron Gate Nature Park (Romania)
- Carpathians Serbian Lynx and Otter distribution in the pilot area. Resolution 10km x10km
- Djerdap National Park and Iron Gate Nature Park orthophotos
- Shape files of zone under different protection of Iron Gate Nature Park

ERDF PP3: Duna-Ipoly National Park Directorate & ERDF PP4: - Sant Istvan University, Hungary

- Shape file of the extended Ramsar site at the pilot area Duna Ipoly National Park (Hungary)
- Road kills data for Hungary 2007 - 2011
- GIS shape files of Red deer (*Cervus elaphus*) and European brown hare (*Lepus europeus*) hunting bag data based on the Hungarian National Game Management Database. The spatial basis of the study is the 10*10km UTM net.

ERDF PP7: NFA (National Forest Administration) ROMSILVA - Maramures Mountains Nature Park Administration

- Orthophotos of pilot area Maramures National Park (Romania)
- Virgin Forest localization of Romania

ERDF PP8: NFA (National Forest Administration) ROMSILVA - Iron Gates Natural Park Administration & ERDF PP9: Regional Environmental Protection Agency Sibiu, Romania & IPA PP1 Public Enterprise Djerdap National Park, Serbia

- Description and list of roads present in 1990 and still in operation plus the foreseen intervention in 2013
- Shape file of distribution of NATURA 200 sites in the Carpathians
- Capture report on Romania road kills (Brown Bear)
- Shape files of orographic units of the Carpathians range
- Shape file of Romania Protected Areas
- Djerdap National Park zoning
- Orthophotos of Djerdap National Park
- Shape files of rivers and borders of Serbia

ERDF PP10: State Nature Conservancy of the Slovak Republic

- Shape files of the Slovak distribution of European wolf (*Canis lupus*), European Otter (*Lutra lutra*), Brown Bear (*Ursus arctos*), European Lynx (*Lynx lynx*), Carpathians Chamois (*Rupicapra rupicapra tatraica*), European hare (*Lepus europeus*).
- Shape file of forest age in Slovakia
- Orthophotos of the Poiplie Pilot Area (Slovakia)
- Road kills (several species) for Slovakia

ERDF 20% PP1: Agency for Nature Conservation and Landscape Protection – Czech Republic

- License agreement of The NCA CR's finding/occurrence Data Database, the Habitat Mapping Digital Vector Layer, in original and updated format, written reports from projects funded by the NCA CR for the Czech Republic layer of the Carpathians Convention
- Road kills data for Czech Republic

10% PP1: Carpathians Biosphere Reserve (Ukraine)

Shape files of:

- Carpathians Biosphere Reserve borders
- Carpathians Biosphere Reserve botany

3.2.3 The Role of external partners active in the CC area for data acquisition

As the Ukraine is currently in the applicant status for becoming a member in the European Union, the Ukraine was not sufficiently covered with CORINE LANDSAT Data. To integrate also these famous Ukrainian Oblasts into the modelling approach.

EURAC decided to purchase Land use and land cover maps for the entire Ukrainian Carpathians based on LANDSAT TM/ETM Images from 2000 from Humboldt Innovation GmbH (Technology Transfer Office of Humboldt University). The decision was taken because it was the only provider that offered already classified Landsat-Images (Pixel data) with a resolution of 30m.

For assuring data accessibility, EURAC; UNEP Vienna; Daphne - Institute for Applied Ecology; State Nature Conservancy of the Slovak Republic; The Environmental Information Centre GRID Warsaw; WWF Danube – Carpathians Programme; Slovak Forest Centre, agreed to share a common Memorandum of Understanding to enable the exchange of data directly surveyed within the projects. The Memorandum of Understanding aimed at providing a durable basis for the collaboration among the above-mentioned Partners in data collection and analysis in the field of biological and landscape diversity. The Partners agree to the principle of “open source” exchange of data elaborated during projects, including new data, for the purpose of implementation of the Protocol on Conservation and Sustainable Use of Biological and Landscape Diversity.

Collaboration will include addressing data management and access in the Carpathian region, i.e. better access to existing data, better knowledge of data quality and the generation of new data in a manner that allows data sharing among researchers and/or other interested persons. Contributing to the establishment of an interactive geo-referenced web based joint information system opened and accessible to all (Carpathian Integrated Biodiversity Information System) in the framework of the Carpathian Convention and under the coordination of UNEP Vienna – ISCC

3.3 Choosing habitat factors

The choice of the habitat is species-specific and it is driven by availability of food, breeding sites, safety from predators and other hazards, presence of competitors or facilitating species, and other factors. However, these factors are rarely included in GIS suitability models because they are difficult to quantify. No GIS layer is available with this information and besides this kind of information is not site-specific. Some of these factors may be obtained indirectly, for examples identifying the suitability habitat for a prey species (i.e. red deer) can be used as an indicator of “prey abundance” for the wolf. Typical GIS suitability models are based on one to five factors, including land cover, one or two factors related to human disturbance, and one or two topographic factors. The reason to focus on these factors is pragmatic and simple: these factors are relevant to characterise landscape patches and aside geo-referenced data are available for the entire planning area. The Habitat Suitability Model is a mathematic calculation that produces a geometric

mean among the different suitability values given to each habitat factor. The factors, their separation in classes and the assignments of weights are due to the necessity to adapt the model to the ecological requirement of certain umbrella species. Since every species is bonded to ecologically crucial habitat characteristics, it is essential to divide the habitat factors in categorical (land cover, topographic classes) or continuous (per cent slope, distance from a cover type or road) variables. Only species having clear seasonalities (i.e. bear), the values assigned to the factors' classes change between summer and winter - in order to gain a more complete view of the locations of possible occurrence of this species. GIS layers commonly used in habitat suitability models include land cover, topographic variables, distance to streams, human disturbance/facilities. In the next paragraphs the characteristics of each factor are described.

3.3.1 Land cover

In many suitability models, the CLC classes are grouped in the following six classes:

Table 3: Corine Land Cover Classes

Forest (1)	Grassland (2)	Non-vegetated natural areas (3)	Human Landscape (4)	Agricultural areas (5)	Water bodies (6)
311-Broad-leaved	321-Natural	331-Beaches, dune	111-Continuous urban fabric	211-Non irrigated	411-Inland marshes
312-Coniferous	322-Moors / heathland	332-Bare rocks	112-Discontinuous urban fabric	212-Permanently irrigated	412-Peat bog
313-Mixed	323-Sclerophyllous	333-Sparsely vegetated	121-Industrial/commercial	213- Rice fields	421-Salt marshes
	324-Transitional	334-Burnt areas	122-Roads/railways	221-Vineyards	422-Salines
		335-Glaciers	123-Port areas	222-Fruit trees	423-Intertidal flats
			124-Airports	223-Olive groves	511-Water courses
			131-Mineral extraction sites	231-Pastures	512-Water bodies
			132-Dump sites	241-Annual crops	521-Coastal lagoons
			133-Construction sites	242-Complex cultivation	522-Estuaries
			141-Green urban areas	243-Agriculture + natural vegetation	523-Sea/Ocean
			142-Sport/ leisure, facilities	244-Agro-forestry	

Land cover is considered as the most important factor in the habitat models because it is related to food, hiding cover, thermal cover, and (for land cover classes like urban land use) human disturbance. Referring to the literature (i.e., Beier et al., 2008; Conrad et al., 2012; Jordan et al., 2003) it is possible to estimate the degree of suitability of each species in respect to each CORINE classes group (see “Habitat suitability”).

3.3.2 Topographic variables

Elevation

Elevation is a determinant of land cover. It also affects the thermal environment of an animal, the amount of precipitation, and the form (rain, snow) of precipitation. Fortunately, digital elevation models (DEM) are available in a sufficient resolution worldwide. Elevation is applied as the occurrence of species is related to a certain range of elevation. Referring to literature references (i.e., Beier et al., 2008), usually 3 classes (below, within, and above the elevation limits) or 5 classes (i.e., 0-500m; 500-1000; 1000-1500; 1500-2000; 2000-2500m a.s.l.) are applied.

Topographic position

Topographic position is correlated with moisture, heat, cover, and vegetation. It is also relevant to cost (energy effort) of movement, and is therefore a crucial factor to be included in the suitability model. Topographic position can be estimated by classifying pixels into any number of classes such as steep slope, ridge top, or valley bottom.

Distance to streams

Distance to water is correlated with water, movement, and food for some species. The model includes it in the second step (see 4.2.), since it is a crucial ecological factor for the aquatic umbrella species selected (Otter).

3.3.3 Human disturbance

Factors related to this category can be based on the critical distance umbrella species keep from certain human disturbance facilities (used in the present model):

Distance to roads: This factor defines a buffer zone close to national and international roads and it is usually divided in 3 to 5 classes (0-50 m, 50-200m and so on).

Distance to Human Impact Facilities: Calculates a buffer zone related to the size and position of human facilities like settlements, and/or other infrastructures, according to the available data.

3.1.1. Data preparation, identification and selection of the most appropriate GIS Habitat Suitability Model

The choice of the GIS model was preceded by an extensive literature review on the application of several GIS Habitat Suitability Models. *CorridorDesign* and *Linkage Mapper* (Majka et al., 2007; <https://code.google.com/p/linkage-mapper/>) were chosen as applicative tools because they fulfilled our requirements using an easily-understandable methodology, applying easy-to-collect data and a user-friendly interface. This model approach joins together the assessment of the quality of habitat for certain species within the study area, and serving as the required cost layer for least-cost path and corridor analyses. Once habitat factors are defined, and before the design of the habitat suitability and the creation of most probable ecological paths, some data need to be prepared in order to be included in the model.

1- Land Cover Reclassification:

Land cover have to be reclassified from 44 original classes to 6 classes in order to be included into the model, as explained in the previous paragraph. The easiest way to reclassify a raster image is to use the GIS Arc tool *reclassify*. In this case, the raster image needs to have an attribute table. In case it does not, one can right click on the image *properties > symbology > display as unique values*. If the system asks to create the attribute table, allow it to do that. Once the creation of the attribute table is done, the GIS Arc tool *Reclassify* can be used to give new values to the input raster. *Spatial Analyst > Reclassify* (See image below) Practically, the preferred raster image is added into the window box, and the value field is selected; in the new values tab, the new values are assigned manually. In the case of the CORINE Land Cover, the 44 classes are reduced into 6. (see Table 2 for CORINE classes reclassification).

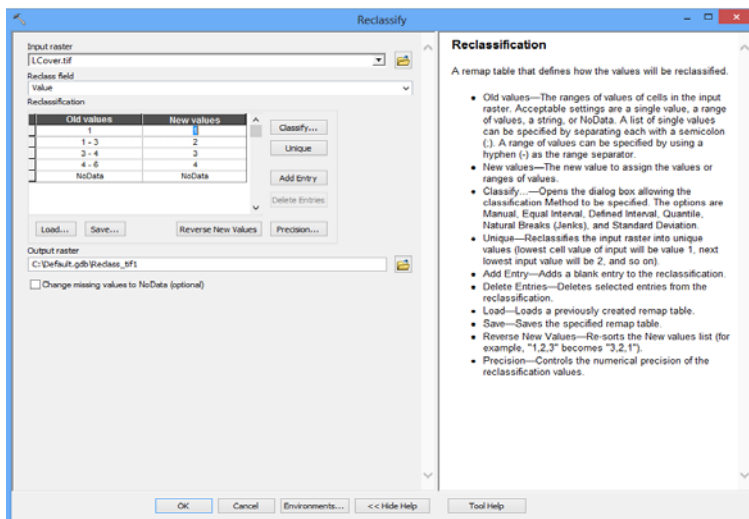


Figure 2: Spatial analyst > Reclassification > Reclassify

2- *Distance from road and distance from urban:*

This raster image can be created by applying the Euclidean distance tool from the GIS Arc tool *Spatial analyst tool > distance > Euclidean distance*. In the input raster, you add the shapefile urban or roads and you name it. Usually the system gives you an output cell size, automatically. Leave it as it is if you are not working with other raster image; in our case we should choose 100 because we are working with raster, which have a resolution of 100x100 meters. (The other tabs could be left empty).

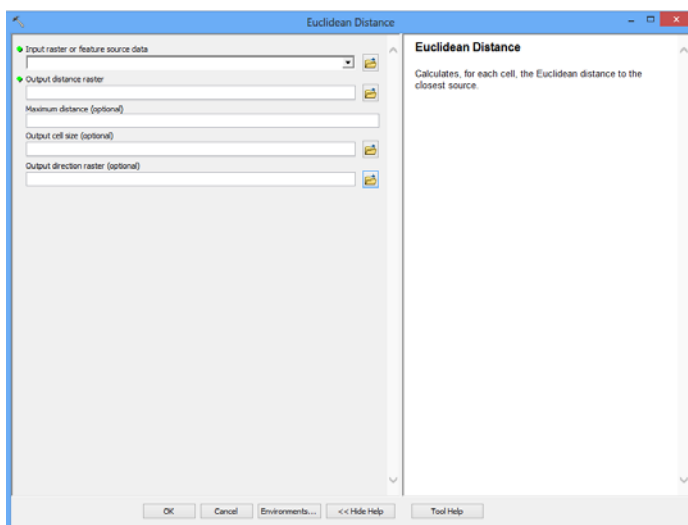


Figure 3: Euclidean Distance

3- *Elevation*

Usually the DEM (Digital Elevation Model) is used as it is.

4- *Slope*

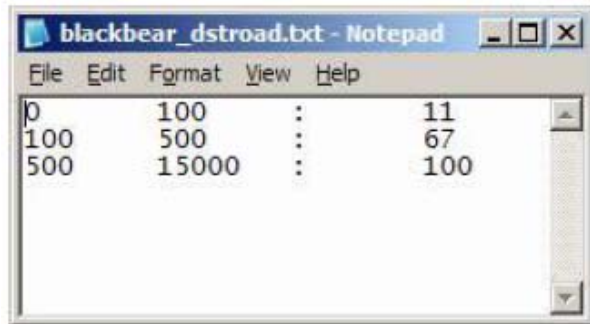
In order to create the topographic position of a raster image (DEM), the GIS Arc tool *slope* should be used. *Spatial analyst tool > surface > slope*. The DEM can be added, including the name of the output raster and leaving the other tab empty.

5- *Create species factor reclassification files (for the Habitat suitability model)*

CorridorDesign uses reclassification text files to give suitability values to the factors' classes. For each species, it is necessary to create as many text files as the number of factors (land cover, topography, elevation, distance from roads and distance from urban) included into the suitability model. The text file shows the required format for reclassifying continuous variables such as distance-from-roads and elevation. This file is simply a tab-delimited text file, with the continuous variable range on the left, a colon, and the suitability score on the right.

Ex: distance from roads file, demonstrated in Table 4:

- From 0 to 100 meters away from a road, the suitability score for black bear is 11.
- Between 100 and 500 meters away from a road, the suitability score is 67.
- Farther than 500 meters away from a road, the suitability score is 100.



Distance from Road (meters)	Reclassification Rule	Suitability Score
0	100	11
100	500	67
500	15000	100

Figure 4: Reclassification of the suitability model (distance to road).

6- Clipping layers to create the area of investigation

Sometimes it is necessary to “cut” the data in order to fit the study area. In order to do so the GIS ArcTool *clip* can be used. *Data management tool > raster> raster processing > clip* in case of a raster image. In case of a vector data the GIS ArcTool *clip* found in *Analysis tool >Extract > Clip* can be used.

7- Add CorridorDesigner toolbox to ArcToolbox.

Show the ArcToolbox window by clicking the ArcToolbox button. Right-click the ArcToolbox folder inside the ArcToolbox window and click Add Toolbox. Click the Look in dropdown arrow and navigate to the location of the CorridorDesign toolbox. Click the toolbox. Click open. The CorridorDesign toolbox is added to the ArcToolbox window

4 Technical Steps:

Once habitat factors are defined and the data collected and re-classified, the design of the habitat suitability (*Habitat Suitability Model*) for each selected umbrella species, and the identification of the most probable core areas and ecological paths (*Least Cost Paths*) represent the two main steps of the GIS model.

4.1 First step: Application of the Corridor Designer – creation of a Habitat Suitability Model

Questions:

What is the potential suitability value of the different habitat types according to each umbrella species?

Where are located the different habitat according to the species' ecological profile?

Expected results

General Habitat suitability map for the considered species ranging from 0% (no habitat) to >50% (best habitat).

4.1.1 Calculation of suitability score of factors' classes

For each class of the habitat factors (such as forest or grassland within land cover) a particular suitability score is assigned. Meaningful thresholds are set to allocate appropriate habitat suitability scores to the categories, whereby the defined thresholds are related to the habitat requirements of breeding sites. A score of zero is assigned when already one particular class of a habitat factor does not correspond to the ecological requirements of the species considered.

To assign a suitability score to each class within each factor, we use a fixed scale between 0 (no suitability) and 100 (maximum suitability) having in mind the following biological interpretation:

- 100: best habitat, highest survival and reproductive success
- 50: sub-optimal habitat, food availability and passage
- 25: occasional use and passage
- 0: avoided/barrier

4.1.2 Assigning weights to each factor for each umbrella species

To estimate the overall suitability of each pixel it is essential to assign a weight to each factor according to their relative importance for the species' ecological needs. In the literature, there is a lack of studies about weight values for diverse habitat factors to consider for each species. Due to this, the weights' values can be subjected to personal interpretation and lead to errors in the suitability calculation. It is, therefore, essential to check the factors' values and weights within an expert's consortium and find a common agreement upon them.

Example: assigning a weight to the factors for the Lynx species.

When considering only 3 basic factors like land cover, topographic position and distance to roads, land cover for the Lynx could be assigned a weight of 60%, topographic position a weight of 20%, and distance-to-roads a weight of 20%, making land cover three times more important than the other factors.

4.1.3 Calculation of pixels' Suitability value with CorridorDesign

For the calculation of the pixel's suitability value, the habitat factor classes scores potentiated with the habitat factors' weights need to be combined to obtain for each pixel a final score between 0 and 100. Therefore a weighted geometric mean is applied, which is the product of the habitat factor classes potentiated with the habitat factors' weights. This approach better reflects a situation in which one habitat factor limits the suitability in a way that cannot be compensated by other factors. Weighted geometric mean better models a situation in which a deficit in one factor cannot be compensated by high scores for other factors. For instance, if urban areas are poor habitat under all circumstances, this factor's class will get a score of 0. Applying the geometric mean leads in the final calculation to a pixel values of 0. And that reflects the real situation best.

4.1.4 Habitat suitability is limited by its worst factor

The Math: Suitability = $\prod_{i=1}^n (S_i^{W_i})$

Where Π indicates the product to combine the n habitat factor classes (*i*) with their scores (*S_i*) and their habitat factors weight (*W_i*).

Following that procedure, it is necessary to create suitability classes to simplify the model approach. Therefore the obtained pixel values are divided in 4 suitability classes (Beier et al., 2008) accordingly:

- 1- Suitability > 50 – 100% = Appropriate for an optimal habitat, core areas, highest survival and reproductive success (CORE AREAS) (in some cases, we selected 75% as threshold to avoid too many core areas to be displayed and to facilitate the calculation of the least-cost paths)
- 2- Suitability > 25 - < 50% = Sub-optimal habitat, food availability, passage sites (low resistance areas – optimal for least-cost paths)
- 3- Suitability > 0 - < 25% = Occasional habitat, stepping stones
- 4- Suitability 0 = Avoided, non-habitat (Barrier)

4.1.5 Creating a habitat suitability model

In order to process the habitat suitability model for each umbrella species it is necessary to use the data prepared and reclassified, the text files created, and set the weight for each factor. The habitat suitability model tool (*CorridorDesign* tool) allows the reclassification and combination of 2-6 different habitat factors. In our approach, we have used the five factors previously described.

Once you have added the tool to the Arcgis toolbox, double-click the *HSM 1- Create habitat suitability model*. The habitat suitability model tool provides two algorithms for combining habitat factors– geometric mean and additive mean.

- Create a folder to store the output data
- Choose a name for the output habitat suitability model.
- Remember that you are limited to 13 characters for raster names.

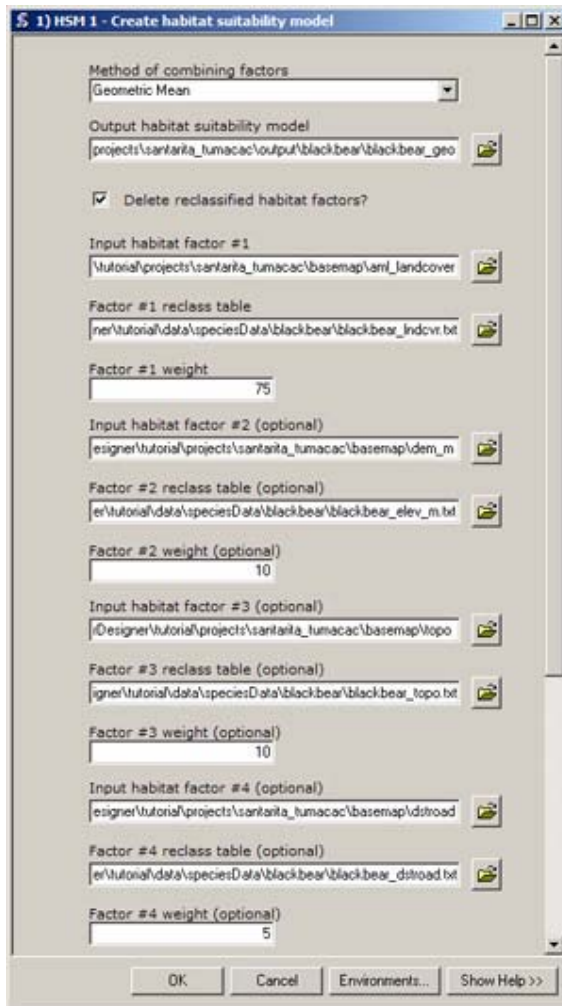


Figure 5: The creation of a habitat suitability model

The *Create habitat suitability model* tool requires three parameters for every habitat factor used in a model:

- 1- Habitat factor: location of raster habitat factor
- 2- Habitat factor reclass table: location of reclass tables discussed above
- 3- Habitat factor weight: importance weight assigned to each habitat factor.

You can browse the input habitat factors (such as land cover), the reclass table and in the weight tab you add the weight. Then you click ok

The generated map is not confirmed by real observation and presence data and gives a general overview of the habitat potential to host a certain umbrella specie.

4.2 First sub-step: Adding a Critical Species' Specific factor

Questions:

According to the species' critical ecological factor, what is the new suitability value of the different habitat types? Where the most probable habitat patches are located?

Expected results

Definition of core areas (pixels having > 50% suitability)

After defining the habitat suitability in a general term, we have to define the quality of the habitat patches according to each species' specific factor.

Objective of this sub-step is the recalculation of the habitat suitability according to each species' strict (fundamental) ecological parameter and not only to the land cover characteristics, moving then closer to real species' habitats.

Each species has its own ecological preferences strictly dependent on a few ecological factors or landscape features. Adding a new factor to the habitat suitability model and performing a new suitability calculation enables a re-categorization of the landscape suitability and therefore the identification of the main areas of species' occurrence. Examples of critical ecological factors can be taken from the literature concerning each studied species in similar environments. The new calculation is performed only on those pixels having a suitability of > 50% (or 75%) from the first step as they identify already a suitable landscape for the species' occurrence or dispersal. This step is extremely important to reduce the size of suitability habitat from only probabilistic to a closer-to-reality view. If a species is strictly dependent on the proximity to or on the presence of a certain source, (i.e., distance to a basic source, size of core area, distance between optimal areas, a certain habitat type, prey density), a standard suitability model has the risk to over predict the amount of suitable habitat in an area. One way to create a more realistic model for each species is to reclassify the developed habitat suitability model in order to better reflect declining suitability with increasing distance from (or absence of) a particular critical factor.

Examples of these ecological parameters (factors) can be:

- Size of core areas
- Presence of particular landscape features (i.e., primeval forests)
- Prey density (could be estimated through the calculation of a habitat suitability model for a prey species: i.e., the red deer for the wolf)
- Distance to the nearest stream
- Distance between core areas

For this reason, only those pixels having a first-step suitability of $> 50\%$ are recalculated, since they represent already a highly suitable habitat. Their suitability values obtained from the first step are re-classified according to one basic, essential, species-specific factor² in the following way:

- Create a new feature class layer i.e., distance to a basic source, size of a core area, prey density;
- Recalculate the existing habitat suitability model assigning a new weight to the new factor based on the proximity to (or presence of) the critical factor.
- The new values will express a more realistic suitability of a certain habitat type for each umbrella species

4.2.1 Required Procedure:

Add a new GIS layer and give it a suitability value

Re-calculate the $> 50\%$ pixels' suitability according to the new values



Figure 6: The creation of a habitat patch map

¹ The detailed description of the re-calculation of the suitability factors can be found in Majka et al., 2007

Identify the most suitable areas according to species critical factors

Core areas are identified by identifying species critical factors so the method to detect them change according to the species characteristics. As instance, for the lynx core areas are detected by selecting the pixels whose suitability value is above 50 and cluster into areas that are bigger than 20.000 hectares.

Create habitat patch map

Having created a habitat suitability model e.g. for the lynx, we can create a map of potential habitat patches. Therefore, the tool *Create habitat patch map* in the *CorridorDesign* Habitat Modeling toolset have to be used.

In the case of the lynx, the parameters selection were:

Moving windows with a radius of 200 m, Habitat patch of 50, a minimum breeding size of 10000 ha and a Minimum population patch of 20000 ha

Create resistance map

Resistance is obtained subtracting the suitability values to 100. In order to create a resistance map the suitability map has to be re elaborated and reclassified. It is possible to do it by working on the attribute table of the suitability map. Concretely a new field has to be added called resist. It has to be a short integer number. Once created, the column has to be selected to perform the field calculator and do the calculation: $100 - \text{values}$ (which is the suitability value). In order to create a resistance map with only one value, the map needs to be reclassified. The reclassify tool into the *spatial analyst* GIS Arc toolbox *Spatial analyst > Reclass > Reclassify* has to be used. As input, the suitability map. The *value filed* is the reclassified field. the manual reclassification is similar to step0. after that, the map should have only three fields: rowid, value, count.

4.3 Second Step: Linkage Mapper- model design – identification of least-cost paths

Questions:

Which are the most probable paths used by each umbrella species to move from one core area to another?

Expected results:

Network of least-cost paths connecting the core areas, enabling the identification of the most probable occurrence and dispersal areas

Once detected the most probable core and occurrence areas, it is necessary to identify, in the areas of minor landscape resistance, the most probable paths for wildlife to disperse. The resistance map and the core areas created in the previous step, will be used to detect the paths. This step allows the identification of possible barriers hindering the free wildlife dispersal through the overlapping with human infrastructures layers. Linkage Mapper uses GIS maps of core areas and resistances to identify and map linkages between core areas. Each cell in a resistance map is attributed with a value reflecting the energetic cost, difficulty, or mortality risk of moving across that cell. Resistance values are typically determined by cell characteristics, such as land cover or housing density, combined with species-specific landscape resistance models. As animals move away from specific core areas, cost-weighted distance analyses produce maps of total movement resistance accumulated.

The tool identifies adjacent (neighboring) core areas and create maps of least-cost corridors between them. It then mosaics the individual corridors to create a single composite corridor map. The result shows the relative value of each grid cell in providing connectivity between core areas, allowing users to identify which routes encounter more or fewer features that facilitate or impede movement between core areas. Linkage Mapper also produces vector layers that can be queried for corridor statistics.

Practical steps:

- *Add linkage mapper toolbox to ArcToolbox.*

The procedure is the same as for adding the *CorridorDesign* toolbox.

- *Run the Linkage Mapper tool to create least-cost paths*

Creating least-cost paths with linkage mapper requires only two set of data: the resistance map and the core areas.

- A project directory needs to be created where saving the work.
- The core areas and the resistance map need to be added.
- The other settings can be left as they are .

The core area feature class needs to have a field name. Fields must consist of positive integers < 999 that identify unique core areas in the core area polygon file. To do so a new field into the attribute table has to be created that can be named NValue as instance. It should be a short integer number. Once created, the field calculator has to be opened and the value field selected. In this case, it will count all the records into the attribute table. Once this step is done,

assigning to 0 a positive values. (es:if your records goes from 1 to 60, assign to 0 = 61). Choose as core area field name and then field you have created =Nvalue

- Add the resistance raster

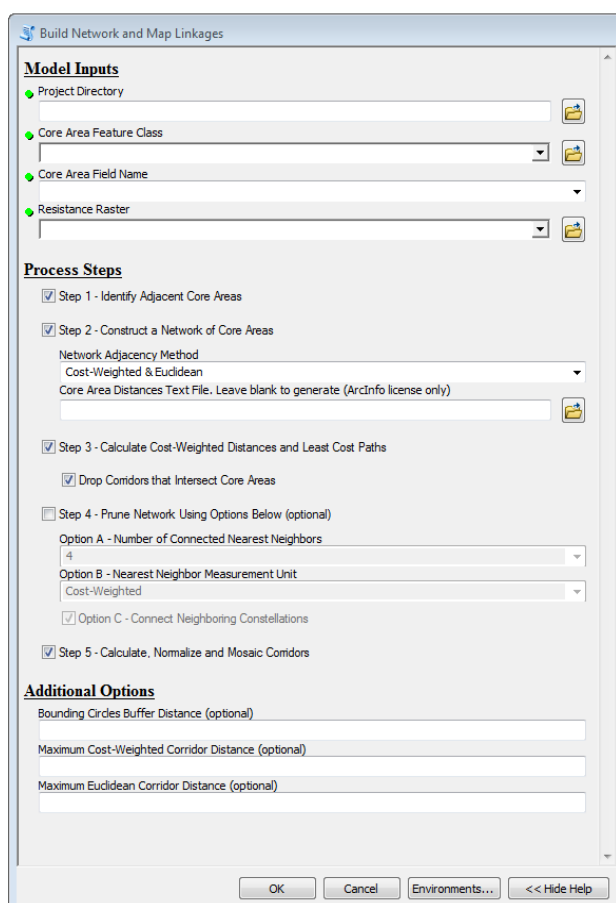


Figure 7: The creation of a habitat patch map

Many habitat models are based on factors such as land cover, topography, and human disturbance, not because the latter fully describe the habitat, but because these are the available factors as appropriate to be implemented as GIS layers (Beier et al., 2008).

4.4 Virtual Model Validation

The validation of the Suitability model map can be performed basically in two ways:

1. Using available real data on the observed presence of the umbrella species in the area derived from empirical research (i.e., radio tracking) and/or national databases based on reliable published literature.
2. Performing site visits in specific areas of probable occurrence following a holistic approach. The on-the-ground analysis of an area has to be coupled with interviews and discussions with local experts and stakeholders (hunters, farmers, foresters, touristic associations, nature conservation agencies, etc.).

The habitat suitability model addresses to wild land areas whose ecological characteristics and distance from human activities are more favourable for the creation (or maintainance) of ecological corridors. The identification of suitable habitat patches for the considered species within the different ecological preferences, along with the assessment of the resistance of the land matrix to dispersal, provide a general framework to interpret the wildlife's movements within and between different habitats and to make an assessment of each catchment in terms of its ability to host source or sink populations.

4.5 Web-GIS

A WebGIS is a GIS application to visualize the results of a GIS analysis. The WebGIS is developed on the web to manage a large extent of geographical information and make it available to a large audience.

Within the framework of the BioREGIO project, a WebGIS has been designed in the attempt to spread the results of the research project, allowing people to know more of the structure of the Carpathians ecological network and its functionality. It contains both raster and vector data and is fully accessible for visualization purposes. It is structured into three main components: an information window; a real time maps browser with different layers containing general information concerning both the landscape and the species' connectivity specifically and a search engine.

4.6 Lessons learned

This suitability model developed in the framework of the BioREGIO project wants to be a first attempts to identify the most probable areas of occurrence and dispersal of seven Carpathians' flag species. The model is a powerful tool that needs few available data to create a probabilistic map of the regional ecological connectivity. To perform a valuable analysis, it needs to receive inputs from local experts regarding the values to give to each factor's class and each factor's weight. More species are involved, more experts are needed and this issue sometimes can be an obstacle. If the input data, factors, values and weight used are correct (or close to the real situation), the model is able to visualize both the structural and the functional connectivity, such as the longitudinal and

lateral ones. Local data on the presence and the extension of human-related infrastructures are needed to detect potential barriers to wildlife dispersal. In many cases, depending on the investigated region, this data could be obsolete and incomplete. Due to the use of the CORINE LAND COVER 2006 as a base landcover map, some landscape features could not be projected in the actual way and some results could be badly interpreted. Therefore, it is essential to perform site visits in specific areas to evaluate and validate the situation detected through the GIS analysis. In this case, the help of local experts and stakeholders is essential, in order to know the real wildlife presence and dispersal and to know which could be the real barriers for a local and regional ecological connectivity.

The model does not want to be predictive; but the results derived from the least cost paths can be useful to prevent future threats to the ecological network due to the development of human infrastructures.

Following a species-based approach, the model identifies the most probable least-cost paths according to the resistance of the landscape. For this reason it is essential to select properly the umbrella species in order to cover most of the ecological preferences of all the other ones. This model is mainly ecological-related. The results could be improved, especially at local scale whether more detailed land cover data would be available. The minimum mapping unit of the CORINE LAND COVER is 25ha and this impedes the comprehensive visualization of all landscape features. Working with landsat classified land cover images with a higher resolution could improve the results and provide a better evaluation of the potential barriers.

4.7 Essential References:

Model:

- Beier, P., Majka, D., Jenness, J., 2008. Conceptual step for designing wildlife corridors. www.corridordesign.org
- Boltžiar M. (eds.), 2012. Conference Abstracts of the 2nd Forum Carpathicum. From Data to Knowledge, from Knowledge to Action, ISBN: 978-80-968901-9-4, 214 pp.
- Conrad, J.M., Gomes, C., P., van Hove, W-J., Sabharwal, A., Suet, J.F., 2012. Wildlife corridors as a connected subgraph problem. *Journal of Environmental Economics and Management* 63, 1-18.
- Fuller, T.K., Berg, W.E., Radde, G.L., Lenarz, M.S., Joselyn, G.B. 1992. A history and current estimate of wolf distribution and numbers in Minnesota. *Wildlife Society Bulletin* 20:42-45. Retrieved from MTU Gray Wolf Recovery Study of 2002

Jordan, F., Báldi, A., Orci, K.-M., Rácz, I, Varga, Z., 2003. Characterizing the importance of habitat patches and corridors in maintaining the landscape connectivity of a Pholidoptera transsylvanica (Orthoptera) metapopulation. *Landscape Ecology* 18, 83-92.

Majka, D., J. Jenness, and P. Beier. 2007. CorridorDesigner: ArcGIS tools for designing and evaluating corridors. Available at <http://corridordesign.org>.

Ostapowicz, K. and Kozak, J. (Eds), 2007. Forum Carpathicum 2010, Conference Proceedings. ISBN: 978-83-88424-54-0

REC/EURAC, 2007. Handbook of the Carpathians Convention. The Regional Environmental Center for Central and Eastern Europe. ISBN: 978-963-9638-15-0

Salvatori, V., Corsi, F., Milton, E.J., Boitani, L., 2002. Use of satellite images for regional modeling of conservation areas for wolves in the Carpathian Mountains, central Europe. WWF International Large Carnivore Initiative for Europe.

Lynx:

Gosselink T, Roberts S, Clark W, Reding D, Linde S (2011) Distribution and population dynamics of bobcats in Iowa. Final Report. State Wildlife Grant T-1-R-14. Iowa. Department of Natural Resources, Des Moines, IA

Kramer-Schadt, S., Revilla, E., Wiegand, T., Breitenmoser, U., 2004. Fragmented landscape, road mortality and patch connectivity: modelling influences on the dispersal of Eurasian Lynx. *Journal of Applied Ecology* 41, 711-723.

Schadt, S., Knauer, F., Kaczensky, P., Revilla, E., Wiegand, T., Trepl, L., 2002. Rule-based assessment of suitable habitat and patch connectivity for the Eurasian Lynx. *Ecological application*, 12, 1469-1483.

Woolf, A., Nielsen, C, K., Weber, T., Gibbs-Kieninger, T, J., 2002. Stetewide modeling of bobcat *Lynx rufus* habitat in Illinois, USA. *Biological Conservation* 104, 191-198

Brown Bear:

Boitani, L., Ciucci, P., Corsi, F., Dupré, E., 1999. Potential ranges and corridors for Brown Bears in the Eastern Alps. *Ursus* 11, 123-130

Ghoddousi, A., 2010. Habitat suitability modeling of the Brown Bear *Ursus arctos* in Croatia and Slovenia using telemetry data. A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science and the diploma of imperial college London

LeCount, 1982 A.L. LeCount Population characteristics of Arizona black bears. *Journal of Wildlife Management*, 46 (1982), pp. 861–868

Vos et al., 2001 C.C. Vos, J. Verboom, P.F.M. Opdam, C.J.F. Ter Braak Toward ecologically scaled landscape indices *The American Naturalist*, 183 (2001), pp. 24–41

Zajec, P., Zimmermann, F., Roth, H.U., Breitenmoser, U., 2005. The return of Brown Bear in Switzerland – suitable habitat distribution, corridors and potential conflicts. *Kora bericht* 28

Wolf:

Belongie, C. 2008. Using GIS to create a grey Wolf habitat suitability model and to assess Wolf pack ranges in the western upper peninsula of Michigan. Volume 10, *Papers in Resource Analysis*

Glenz, C., Massolo, A., Kuonen, D., Schlaepfer, R., 2001. A wolf habitat suitability prediction in Valais (Switzerland). *Landscape and urban planning* 55, 55-65

Kusak, J., Majić Skrbinišek, A., Huber, D. Home ranges, movements, and activity of wolves (*canis lupus*) in the Dalmatian part of Dinarids, Croatia. *European Journal Of Wildlife Research*, volume 51, number 4, 254-262

Chamois:

Expedition report: Chamois, wolves and bears of the Nizke Tatry Mountains, Slovakia. Expedition dates: 14 august – 9 september 2005; 13 august – 8 september 2006; Report published: December 2006; Authors: Slavomir Find’o. Carpathian wildlife society; Biosphere expeditions; Matthias hammer (editor)

Jonas, T., Geiger, F., Jenny, H., 2008. Mortality patterns of the Alpine Chamois: the influence of snow-meteorological factors. *Annals of Glaciology* 49, 56-62.

Suchant, R., Baritz, R., and Braunisch, V. (2003). Wildlife habitat management – a multidimensional habitat management model. *Journal for Nature Conservation* 10(4): 253-268.

European Otter:

Albeke, SE., Nibbelink, NP., Mu, L., Ellsworth, DJ. 2010. Measuring boundary convexity at multiple spatial scale using a linear “moving window” analysis: an application to coastal river otter habitat selection. *Landscape Ecology* 25, 1575-1587.

Bennett A.F. 1999: Linkages in the landscapes. The role of corridors and connectivity in wildlife conservation. *IUCN, Gland*

Loy, A., Carranza, M.L., Cianfrani, C., D’alessandro, E., Bonesi, L., Dimarzio, P., Minotti, M., Reggiani, G., 2009. Otter *Lutra lutra* population expansion: assessing habitat suitability and connectivity in south-central Italy. *Folia zoologica* 58, 309–326.

Schick R.S. & Lindley S.T. 2007: Directed connectivity among fish populations in a riverine network. *J. Appl.Ecol.* 44: 1116–1126.

Capercaillie:

Storch, I. 2002. On spatial resolution in habitat models: Can small-scale forest structure explain Capercaillie numbers? *Conservation Ecology* 6(1): 6.

Suchant, R., Baritz, R., and Braunisch, V. (2003). Wildlife habitat management – a multidimensional habitat management model. *Journal for Nature Conservation* 10(4): 253-268.

European Hare:

Carvalho, JC., Gomes, P. 2003. Habitat suitability for European Wild Rabbit (*Oryctolagus cuniculus*) with implications for restocking. *Game and Wildlife Science* 20, 287-301.

Vidus Rosin, A., Montagna, A., Meriggi, A., Serrano Perez, S. 2009. Density and habitat requirements of sympatric hares and cottontails in Northern Italy. *Hystrix It. J. Mamm.* (n.s.) 20(2) (2009): 101-110

Genghini, M., Capizzi, D., 2005. Habitat improvement and effects on brown hare *Lepus europaeus* and roe deer *Capreolus capreolus*: a case study in northern Italy. *Wildl. Biol.* 11, 319-329

5 ANNEX – Umbrella Species

Technical Steps, Factors, Scores and Weights for each Umbrella Species

The factors, classes, scores and weights used in the Suitability Model for each Umbrella Species are defined in the Annex 1

5.1 Define habitat patch (core area)

A habitat patch is a cluster of pixels that are good enough, big enough and close enough together to support breeding by a particular species. “Good enough” means that they respect the ecological preferences of a species according to studies performed in similar areas; therefore having sufficient resources for the animal. “Big enough” reflects the fact that there needs to be enough area to support at least one breeding unit. “Close enough together” means that the pixels must be clustered, rather than divided into a checkerboard by too much interspersation with pixels of bad habitat (Beier et al., 2008).

To delineate a habitat patch, we must define:

- A circle around every pixel (moving window) to testify the suitability of closer pixels (neighbourhood effect). The size of the moving window is defined based on the spatial requirement of each umbrella species. In our case, the radius of the moving window has been set to 200m for all the species.
- The threshold for habitat quality (defined already in the first and second step = > 50% (or 75%) habitat suitability)
- The minimum area necessary to support a breeding pair (or population) for each umbrella species.

5.2 EUROPEAN LYNX (*Lynx lynx*, L., 1758)

5.2.1 First step: Application of the CorridorDesigner GIS Habitat Suitability Model

Table 5: LAND COVER WEIGHT: 40% (*European Lynx*)

Classes	Scores (% suitability)
Forest	100
Grassland	50
Open areas	25
Urban	0
Agriculture	25
Water bodies	25

Table 6: TOPOGRAPHIC POSITION WEIGHT: 20% (*European Lynx*)

Classes	Scores (% suitability)
Bottom-gentle 0-30°	50
Steep 30-60°	100
Ridge top 60-90°	100

Table 7: ELEVATION WEIGHT: 10% (*European Lynx*)

Classes (m a.s.l.)	Scores (% suitability)
0-500	50
500-1000	100
1000-1500	100
1500-2000	100
2000-2500	50
>2500	0

Table 8: DISTANCE TO HUMAN IMPACT FACILITIES WEIGHT: 15% (*European Lynx*)

Classes	Scores (% suitability)
0-100 m	0
100-500 m	25
500-1000 m	50
> 1000 m	100

Table 9: DISTANCE TO ROADS WEIGHT: 15% (*European Lynx*)

Classes	Scores (% suitability)
0-50 m	0
50-200 m	50
>200 m	100

Total Weight : 100%

The final calculation of the first step has been done as follows (suitability scores in brackets).

Example:

Pixel in a forest (100), on a steep slope (100), at 300 m a.s.l. (50), distant 100m from the nearest road (50) and 500m from the closer Human Impact Facilities (25)

1. $(100 \exp 0,4) * (100 \exp 0,2) * (50 \exp 0,1) * (50 \exp 0,15) * (25 \exp 0,15)$
2. $= 6,31 * 2,51 * 1,47 * 1,79 * 1,62 =$
3. 67,51 % Suitability (potential core area)

5.2.2 Second Step: Adding a Critical Species' Specific factor

Critical ecological factor

Table 10: CORE AREA SIZE (*European Lynx*)

Classes (ha)	Re-classification (% suitability)	Re-classification calculation <i>example</i>	New Suitability classes
0-10.000	25	16,87	Passage sites
10.000 – 20.000	50	33,75	Breeding patch
>20.000	100	67,51	Population patch

5.2.3 Third Step: Linkage model design – identification of least-cost paths

Moving Window:

- According to literature, many different radius of moving windows have been used.
- Based on average home range data = between 25 and 132km² (Woolf et al., 2002; Breitenmoser et al., 2000; Salvatori, 2004). The 5 km radius (7850ha – 78,5km²) was based on the radius of a circle with an area equivalent to the mean annual male home range (Gosselink et al. 2011).
- Local perception: inner radius of 100 m (3.14ha) and outer radius of 750 m (176,6 ha).(annulus)
- In our analysis, we have decided to use a radius of 200m, which covers an area of 12.5 ha

Spatial requirements:

- Assuming a density of one adult lynx per 100 km², 20 resident lynx would require 2000 km². Therefore, we estimate that a functionally connected patch of suitable habitat 2000 km² could sustain a viable lynx population (Schadt et al., 2002)
- Source patches: the major patches of special management interest: (>1000km², 100.000ha)
- Target patches as every suitable area > 100 km², 10.000ha which corresponds with the average home range size of a female lynx (Breitenmoser et al. 1993).
- Core areas are determined by spatial needs of a male (200 km²) (Kramer-Schadt et al., 2004)
- Fragmented forest area patches were considered connected and suitable for home ranges if forest patches were separated by <1 km (Schadt et al., 2005)

5.3 BROWN BEAR (*Ursus arctos*, L. 1758)

5.3.1 First step: Application of the CorridorDesigner GIS Habitat Suitability Model

The brown bear is the only species for which a double habitat suitability model has been calculated, This is due to the ecological habits of this species, that has a clear seasonality (winter/summer). Therefore, two sets of scores have been given to the factors' classes, without changing the weight of the factors. This kind of approach allows the detection of a closer-to-reality view of the core areas and of the ecological connectivity.

Table 11: LAND COVER WEIGHT: 30% (*Brown Bear*)

Classes	Summer Scores (% suitability)	Winter Scores (% suitability)
Forest	100	75
Grassland	50	50
Open areas	50	50
Water bodies	25	25
Agriculture	25	25
Urban	0	0

Table 12: TOPOGRAPHIC POSITION WEIGHT: 30% (*Brown Bear*)

Classes	Summer Scores (% suitability)	Winter Scores (% suitability)
Bottom-gentle 0-30°	50	75
Steep 30-60°	100	50
Ridge top 60-90°	25	0

Table 13: DISTANCE TO HUMAN IMPACT FACILITIES WEIGHT: 10% (*Brown Bear*)

Classes	Summer Scores(% suitability)	Winter Scores (% suitability)
0-100 m	0	0
100-500 m	50	50
500-1000 m	100	100
> 1000 m	100	100

Table 14: ELEVATION WEIGHT: 10% (*Brown Bear*)

Classes (m a.s.l.)	Summer Scores (% suitability)	Winter Scores (% suitability)
0-500	50	50
500-1000	75	75
1000-1500	100	100
1500-2000	100	50
2000-2500	100	0
>2500	50	0

Table 15: DISTANCE TO ROADS WEIGHT: 20% (*Brown Bear*)

Classes	Summer Scores (% suitability)	Winter Scores (% suitability)
0-50 m	0	25
50-200 m	50	50
>200 m	100	100

5.3.2 Second Step: Adding a Critical Species' Specific factor

Table 16: CORE AREA SIZE (*Brown Bear*)

Classes (ha)	Re-classification (% suitability)
0-2000	0
2000-5000	50
>5000	100

5.3.3 Third Step: Linkage model design – identification of least-cost paths

Moving Window:

- 200-m radius to group together pixels with a suitability value of $\geq 50\%$ into the breeding and population patches.
- We chose the 200-m radius to depict suitability relative to the landscape pattern and the spatial requirements and perceptual ability of black bears (Vos et al., 2001).

Spatial requirements:

- Minimum breeding patch size of 50 km² – 5000ha
- Minimum population patch ($n = 50$ bears) size of 300 km² – 30000ha (LeCount, 1982).
- Bear minimum core area: 50 km²/ medium dispersal range: 35km
- Minimum corridor width: between 2 and 5 km (Rogers (1987); Hopkins et al. (1982)

5.4 GREY WOLF (*Canis lupus*, L., 1758)

5.4.1 First step: Application of the CorridorDesigner GIS Habitat Suitability Model

Table 17: LAND COVER WEIGHT: 30% (*Grey Wolf*)

Classes	Scores (% suitability)
Forest	100
Grassland	100
Open areas	50
Urban	0
Agriculture	0
Water bodies	25

Table 18: TOPOGRAPHIC POSITION WEIGHT: 10% (*Grey Wolf*)

Classes	Scores (% suitability)
Bottom-gentle 0-30°	50
Steep 30-60°	100
Ridge top 60-90°	25

Table 19: DISTANCE TO HUMAN IMPACT FACILITIES WEIGHT: 20% (*Grey Wolf*)

Classes	Scores (% suitability)
0-100 m	0
100-500 m	25
500-1000 m	100
> 1000 m	100

Table 20: ELEVATION WEIGHT: 20% (*Grey Wolf*)

Classes (m a.s.l.)	Scores (% suitability)
0-500	25
500-1000	50
1000-1500	100
1500-2000	50
2000-2500	0
>2500	0

Table 21: DISTANCE TO ROADS WEIGHT: 20% (*Grey Wolf*)

Classes	Scores (% suitability)
0-50 m	25
50-200 m	50
>200 m	100

5.4.2 Second Step: Adding a Critical Species' Specific factor

According to Fuller et al. (1992), prey density and the presence of available food is an important factor in the calculation of suitable wolf habitat. Prey density is difficult to quantify since it can vary and fundamentally, it can move across base units of calculation. Rather it would be possible to make a sort of “habitat quality estimation” based on food availability, taking into account the habitat complexity and the generalist diet of this species, dividing it in 3 classes: High, Moderate and Low.

Table 22: Food availability (*Grey Wolf*)

Classes	Re-classification (% suitability)
1 High	100
2 Moderate	50
3 Low	25

Additionally, we can compare the habitat suitability of the Red Deer with the one of the Wolf to reduce the size of suitable areas

5.4.2.1 Ecological requirements for Red Deer

Table 23: LAND COVER WEIGHT: 30% (*Red Deer*)

Classes	Scores (% suitability)
Forest	100
Grassland	100
Open areas	100
Urban	0
Agriculture	0
Water bodies	0

Table 24: TOPOGRAPHIC POSITION WEIGHT: 20% (*Red Deer*)

Classes	Scores (% suitability)
Bottom-gentle 0-30°	100
Steep 30-60°	50
Ridge top 60-90°	0

Table 25: DISTANCE TO HUMAN IMPACT FACILITIES WEIGHT: 20% (*Red Deer*)

Classes	Scores (% suitability)
0-100 m	0
100-500 m	50
500-1000 m	100
> 1000 m	100

Table 26: ELEVATION WEIGHT: 15% (*Red Deer*)

Classes (m a.s.l.)	Scores (% suitability)
0-500	50
500-1000	100
1000-1500	50
1500-2000	25
2000-2500	0
>2500	0

Table 27: DISTANCE TO ROADS WEIGHT: 15% (*Red Deer*)

Classes	Scores (% suitability)
0-50 m	0
50-200 m	50
>200 m	100

Data on wolf prey selection and diet composition suggest that densities of red deer (*Cervus elaphus*), wolves' preferred prey, may be governing kill rates on both deer and other co-occurring species of ungulates (Jedrzejewski et al. 2000). > 10 deer / 10km² (Rumanian ministry of agriculture)

Prey lack cost (P) – Ungulate densities provide a measure of habitat suitability and carrying capacity for large carnivores. The inverse of total ungulate density is a measure for prey lack cost (P).

To prevent the modelling of an exceedingly great ecological network due to high populations of common roe deer and wild boar all over the countryside, more weight was given to planning units with sizeable red deer populations, red deer being also indicative of good forest quality and an important conservation target. Thus, areas with the low densities of red deer were considered less suitable for large carnivores.

5.4.3 Third Step: Linkage model design – identification of least-cost paths

Moving Window:

- Radius: 5-km; Area covered: ca. 80 km² (Salvatori et al., 2002) – home range
- Local perception radius: 200m = 0.125 km² – 12,56 ha

Minimum patch size:

- Wolf minimum breeding area: 10,000 ha = 100 km²
- Medium dispersal range: km 35
- Minimum population size: 200 km²/ (20.000 ha)

Minimum corridor width:

- Between 12 and 22 km (Nowak & Paradiso (1983); Ballard & Spraker (1979))

Table 28: Summary of home ranges of individual wolves and packs in Europe (radio-tracking).

Country (Region)	Home-range Size km ²	References
Italy (Apennines)	120–200	Ciucci & Boitani (1998)
Spain (Leon, Zamora)	195 243	Vila et al. (1990)
Croatia (Dalmatia)	151	Kusak & Huber (2000)
Romania (southern Carpathians)	87 170	Promberger-Fürpass et al. (2001)
Poland (Białowieża)	167	Okarma et al. (1998)
Sweden, Norway (Scandinavia)	750	Håkansson et al. (2000)

5.5 CHAMOIS (*Rupicapra rupicapra* L. 1758)

5.5.1 First step: Application of the CorridorDesigner GIS Habitat Suitability Model

Table 29: LAND COVER WEIGHT: 50% (*Chamois*)

Classes	Scores (% suitability)
Forest	25
Grassland	100
Open areas	100
Urban	0
Agriculture	0
Water bodies	0

Table 30: TOPOGRAPHIC POSITION WEIGHT: 20% (*Chamois*)

Classes	Scores (% suitability)
Bottom-gentle 0-30°	0
Steep 30-60°	50
Ridge top 60-90°	100

Table 31: DISTANCE TO HUMAN IMPACT FACILITIES WEIGHT: 10% (*Chamois*)

Classes	Scores (% suitability)
0-100 m	0
100-500 m	50
500-1000 m	100
> 1000 m	100

Table 32: ELEVATION WEIGHT: 15% (*Chamois*)

Classes (m a.s.l.)	Scores (% suitability)
0-500	0
500-1000	50
1000-1500	100
1500-2000	100
2000-2500	50
>2500	25

Table 33: DISTANCE TO ROADS WEIGHT: 5% (*Chamois*)

Classes	Scores (% suitability)
0-50 m	0
50-200 m	0
>200 m	100

5.5.2 Second Step: Adding a Critical Species' Specific factor

Areas with available winter forage for chamois were delineated according to the medium snow cover which is related to the presence of broad leaved forage trees, whose height is below the chamois' reach (200 cm) (Suchant et al., 2003).

Table 34: SNOW COVER (*Chamois*)

Medium Snow Cover (cm)	Re-classification, (% suitability)
0-100	100
100-200	50
>200	0

In this case, since snow cover is a difficult data to achieve, the identification of winter suitable sites will be performed by splitting the Forest Factor of the CORINE LAND COVER in all its classes and selecting only the broad-leaved class. Additionally, the exposition of the suitable sites can have an influence on landscape selection, as reported by Jonas et al., 2008. Sun-exposed suitable sites are favorable for chamois distribution. Another way for selecting best suitable sites can be done by comparing the wolf and lynx distribution, as chamois is one of their preferred preys.

5.5.3 Third Step: Linkage model design – identification of least-cost paths

Moving Window:

- Radius: 1.8 km. Area covered ca. 10 km²
- Potential dispersal area: 40-200 km²
- Reaction distances between 43 and 400 m
- Radius: 200m = 0.125 km² – 12,56 ha

Minimum patch size:

- Mean home range in winter : 300 ha = 3 km² (Suchant et al., 2003)
- Chamois minimum core area: 10 km²/ medium dispersal range: 10km

Minimum corridor width:

- Difficult to quantify, outermost, alpine regions

5.6 EUROPEAN OTTER (*Lutra lutra*, L., 1758)

5.6.1 First step: Application of the CorridorDesigner GIS Habitat Suitability Model

Table 35: LAND COVER WEIGHT: 40% (*European Otter*)

Classes	Scores (% suitability)
Forest	50
Grassland	50
Open areas	50
Urban	0
Agriculture	25
Water bodies	100

Table 36: TOPOGRAPHIC POSITION WEIGHT: 20% (*European Otter*)

Classes	Scores (% suitability)
Bottom-gentle 0-30°	25
Steep 30-60°	100
Ridge top 60-90°	100

Table 37: DISTANCE TO HUMAN IMPACT FACILITIES WEIGHT: 5% (*European Otter*)

Classes	Scores (% suitability)
0-100 m	0
100-500 m	25
500-1000 m	100
> 1000 m	100

Table 38: ELEVATION WEIGHT: 15% (*European Otter*)

Classes (m a.s.l.)	Scores (% suitability)
0-500	100
500-1000	50
1000-1500	50
1500-2000	25
2000-2500	0
>2500	0

Table 39: DISTANCE TO ROADS WEIGHT: 20% (*European Otter*)

Classes	Scores (% suitability)
0-50 m	0
50-200 m	50
>200 m	100

5.6.2 Second Step: Adding a Critical Species' Specific factor

Table 40: DISTANCE TO WATER (*European Otter*)

Distance to water (m)	Re-classification (% suitability)
0-300	100
>300	0

Otter habitats tends to develop along linear features of the landscape, namely the hydrographical systems. Analyses examining the connectivity of the landscape along linear features such as rivers are relatively new (Bennett, 1999; Schick and Lindley, 2007) and pose some specific problems in

that both longitudinal and lateral connectivity must be evaluated. Longitudinal connectivity refers to otters moving within one river system, while lateral connectivity refers to dispersal movements toward neighboring rivers, which contribute to range expansion and the maintenance of gene flow among populations living in different river basins. As river catchments can be considered as closed systems, the longitudinal connectivity can be simply evaluated through the distribution of suitable habitat patches, while the lateral connectivity must also consider the resistance (permeability) of the land matrix to dispersal by otters between catchments.

5.6.3 Third Step: Linkage model design – identification of least-cost paths

Main river courses and first and second order tributaries were selected from the national hydrographical network

To validate the model, we considered a spatial scale of 10 x 10 km, which is in the order of magnitude of an otter's home range, i.e. 10–20 km (Loy et al 2009).

Moving Window:

- Radius: 1.8 km; Area covered: 10km²
- Radius: 200m = 0.125 km² – 12,56 ha
- Better to use radius of 100m = 3ha (Albeke et al., 2010)

Minimum patch size:

- Otter minimum core area: 10 km²/ medium dispersal range: 15km

5.7 WESTERN CAPERCAILLIE (*Tetrao urogallus*, L., 1758)

5.7.1 First step: Application of the CorridorDesigner GIS Habitat Suitability Model

Table 41: LAND COVER WEIGHT: 40% (*Wester Capercaillie*)

Classes	Scores (% suitability)
Forest	100
Grassland	100
Open areas	50
Urban	0
Agriculture	0
Water bodies	0

Table 42: TOPOGRAPHIC POSITION WEIGHT: 20% (*Wester Capercaillie*)

Classes	Scores (% suitability)
Bottom-gentle 0-30°	100
Steep 30-60°	50
Ridge top 60-90°	0

Table 43: DISTANCE TO HUMAN IMPACT FACILITIES WEIGHT: 5% (*Wester Capercaillie*)

Classes	Scores (% suitability)
0-100 m	0
100-500 m	50
500-1000 m	100
> 1000 m	100

Table 44: ELEVATION WEIGHT: 15% (*Wester Capercaillie*)

Classes (m a.s.l.)	Scores (% suitability)
0-500	0
500-1000	50
1000-1500	100
1500-2000	100
2000-2500	0
>2500	0

Table 45: DISTANCE TO ROADS WEIGHT: 20% (*Wester Capercaillie*)

Classes	Scores (% suitability)
0-50 m	0
50-200 m	50
>200 m	100

5.7.2 Second Step: Adding a Critical Species' Specific factor

Table 46: FOREST AGE (*Wester Capercaillie*)

Forest age (years)	Re-classification (% suitability)
0-10	100
10-30	0
30-60	0
60-80	50
>80	100

5.7.3 Third Step: Linkage model design – identification of least-cost paths

Moving Window:

- Radius: 100m. Area covered 3ha

Minimum patch size:

- Capercaillie minimum core area: 0,5 km² 50ha

Medium dispersal range: 5-10km

A network of suitable habitat patches within the capercaillie's mean dispersal distance of about 5-10 km (see review in Storch & Segelbacher 2000) should be maintained in order to secure gene flow through highly fragmented capercaillie habitats.

Only patches ≥ 50 ha were considered in the analyses. The threshold was chosen following Storch (1999) and Suchant (2002) who found that 50–100 ha of potential habitat was the minimum area for holding capercaillie.

5.8 EUROPEAN HARE (*Lepus europaeus*, Pallas, 1759)

5.8.1 First step: Application of the CorridorDesigner GIS Habitat Suitability Model

Table 47: LAND COVER WEIGHT: 40% (*European Hare*)

Classes	Scores (% suitability)
Forest	0
Grassland	100
Open areas	25
Urban	0
Agriculture	100
Water bodies	0

Table 48: TOPOGRAPHIC POSITION WEIGHT: 20% (*European Hare*)

Classes	Scores (% suitability)
Bottom-gentle 0-30°	100
Steep 30-60°	50
Ridge top 60-90°	30

Table 49: DISTANCE TO HUMAN IMPACT FACILITIES WEIGHT: 5% (*European Hare*)

Classes	Scores (% suitability)
0-100 m	25
100-500 m	100
500-1000 m	100
> 1000 m	100

Table 50: ELEVATION WEIGHT: 15% (*European Hare*)

Classes (m a.s.l.)	Scores (% suitability)
0-500	100
500-1000	50
1000-1500	25
1500-2000	0
2000-2500	0
>2500	0

Table 51: DISTANCE TO ROADS WEIGHT: 20% (*European Hare*)

Classes	Scores (% suitability)
0-50 m	25
50-200 m	100
>200 m	100

5.8.2 Second Step: Adding a Critical Species' Specific factor

Table 52: ENVIRONMENTAL DIVERSITY (*European Hare*)

Environmental diversity (Shannon index)	Re-classification (% suitability)
0-0.5	0
0.5-1	25
1-1.5	50
1.5-2	100
>2	100

5.8.3 Third Step: Linkage model design – identification of least-cost paths

Moving Window:

- Radius: 100m area covered: 3.14ha – 0,314 km²

Minimum patch size:

- Hare minimum core area: 0.5 km² / medium dispersal range: 15km