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Report on methodological evaluation of approaches to migration corridors

Martin Strnad, Tereza Mináriková, Alena Dostálová, Jan Plesnik, Jan Vrba, Michael Hošek and Sophie Condé

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Authors' affiliation:

Martin Strnad, Nature Conservation Agency of the Czech Republic (CZ)
Tereza Mináriková, Nature Conservation Agency of the Czech Republic (CZ)
Alena Dostálová, Nature Conservation Agency of the Czech Republic (CZ)
Jan Plesnik, Nature Conservation Agency of the Czech Republic (CZ)
Jan Vrba, Nature Conservation Agency of the Czech Republic (CZ)
Michael Hošek, Nature Conservation Agency of the Czech Republic (CZ)
Sophie Condé, Muséum national d'Histoire naturelle (FR)

EEA project manager:

Valérie Laporte, European Environment Agency (DK)

ETC/BD production support:

Muriel Vincent, Muséum national d'Histoire naturelle (FR)

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European Topic Centre on Biological Diversity
c/o Muséum national d'Histoire naturelle
57 rue Cuvier
75231 Paris cedex, France
Phone: + 33 1 40 79 38 70
E-mail: etc.biodiversity@mnhn.fr
Website: http://bd.eionet.europa.eu/

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Abbreviations

AIC - Akaike Information Criterion

ALPARC - Alpine Network of Protected Areas

BUND - Bund für Umwelt und Naturschutz Deutschland

CIPRA - International Commission for the Protection of the Alps

CLC - COoRdinate INformation on the Environment on Land Cover

DEM – Digital elevation model

EEA European Environmental Agency

ENFA - Ecological Niche Factor Analysis

FANTER - Factor Analysis of the Niche Taking the Environment as Reference

GIS – Geographical informatin system

GNESFA - General Niche Environment System Factor Analysis

GUIDOS - Graphical User Interface for the Description of image Objects and their Shapes

HIS - Habitat suitability Index

HSM - Habitat suitability model

ISCAR - International Scientific Committee for Alpine Research

JRC – Joint Research Centre

LARCH - Landscape ecological Analysis and Rules for the Configuration of Habitat

LC species – Large carnivore species

LCP - Least cost path

NATREG - Managing Natural Assets and Protected Areas as Sustainable Regional Development Opportunities

PCA – Principal component analysis

SE- IBM - Spatially explicit individual-based model

SD – Standard deviation

SMA – Significant migration area

SPAs – Special protection areas

SRTM - Shuttle Radar Topography Mission

Executive summary

Presented study is consisted of three main parts:

- **Introduction gives general overview of landscape fragmentation problematic** and briefly defines topics such as connectivity conservation, biological corridors and their effectiveness.
- Within this review, **the term biological corridors is preferred** because it clearly reflects both the structural and functional aspects of the landscape features.
- **In term of effectiveness, it must be stressed that biological corridors are species, guild, community and landscape specific**. The controversial vagueness of corridors can have a beneficial effect leaving room for different operating forms and uses. This flexibility is also valuable in mitigation for climate change.

- **The second part of this study is the review of projects and also scientific articles throughout the Europe**, which are focused on proposing and or establishing biological corridors / suitable habitats on the landscape scale.
- It shows **methods used in ecological network planning are based on two main steps**: species selection and selection of area, scale and type of network.
- The first step is a decision for which target species is the network being planned and the best choice would be to select such umbrella species that will also cover ecological demands of wider spectrum of ecologically similar species.
- For the second step, in most studies, the area of interest has been defined either by geography (single or more forested areas/mountain ranges) or by its conservation importance (Natura 2000 sites or national protected areas designated for the forest species) or politically (e.g. area of one or more European states, e.g. area under the Framework Convention on the Protection and Sustainable Development of the Carpathians.
- For **ecological network delineation**, the best methodological approach is preformation of habitat suitability analysis using species occurrence data. This approach produces highly accurate results accepted by experts and also other stakeholders. The quality of the results can be significantly increased by performing field mapping and evaluation of the barrier effects on site. However, this method is very expensive and therefore can be used only on regional/national level.
- The principal **recommendation regarding the protection of landscape connectivity for large mammals** is to delimit and protect a network of areas of European level interconnected by corridors that will provide connection within and between territories of permanent and temporal occurrence of large mammals.
- The principal **recommendation for effective protection of European landscape from fragmentation** is to incorporate this serious topic into EU and national legislation in the context of the new Green Infrastructure Communication adopted by the European Commission (May 2013) and require the landscape fragmentation as an obligatory topic in the process of environmental impact assessment by updating relevant EU directives.
- The principal **recommendation based on the evaluation of the effectiveness and use of overpasses and underpasses** is to plan proper long-term wildlife monitoring that should begin before and continue after the site specific passage is built. Road mitigation structures have to be built on well chosen spots based on species monitoring data. There is a lack of data from such monitoring. Better collaboration between road construction companies and ecologist is needed. Landscape permeability should be secured in wide area around the road mitigation structure to allow free animal movement. Restricting human use of crossing structures, especially at night, is essential in ensuring effective use by wildlife. Multiple crossing structures should be constructed at a crossing point to provide connectivity for all species likely to use a given area.

- **The third part is the case study that sum up results based on ecological network and biological corridors proposal investigation** in the countries neighboring to the Czech Republic.
- **NATURA 2000 sites designated for large carnivores are one of the basic legislative tools** to ensure proper protection and enhance management practices for large carnivores' population sustainability.
- Polish and Czech sites designated for large carnivores shows the highest spatial overlap with ecological network. Nevertheless, this fact is especially caused due to the fact that ecological networks are planned a priory to encompass broad areas.

- **The largest overlap of sites from CDDA with ecological network proposal** has been found in the Poland and the Czech Republic. Approximately 75% of Polish and 70% of Czech nationally protected areas are included into the national ecological network proposal for the large mammals. The German and Upper Austrian overlap of the nationally designated areas and ecological network is much smaller, constituting only up to 11,5% and 1,5% respectively. Nationally protected areas designated to protect forest habitats and large mammals can serve as stepping stone areas and enhance spatial connectivity.
- **The most frequent Corine Land Cover category within the proposed ecological network for large mammals is the forest.** The biggest share of the forest category within the whole ecological network can be found in Germany (89,53%) following by Upper Austria (70,5%), Czech Republic (62,17%) and Poland (56,2%).
- **Agricultural areas category has been identified to be the second most represented,** followed by grassland category. Water bodies, non-vegetated natural areas and human landscape made up minor portion of the whole network in the respective country.
- **The agricultural areas and grassland rather hinders than facilitates large mammals migration**. The attention has to be paid especially to these non-forested areas that host the majority of migration barriers or can be a barrier just by themselves.
- The ecological network in Central Europe is made up of better Wilderness Quality Index categories. This is largely due to the fact that ecological network is primarily planned in mountain and foothill areas with higher altitude. Another factor that reflects quality of WQI is also the prevailing forest cover.
- **We evaluated the possible city conflicts with buffer zone around the corridor axes**. Altogether fifty cities somehow overlaps with the proposed network in the Poland. Three cities that are in conflict with 500 m wide corridor buffer zone were identified in Germany. These are the cities of Trier, Bad Hersfeld and Jena. Four cities in the Czech Republic, namely Břeclav, Hranice, Chomutov and Hodonín, are expected to overlap with ecological network in the Czech Republic in the future. The surroundings of the biggest cities such as Linz and Vocklabruck is expected to be the most affected by the urban sprawl in the Upper Austria.
- We recommend that the future development of all the above mentioned cities should be monitored and their possible negative impacts on the landscape permeability for migrating animals should be assessed and prevented in spatial planning processes.
- **Traffic infrastructure has been identified to be one of the most critical barriers** hindering free animal migration through the landscape. The highest number of critical sites on highways have been identified in Germany. Critical sites for migration have been identified on five main highways in Poland as well as on five highways and six speedways in the Czech Republic. Four motorways A1, A7, A8 and A9 have been identified to cross the corridor network in the Upper Austria.
- We recommend to plan mitigation structures with close cooperation with road construction companies and build them immediately within the process of road construction.
- Natural biotopes (NATURA 2000 biotopes) consists minor portion of the whole corridor surface area in the Czech Republic. Most of the natural habitats within corridor network are located in the mountainous border areas, which are usually also protected such as national parks or protected landscape areas. These areas turned out to be also the most suitable for the long-term occurrence of large carnivores in the country and serve as core areas of high biodiversity importance.

1. Introduction

Habitat loss and fragmentation are among the most pervasive threats to biological diversity. Landscape fragmentation is a transformation of large habitat patch into smaller more isolated fragments of habitats, mainly caused by human activities. The large-scale natural and semi-natural habitat fragmentation and loss caused by agricultural intensification and transport infrastructure and urban development have significantly changed the landscape across the world, both in developed and developing countries (Secretariat of the Convention on Biological Diversity 2010, Kareiva & Marvier 2011). In spite of the planning concept of preserving large unfragmented areas, fragmentation has continued in Europe during the last 20 years and its rate is projected even to increase in the future (EEA 2011). Fragmentation usually has significant negative effects on all the three main commonly recognized levels of biodiversity (for a review, cf. Saunders et al. 1991, Debinski & Holt 2000, Fahring 2003, Jaeger & Fahring 2004, Tischendorf et al. 2005, Fischer & Lindenmayer 2007, Di Giulio et al. 2009, Didham 2010, Holderegger & Di Giulio 2010, Selva et al. 2011, but see Tscharntke et al. 2002, Grez et al. 2004, Yaacobi et al. 2007).

As the landscape has been to run out of large tracks of intact habitats, interest is growing in increasing the connectivity of remaining habitat blocks, thereby facilitating movement, e.g. natal dispersal, seasonal migration, exploration, searching for a mate or daily foraging, of individuals among patches. It has become increasingly recognised that the relationship between dispersal capacity and spatial arrangement of habitat patches in the landscape can affect species´ persistence on a regional scale (Wiens et al. 1993, Lindenmayer et al. 2008). The most popular way to increase connectivity relies on protecting or creating corridors (Anderson & Jenkins 2006, Crooks & Sanjayan 2006, Hilty et al. 2006, Aune et al. 2011, Primack 2012). In addition, maintaining and improving connectivity by i.a. increasing connectivity through designing and managing corridors, removing barriers for wildlife dispersal, locating reserves close each other and promoting restoration is one of the most favoured option within climate change adaptation (Donald 2005, Kettunen et al. 2007, Heller & Zavaletta 2009, Plesník 2009, 2011, Doswald & Osti 2011). Nevertheless, before investing in connectivity projects, conservation practitioners should analyse the benefits expected to arise from increasing connectivity and compare them with alternative instruments (e.g., maintaining and increasing the area of high quality habitats, prioritizing areas that have high environmental heterogeneity and controlling other anthropogenic threatening process through addressing the biodiversity loss and climate change drivers), to ensure as much biological diversity conservation and resilience to climate change as possible within their budget (Hodgson et al. 2009).

Therefore, the review aims at current knowledge on the concept of biological corridors and their typology. It also presents recent opinions on their effectiveness. Because overpasses or underpasses are either biological corridors themselves or an integrated part of the bigger biological corridors, special attention was paid to efficacy of these artificial, man-made landscape elements. The review covers not only scientific literature, but science-policy interface and policy documents were also reviewed.

1.1. Biological corridors – definition and typology

Biological corridors have a relatively long history in nature conservation and management. They have been used as a conservation technique since early in the 20th century. In the late 1970s and early 1980s, a concept of an ecological network was raised and developed to be applied in various parts of the world (Jongman & Pungetti 2001, Bennett & Mulongoy 2006, Bonnin et al. 2007, Shadie & Moore 2009, Jongman et al. 2011).

1.2. Connectivity conservation – key definitions

Like any new emerging science, the literature for connectivity conservation is replete with a range of commonly used terms because the terminology has not been standardized yet.

Connectedness is a relatively static approach. A topological space is connected if each pair of points in it is joined by path. It is most often presented by visual relationships, e.g. on maps. In landscape ecology, connectedness means the physical links between elements of the spatial structure of a landscape, with no direct link to any biota (Baudry & Merriam 1988). On the other hand, connectivity is the degree to which the structure of a landscape helps or impedes the movement of wildlife (Taylor et al. 1993, Tischendorf & Fahring 2000). Connectivity is a parameter of landscape function, which measures the processes by which sub-populations of the particular species are interconnected into a functional demographic unit (Baudry & Merriam l.c.). A landscape is well connected when organisms or natural ecological/evolutionary processes can readily move among habitat patches over a long time. Thus, connectivity refers to the ease with which organisms move between particular landscape elements, about within the landscape (Kindlmann & Burtel 2008). It depends on several attributes of the species, as well as the interaction between the species and the landscape (see below). Various ways how to measure connectivity have been developed: for a review, see Crooks & Sanjayan l.c., Kindlmann & Burtel l.c.). Some authors, e.g. Baguette & van Dyck (2007), Kindlmann & Burtel (l.c.), Opermanis et al. (2012) consider both the connectedness and connectivity sensu stricto (functional connectivity) as two components of connectivity.

Although structural connectivity is easiest to quantify and map, functional connectivity is more important (Worboys et al. 2010).

Worboys et al. (l.c.) further refine the concept of connectivity very well and define four major types of connectivity commonly used in conservation science. These include:
Habitat connectivity – connecting patches of suitable habitat for a particular species or species group.
Landscape connectivity - connecting patterns of vegetation cover in a landscape.
Ecological connectivity – connecting ecological processes across landscapes at varying scales. Ecological processes include trophic relationships, disturbance processes, nutrient flows and hydro-ecological flows.
Evolutionary process connectivity – maintaining the natural evolutionary processes including evolutionary diversification, natural selection and genetic differentiation operating at larger scales. Typically evolutionary processes require movement of species over long distances, long time-frames and management of unnatural selection forces.

There is a plethora of terms used for corridors in the recent landscape ecology, conservation biology, wildlife management, spatial ecology and landscape planning, e.g. conservation corridors, dispersal corridors, ecological corridors, movement corridors, faunal dispersal corridors, green bridges, green highways, greenway corridors, greenways, habitat corridors, land bridges, landscape corridors, landscape connection, linear conservation areas, line corridors, landscape linkages, riparian corridors, steam corridors, strip corridors, wildlife corridors or wildlife movement corridors (Hess & Fischer 2001). Within this review, we prefer the term biological corridors because it clearly reflects both the structural and functional aspects of these landscape features (Mackovčin et al. 2005, Plesník 2008).

Biological corridors are physical landscape elements that facilitate and provide connectivity and coherence at various spatial and time scales. They usually consist of lower quality habitats that may be highly influenced by edge effects but that nonetheless allow movement of individuals among higher quality patches (Bonnin et al. l.c., Worboys et al. l.c., Kareiva &

Marvier l.c.). Edge effects refer to differences in both the environmental and biotic conditions between the edges and interiors of habitat patches. Together with core areas, in the United States also called hubs, they are key spatial structural and functional elements of ecological networks, in the European Union of the Green Infrastructure (GI) respectively (Jongman & Pungetti l.c., UNEP 2003, Bennett & Mulongoy l.c., Bonnin et al. l.c., Ruiz et al. 2009, European Commission 2011a, 2011b, 2012, Jongman et al. l.c., Vimal et al. 2012).

Ideally, biological corridors support all the above types of connectivity, not only habitat connectivity, as often suggested. The primary ecological rationale for biological corridors in nature conservation and landscape management is to increase population persistence by allowing continued exchange of individuals within a previously connected population. Movement of individuals among subpopulations may reduce regional and local extinction rates by a number of mechanisms (Rosenberg et al. 1997):
Decreasing variability in birth and death rates.
Increasing (re)colonization rates of unoccupied patches.
Decreasing inbreeding depression, i.e. increasing gene flow.
Increasing potentially adaptive genetic variance for maintaining population fitness.

Therefore, main functions of biological corridors include (Hess & Fischer l.c.):
Permit colonization of new sites as they become suitable.
Allow organisms to move out of sites as they become unsuitable.
Permit re-colonization of sites where wildlife populations have become extinct.
Allow species to move between separate areas needed to different stages of their life cycles.
Increase overall extend of habitat, particularly for species with extensive space requirements.

1.3. Types of biological corridors

Traditionally, corridors have been viewed as linear strips of habitat that facilitate the movement of organisms through landscapes. Nevertheless, there are three main types of biological corridors (Jongman & Pungetti l.c., Bonnin et al. l.c., European Commission 2011a):
Linear corridors – they are strips of habitat that are thinner or poorer in quality than the patches of similar habitat that connect, e.g. hedgerows, strips of forests, and the vegetation growing on banks of rivers and streams.
Linear corridors with nodes – in addition to the linear corridors, they have some rather broader parts, used e.g. by wild animals for resting during movements.
Stepping stones – these are isolated patches of suitable habitat between larger ones as a series of non-connected habitats that allow organisms to move from one to another.
Landscape corridors – they are diverse, uninterrupted landscape elements, e.g. riparian zones.

Both artificial overpasses and underpasses, called together as ecopassages, are either linear corridors themselves, or a part of linear corridors. Underpasses (tunnels, culverts) can range greatly in size, anywhere from small pipe culverts (0.3m – 2m in diameter), to large underpasses crossing under road bridges. They are typically constructed of concrete, smooth steel, or corrugated metal (Glista et al. 2009, Fairbank 2012).

On the other hand, overpasses provide wildlife with a wide bridge-like structure (viaducts, bridges, culverts, pipes), connecting habitat on either side of a transport corridor. Also overpasses can range greatly in width from only a few meters to over 200 m on each end and are typically planted with natural vegetation to appear as a continuation of surrounding habitat (Corlatti et al. 2009, Glista et al. l.c.. Fairbank l.c.).

1.4. Effectiveness of biological corridors

Some scientists have cautioned that biological corridors may do more harm than good (Simberloff et al. 1992). These researchers worry that the same features that facilitate the movement of organisms may also facilitate the spread of undesirable species and fire from one patch to another. They also recall that the edge effects can increase vulnerability to fire, invasive weeds, non-native competitors and predators, and pathogens. So, the combination of large amounts of edge and higher dispersal among patches could make corridors disastrous.

There has also been much debate on the functional significance of biological corridors among sites of high biodiversity value, mostly in terms of ecological relevance and the fact that in many areas the landscape is not a binary landscape of natural areas and inhospitable terrain (such as in built-up areas or in highly intensified agricultural systems) but a mix of natural and semi-natural habitats and production landscapes that vary in their permeability of different organisms, many of whom may even depend on the matrix for their movements and life-cycle (Chetkiewicz et al. 2006, Hilty et al. l.c., Vimal et al. l.c.).

1.5. Effectiveness of biological corridors – state of the art

In the past, empirical studies addressing the effects of biological corridors were either small in scale or ignored confounding effects of increased habitat area created by the presence of as corridor. Fewer than of half of the 32 studies reviewed by Beier & Noss (1998) provided persuasive data regarding the utility of corridors: other studies were inconclusive, largely due to design flaws. Therefore, until recently, the ability to determine biological corridor effectiveness has been limited. In addition, although the results from an individual study may be convincing, each study only addresses the issue on case-by-case basis, often with a limited number of species and replicates an in one ecosystem. Thus, any single study does not address the primary question about corridors that needs answering.

During recent decades more data have become available on corridors and how they address the problem of fragmentation (Tewksburry et al. 2002, Bennett & Mulongoy l.c., Damschen et al. 2006, Dixon et al. 2006). Gilbert-Norton et al. (2010) have recently conducted a meta-analytic review of the effectiveness of biological corridors and concluded that, over the previous ten years, there had been a growing body of well-designed experiments to assess the efficacy of corridors. This has been done on a case-by-case, and often species-by-species, basis and generally in terms of their main function, which is to increase the movement of plants and animals between habitat fragments. Measures were both direct (proportion of individuals that moved, movement rate of individuals and number of seeds moved) and indirect (species abundance and richness). They analysed 78 experiments from 35 studies conducted between 1988 and 2008 and found that the amount of movement between habitat patches was approximately 50% greater if corridors were in place compared to patches that were not connected by corridors.

The beneficial impact of corridors varies from species to species, for example, a literature survey conducted by Alterra in the Netherlands found that from 18 species of butterflies, mammals and amphibians, nine are strongly dependent on corridors whilst nine are only dependent to some extent or not at all (Vos et al. 2005). Thus, biological corridors are species/guild/community/landscape specific (Haddad et al. 2003).

Some have criticised biological corridors for their lack of definition in that they can vary in size and goals. However, on the basis of an in-depth analysis of biological corridors in the Netherlands, Van der Windt & Swart (2008) suggest that the vagueness of biological corridors provides them with a valuable flexibility i.e. because a biological corridor does not prescribe a certain size or function it can be used by many people and for different landscapes and species. They describe it as a boundary object which is strong enough to bind and flexible enough to leave room for different operating forms and interpretations. This flexibility is also valuable in mitigation for climate change, as its impacts are constantly changing. In particular, stepping stones can improve landscape permeability and protect biological diversity: contrary to linear biological corridors they usually provide micro- and meso-climatically different habitats (Donald l.c., Plesník 2009, 2011).

1.5.1. Biological corridors and invasive alien species and pathogens

One criticism of corridors is that they might facilitate the movement of pathogens invasive alien species, thereby increasing the probability that such species will become established and threaten other species, habitats and ecosystem processes (Simberloff et al. l.c., Hess 1994). However, five years of monitoring the plant community within the experimental clearings has not given much credence to this concern: The number of non-native plant species did not differ between connected and unconnected clearings (Damschen et al. l.c.). To date no corridor created for restoration or conservation is known to have promoted the spread of invasive species (Haddad et al. 2011).

1.5.2. Biological corridors and genetic structure of the respective populations and microevolution

The detrimental effects from increased connectivity on genetic structure of the respective wildlife populations are much less understood and certain. There have been examples of hybridization as an unintended consequence of connecting habitats (Hilty et al. l.c., Rhymer & Simberloff 1996, Aune et al. l.c.). However, most examples are the inadvertent result of human activities that connect habitats and the circumstances in which such effects are likely limited (Hilty et al. l.c.).

The facilitation of gene flow may not always lead to positive conservation outcomes (Tallmon et al. 2004, Horskins 2005). This is because gene flow is a powerful homogenizing force that can quickly wipe out genetic distinctions that have accumulated in isolated populations from natural selection and genetic drift. In other words, even a small number of individuals occasionally moving from one population to another may be sufficient to offset natural election for site-specific adaptations. This emphasizes the importance of understanding historical conditions so as to not disrupt ongoing evolution. In addition, outbreeding depression can reduce the fitness of resulting offspring. Thus, movement is sometimes counterproductive for a species of conservation concern, and conservationists must weigh the risk of inbreeding versus those of outbreeding. On the other hand, there are examples that landscape connectivity really influences gene flow in the target wild species (Coulon et al. 2004, Dixon et al. l.c.).

In addition, some evolutionary biologists suggest that fragmentation of a population can enhance its polymorphisms through natural selection and genetic drift (Kareiva & Marvier l.c).

1.5.3. Biological corridors and trophic interactions in an ecosystem

It has been suggested that increased connectivity may alter the existing predator and prey relationships in an area and create new source sink mortality dynamics that were not predicted (Crooks & Sanjayan l.c., Hilty et al. l.c, but see Ryall & Fahring 2006). This is particularly problematic with the introduction of an exotic predator into a previously naïve population. When assessing connectivity it is important to recognize the presence of invasive alien species in each patch and to guard against movement of undesirable species that might introduce demographic impacts on native species.

Nevertheless, most biological corridor studies record no evidence of predation in or around the corridors. Conversely, there is some evidence that predator species use different biological corridors than their prey (Little et al. 2002).

1.5.4. Biological corridors and edge effect

Another suite of worries concerns the poor quality of the habitat within corridors. Particularly within linear biological corridors and linear biological corridors with nodes, due to its shape (a high ratio of edge to interior), there could be a pronounced edge effect. This shape increases the chance that species of concern will interact with humans, their pets, and their livestock. Biological corridors could be harmful, if, e.g. animals are drawn out of the safety of larger habitat patches into areas where they are more likely to be killed by hunters or dogs (Little et al. l.c.).

In extreme cases, biological corridors can function as an ecological trap, i.e. a habitat patch that does not provide the respective species with necessary conditions for reproduction and survival but that attract individuals even if they suffer from at least sub-optimal habitat there. Thus, its population cannot exist there for long time and individuals experience lower fitness. Moreover, the species prefers such habitats and even avoids more suitable ones (Donovan & Thompson 2001, Schlaepfer et al. 2002). Ecological traps occur not only in the landscape substantially disturbed and degraded by humans, but also in relatively well-preserved environment. In a quickly changing landscape, they can be more common than previously thought. In most cases, an ecological trap causes local population extinction (Battin 2004). Traps arising from degradation of existing habitats are more likely to facilitate extinction than those arising from the addition of novel trap habitat (Fletcher et al. 2012).

Empirical evidence and evidence from experimental studies do not always support the presumption (Haddad et al. 2011).

1.5.5. Biological corridors and unexpected alterations of habitats

A further complication is that biological corridors can affect habitat patch shape in ways that may alter their function in unexpected manner. For example, they may act as “drift-fences”, intercepting individuals moving through matrix habitat and diverting them into connected patches (Haddad & Baum 1999, Fried et al. 2005). From a conservation perspective, these problems are not trivial.

Serious decline in richness and abundance of Europe’s biodiversity in the recent time is caused mainly by intensifying management practices in agriculture and forestry that are closely bounded with consequent decline in traditional management on which many habitats and species depend. Habitats and ecosystems are becoming smaller, more fragmented and their isolation from other areas is increasing. Habitat isolation and it´s loss prevent many species from reaching migration and/or dispersal refugees, forces them to live in suboptimal habitats that may not be large enough for them to maintain viable populations.

The most affected groups of species influenced by fragmentation of the landscape are those bounded to the well-preserved natural environment and have great demands on the size of the home range or their biology include regular or occasional migration. Especially the three species of large carnivores, the wolf, the lynx and the brown bear are coming into fore. Large carnivores are very similar in ecological requirements as these species are strictly tied to large forested areas with low human disturbation. Furthermore, long distance migration is an integral part of their biology (Andersen et al. 2003). They occur strictly in forested mountain or foothill areas. Their spatial demand on home range size is large and comprises usually hundreds of square kilometres. Their core relatively continuous population inhabits the Northern, Eastern and Southern Europe (Scandinavia, the Carpathians and Dinaric mountains), but the population density is low due to territorial aggression. On the other hand the population in the Central and Western Europe has more or less discontinuous character as the species range covers the area of many countries and distribution of the subpopulations is often separated. Sub-adult individuals are forced to seek free niche for reproduction and they have to migrate considerable distances often across national borders. Long-term survival of these populations are considerably threatened by other factors such as illegal hunting and many populations would probably disappeared without strengthening through the process of natural immigration of new individuals (or even by reintroduction interventions). Small populations are generally more prone to disturbations such as the emergence of new barriers, habitat loss and change, increase in illegal hunting, etc. Protection of these species should be dealt with at the European level (Linnell et al. 2007).
Migratory behaviour is also typical for species of large European ungulates. This concerns especially long migration of the Moose and the Red deer or European bison rather migrate on short or middle distances up to a few tens of kilometres. Given that large ungulates have similar environmental requirements as large predators, this fact can be taken as an indicator of environmental status in areas where large carnivores are absent. Large carnivores and ungulates demands on the quality and structure of habitats will also cover the demands of another smaller species which are also closely bounded to forested habitats. If we ensure the protection and mutual connectivity of habitats for umbrella species, then we will also address the issue of protection of entire forest species ecosystems composition, including a number of other endangered species of mammals and birds (Lambeck 1997).

As a result, fragmentation of the landscape is perceived today as one of the hot issues as it was mentioned above. The open landscape composing of natural and semi-natural habitats, supposed to act as a connecting element between various populations, is now losing its capacities. In many cases, this is an irreversible process making the protection of the existing linear connections a key task within nature conservation. Ecological networks in the broadest sense are hence coming to the fore with their basic attribute of suitable habitats and desired continuity.

Second part of this study provides a brief overview of some projects that has dealt with ecological (biological) corridors and/or ecological network (suitable habitat sensu lato) planning and implementation throughout the Europe.

2. Review of the projects focused on ecological networks / biological corridors for large mammals in the Europe.

2.1. Southern Europe

2.1.1. Slovenia

2.1.1.1. Bears suitable habitat and corridors in Slovenia

General overview

The study, conducted by the Slovenian Forestry Institute and Miha Adamic Biotechnical faculty aims at identifying the most suitable locations for the construction of wildlife bridges/underpasses, enabling safer crossing of the highway by the bears. Using GIS and artificial intelligence based modelling, broad potential dispersal bear corridors were identified, taking into account actual land cover between the patches of suitable habitat. Thus identified most probable locations of highway crossings by the brown bears were taken as the most convenient locations for the construction of the wildlife bridges/underpasses.

Project methodology

The study focused on the oldest section of the fenced 6-lane highway, built in 1972, between the capital of Ljubljana and the Adriatic coast, which is already cutting through the prime bear habitat. An expert system for classifying the habitat suitability for brown bear was developed. The knowledge base for the expert system, induced by a machine learning method from recorded bear sightings, was linked to the GIS thematic layers. The main factors considered by the expert system were: the land use types (rendered by the Corine Land Cover database), other human impacts and the topography. The expert system was implemented in GIS, thus enabling the mapping of suitable brown bear habitats.

Results

Based on the habitat map and land cover map, the potential corridors from 11 characteristic points within the core habitat area towards the Alps were identified (fig. 1). Irrespective of the point of origin, all 11 routes cross the highway at only 3 sites. Therefore, these sites should have a priority when planning the overpasses or underpasses (Kobler and Adamic 1999).

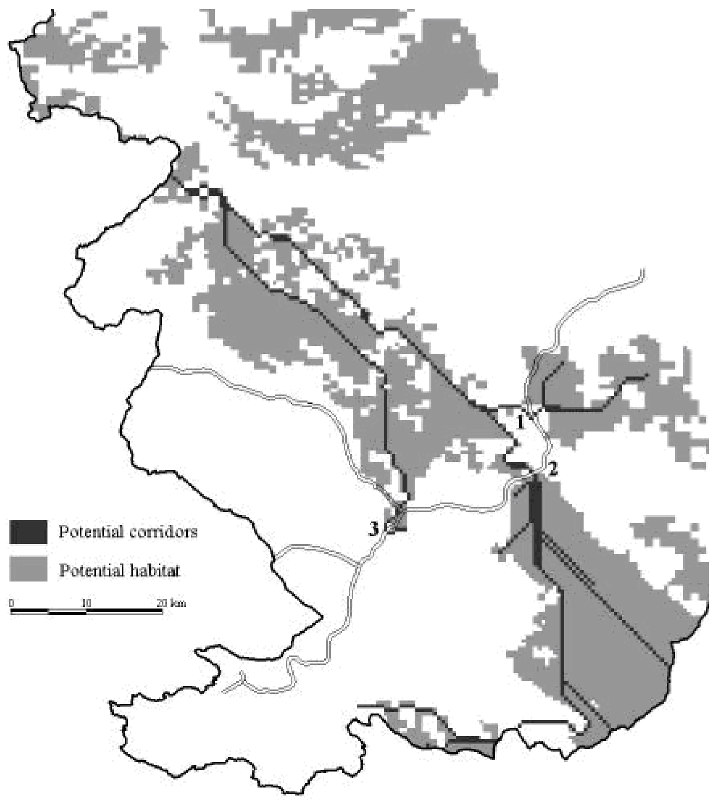


Figure 1. The habitat map with potential movement routes and the expected locations of the overpasses or underpasses in Slovenia.

2.1.2. Italy

2.1.2.1. Ecological network in Regione Abruzzo

General overview

The Alterra research project was commissioned by Regione Abruzzo with the goal to analyze and propose the ecological network in the region.

In this study the ecological network was analyzed at two levels: the potential for ecosystem functioning was assessed for Abruzzo Region, and the situation for the Brown bear, which mainly lives in Abruzzo and other surrounding national parks, was assessed at a supra-regional level. These both studies were done with different tools and methods. As a result of both studies, the ecological network, consisting of core areas and corridors, was proposed in the region. Recommendations were made for the network protection and further development.

Project methodology

Regional ecological network

The landscape ecological model LARCH was used for the Regional analysis. Four ecosystem types were selected, which cover most important natural habitat types in the study area: woodland, grassland and steppe, wetland, and shrubland, all gained from the regional land use map. Seven species were selected as indicators for different ecosystems, to be able to assess in more detail the functioning of ecosystems and ecological networks.

These species are the Wolf, Chiffchaff, Common toad, Hedgehog, Green lizard, Stonechat and Crested newt.

The size of a natural area (habitat patch) in the analysis determined the potential number of individuals of a specific species it can contain. The distance to neighbouring areas determined whether it belongs to a network for the species. The carrying capacity of the network determined whether it can contain a viable population. If that was the case, the network population was evaluated as viable or sustainable for the species.

The study shows that the region has no serious fragmentation problem at the moment, considering the viability of the networks for given species. The 50% of natural habitat is sufficient for most species at present, with the only exception of wolf, which population is partly dependent on the neighbouring regions and in which case it is " a nearly a sustainable population" (based on the natural habitat and natural prey available in Abruzzo alone).

Brown bear supra-regional ecological network

For the Brown bear metapopulation analysis two models, SmallSteps and METAPHOR are used.

SmallSteps, a movement model, provides an estimate of the connectivity of habitat patches for the Brown Bear over a large part of the Apennine mountain region. Connectivity is defined as the probability of reaching another habitat patch when dispersing from the natal patch. The model takes into account the properties (resistance) of the landscape in-between the patches (landscape matrix).

Calculated connectivity is used in METAPHOR, a population dynamic simulation model, to estimate metapopulation viability. Both models require identification of habitat patches, as starting and endpoints for dispersal movements, and as reproduction sites. A species-specific habitat suitability model was used to identify patches (Posillico et al. 2004). The metapopulation simulations for the Brown bear are based on an optimistic view of population growth rate, potential population size (carrying capacity) and mortality risk while dispersing.

The patch connectivity data itself, obtained from movement simulations on the large spatial scale, indicate that habitat patches for the bear are not well-connected, even for an optimistic estimate of an individual's inclination to venture out into low quality or hostile habitat. Corridors may thus improve connectivity a lot, but (according to scenario studies) only when these corridor zones are connected to relatively high quality habitat. Zooming in on the corridor zones between protected areas in the Abruzzo region, results from the movement model indicate that corridors indeed may improve connectivity locally, and more closely link the Sirente-Velino area to the Gran Sasso Park.

Results

Based on all the above mentioned data, a lay-out for a possible ecological network in Abruzzo region has been prepared (fig. 2). This lay-out is for terrestrial corridors, i.e. for the forest, shrubland and grassland ecosystems.

This network is based on areas with the best potential for realizing corridors (based on habitat present already), and taking the present national parks as the 'core- areas' for the ecological network.

The corridors are proposed as 250 m wide, with up going vegetation that provides cover, shelter and reduces exposition for migrating animals. Corridor areas should be protected for further development. In these identified corridors activities like roads construction should always go with mitigating, and sometimes compensating measures. The corridors should in part be improved, by planting hedges, wood rows, to guide and facilitate wildlife movements from one park to the other.

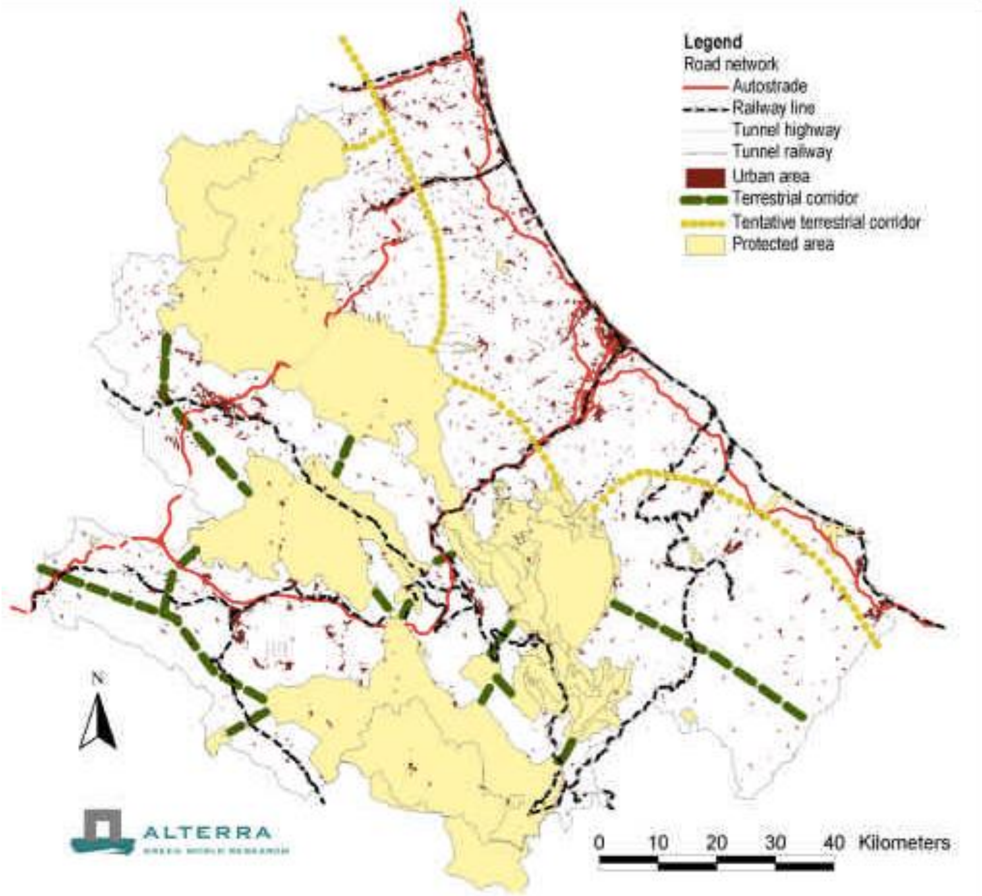


Figure 2. Proposed dryland corridors (forest with open shrubland and grassland) in the Abruzzo region – indicative map (Sluis et al 2003).

For the short corridors, which form connections between the national parks, authors stress that 2 km wide buffer zones should be considered, in which a mosaic of different functions are combined. Besides protective vegetation, forests, also small-scale organic farming could be allowed, including orchards, grain, etc. This will provide food for migrating species. In the event of damage farmers should be compensated.

2.1.2.2. Forest habitat network in a lowland area in Lombardy

General overview

The Università degli Studi di Milano Bicocca research project, supported by the Regione Lombardia, was carried out in the Lombardy with the goal to verify the method of using focal species to plan woodland ecological networks (Bani et al. 2002).

In this study the interpreted satellite image to compare land-use patterns with the presence or abundance of focal species (woodland birds and mammalian carnivores). This method produced “suitability maps” for focal species on which corridors can be drawn as lines connecting core areas through the best available habitat in the matrix. These potential corridors are a useful guideline for implementation of a regional ecological network (fig. 3).

Project methodology

The study was carried out in the area north of Milan that covers about 2500 km^2. The occurrence data of the woodland bird species and small predators - Red fox (*Vulpes vulpes),* European badger (*Meles meles),* Weasel (*Mustela nivalis),* Stone marten (*Martes foina)* - and data on forest habitat openness and urbanization were collected. Focal species, whose occurrence was associated with a high proportion of woodland habitat, were selected. Birds focal species were Great Spotted Woodpecker (*Dendrocopos major),* Green Woodpecker (*Picus viridis),* Nuthatch (*Sitta europaea),* and Marsh Tit (*Parus palustris).* Small predators focal species were European badger (*Meles meles),* Weasel (*Mustela nivalis)* and Stone marten (*Martes foina).*

The distribution model was developed to relate types of land use (gained from the satellite images with band 30 x 30 m) to the distribution and abundance of the focal bird species and then focal small predator species. The relation between habitat composition and focal species abundance was analyzed. Based on this analysis, habitat types significantly related to focal species abundance was identified. This was used to produce a habitat suitability map for focal species.

Results

The habitat suitability modelling was used to the construction of an ecological network. This procedure required consideration of landscape connectivity, which was modelled as matrix resistance relative to the needs of these focal woodland species. The lowest resistance lines were those connecting significant habitat core areas through a path of 30 x 30 m cells with the best available land cover. As defined by the authors, these lines connect core areas larger than 25 ha for birds and core areas of 50 ha for carnivores, an area that includes at least one or more home ranges. The width of corridors wasn't proposed by the authors.

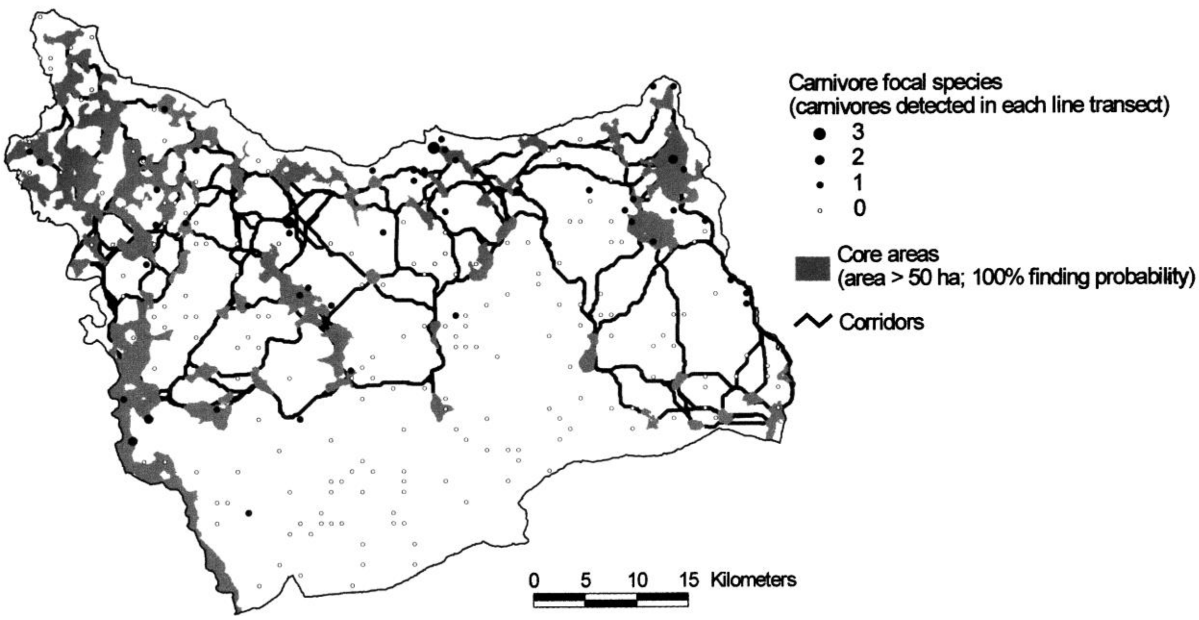


Figure 3. Ecological network drawn by means of data on focal carnivore species in Lombardy (Bani et al 2002).

2.1.2.3. Corridors for brown bears in the eastern Alps

General overview

The research project (Boitani et al. 1999), conducted by the Universita di Roma and Istituto Ecologia Applicata, focused on identifying areas of potential bear occurrence and bear corridors in eastern Alps using Mahalanobis distance statistic. The environmental habitat quality was calculated and different levels of this suitability index were used to identify potential optimal and sub-optimal areas and their interconnecting corridors. The model identified 4 major areas of potential bear presence having a total size of about 10 850 km^2. Assuming functional connectivity among the areas and mean density for west European countries, the Eastern Alps could support 108 - 325 bears. Potential ranges were also compared with existing protected areas to evaluate gaps between bear range with adequate protection and range needing protection.

Project methodology

The study area was Central and Eastern Italian Alps, size of 41 129 km^2. The project methodology was strictly based on statistical models. 12 environmental variables (human density, road density, elevation, slope, aspect and seven land use variables) were selected for GIS model using Mahalanobis distance statistic. The model was based on the calculating the extent of environmental characteristics from the bear actual home ranges, thus identifying bear habitat requirements (habitat suitability index), and being able to find the potential optimal and suboptimal bear areas and connecting corridors.

Results

Optimal zones, identified in the study, were concentrated in the forested areas with the elevation from 800 m., where human disturbance is generally low. Sub-optimal areas consist of lower quality habitats, and therefore can support lower bear densities, but are useful to reduce fragmentation of optimal areas. The third level areas serve as buffer zones and connecting zones to optimal and suboptimal areas (fig. 4).

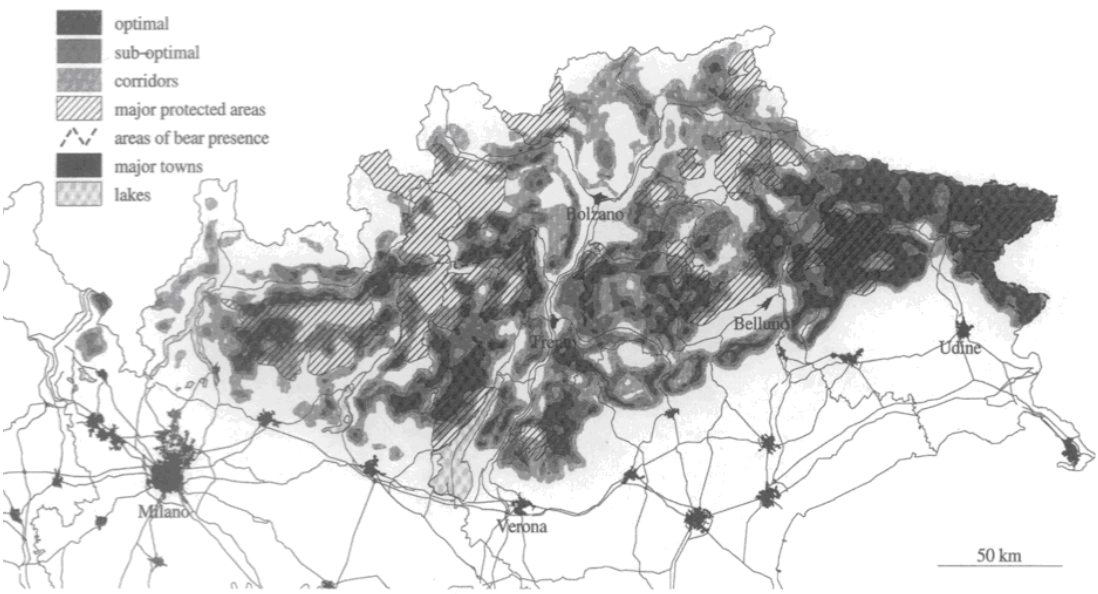


Figure 4. Potential areas for bear in the Italian Eastern Alps (Boitani et al. 1999).

When optimal and sub-optimal areas were merged and only areas with more than 900 km^2 were selected, than 4 main areas of bear presence were identified, having a total size of about 10 850 km^2. All of these areas are highly fragmented with the fragmentation level increasing from the East to the West.

Assuming functional connectivity among the areas and mean density for west European countries, the Eastern Alps could support 108 - 325 bears. Potential ranges were also compared with existing protected areas to evaluate gaps between bear range with adequate protection and range needing protection.

Only 31 % of existing protected areas were found suitable for bears. Therefore, authors suggested that the bear protection in the area should be based more on protecting important bear corridors than on protected areas.

2.1.3. Spain

2.1.3.1. LA GESTIÓN DE LA CONECTIVIDAD ECOLÓGICA DEL TERRITORIO EN ESPAÑA: INICIATIVAS Y RETOS (Management of Ecological Connectivity in Spain: initiatives and challenges)

General overview

Gurrutxaga and San (2011) published a general overview of ecological networks in Spain. In general, no common ecological networks at the state level are reviewed, however several regional systems are described for Catalonia, the Basque Country, Navarra, Madrid, Muricia Region, Austurias and Galicia; in other regions (e.g. in Valencia) ecological networks are under preparation. Special attention of the review is on legislative and administrative requirements and on involvement of Natura 2000 network.

Paper also summarizes main projects related to ecological networks. The most important projects related to this study are the following:

- Oso Cantabria - Conserving the Cantabrian brown Bear and combating poaching (LIFE00 NAT/E/007352). This LIFE projects aims on protection of ca 80 brown bear individuals in the Cordillera Cantárica, especially on communication of protection with local stakeholders (to decrease poaching) and direct protection of local farmers to eliminate damages caused by brown bear. Connectivity was not stressed within this project.

- Lince Andalucía - Population recovery of Iberian Lynx in Andalusia (LIFE02 NAT/E/008609). The project targets a global and comprehensive strategy for the conservation of the Iberian Lynx in Andalucía. The aim is to allow maintenance and stabilisation of the existing populations, increase the number of individuals, and **create new territories and connectivity between isolated subpopulations**. In addition, the project searches to enhance genetic variability of current populations by translocation specimens from Andujar-Cardeña to Doñana. All these actions are to be accompanied by a wide and massive awareness raising campaign helping to gain a constructive attitude of the population, especially in the areas concerned. More details may be found on the Life web pages[1] and project pages[2]. Palomares et al. (2000) summarised important results on the

[1] http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.createPage&s_ref=LIFE06%20NAT/E/000209&area=1&yr=2006&n_proj_id=3160&mode=print&menu=false

habitat preference of the lynx.

In general, authors conclude that Spain is not a leading country concerning the ecological networks and in comparison to other European countries there is a lot work to be done.

2.1.3.2. SPEN – Country Study for Spain

General overview

Sunyer and Manteiga (2008) reviewed present state of ecological networks in Spain. Review is based on internet pages of relevant regional governments, which are responsible for nature conservation and on the questionnaires filled during the 5th International Spatial Planning, held in Malaga (Spain) the 23 - 25 November 2008.
Ecological networks are required according to the Nature Conservation Act from 2007 in Spain, the former act (from 1989) referred to ecological connectivity. However, the ecological network concept is still not widely known or understood.
There is no State policy framework on ecological networks, however five regions, out of 17, started to define their ecological networks (Basque Country, Navarra, Madrid, Asturias, Catalonia). Only the Basque Country and Catalonia have a clear policy on ecological networks. A general problem is lack of coordination of regional activities, e.g. see L´Alt Pirineu Aran spatial plan which is not connected to France and Aragon neighbours (fig. 5).

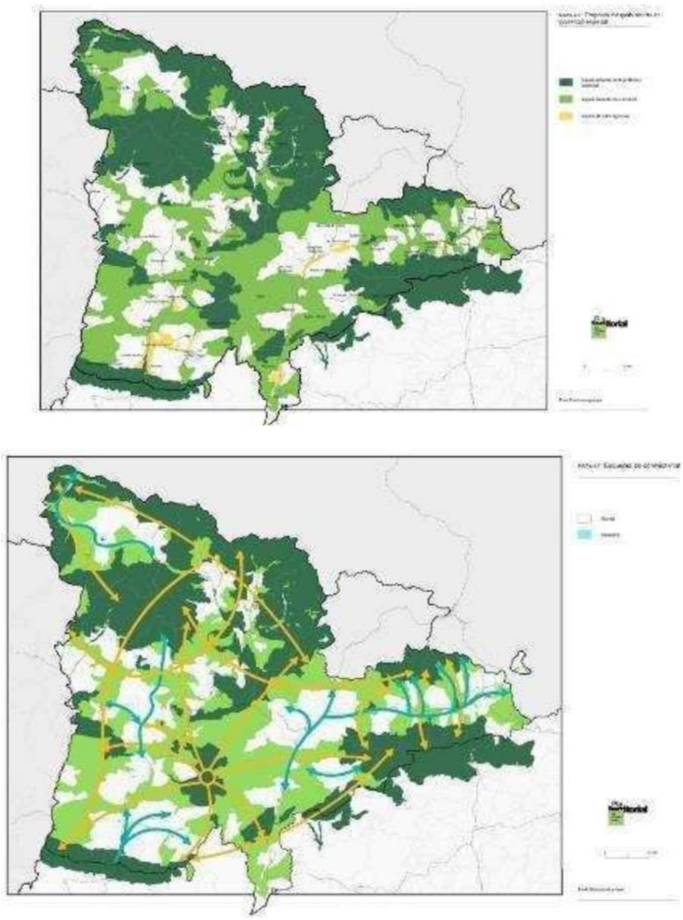


Figure 5. Extract from the L´Alt Pirineu Aran spatial plan (2006). The top map shows protected areas (dark green), connectivity areas (light green) and agriculture value areas (yellow) in the district. The bottom map outlines the desired connectivity. The Northern border is with France and Andora, the

[2] http://www.lifelince.org/

West with Aragon region, and the South and Southeast with other regional districts (Sunyer & Manteiga 2008).

Most of the concepts are based on present protected areas, including Natura 2000 network. Navarra started work on ecological network in 1997 when the first draft was prepared (fig 6.). However, no further work on changes in the draft of ecological network has been done.

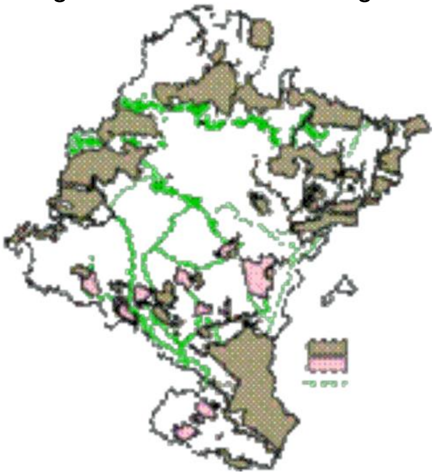


Figure 6. First draft of Navarra´s ecological network (1997). In brown Natura 2000 sites, in pink nodes, in green corridors (Sunyer & Manteiga 2008).

In Catalonia the ecological network is defined as: a network of natural sites, consisting of a conjunction of sites of high natural value, which are generally protected, surrounded by buffer zones and joined together by other sites of a smaller size that are well conserved and situated in such a way as to allow the movement and dispersion of flora and fauna species and the maintenance of the flows that guarantee the functionality of ecosystems (Mallarch and Germain 2006). Work on the network started in 1995. As a result, Catalonian spatial plans include the principle of connectivity, and are structured in three systems: open spaces, settlements and mobility infrastructure. Within the open spaces – the non-urban land component – includes special protection land (high agricultural and ecologic importance areas, including ecological connectivity), territory protection land (at present not urban), and preventive protection land (not urban due to ecological or technological risk, landscape interest, strategic interest).
In Madrid region large effort on ecological networks have been done since 1997, however at present ecological networks are not incorporated into Madrid town planning, which takes into account only the interest of sectoral plans (energy, water, transport) and legally protected areas.
Asturias brown bear endangered species recovery plan – each of the three regions (Asturias, Castile-Leon, Cantabria), where brown bear is present, developed each own recovery plan, which are legally binding. Most important goals of the Asturias brown bear recovery plan are: demarcate with the greatest precision the communication corridor between the two populations; identify the elements that may hamper the dispersion of individuals; prepare a special plan for restoration corridor; avoid any possible fragmentation of the habitat in the western population, identifying internal corridors.

2.1.3.3. Habitat Selection and Movement by brown bears in Multiple-Use Landscapes

General overview

An impressive PhD thesis on brown bear by Jodie Martin carried within a collective of authors on brown bear ecology in Cantabrian Mountains and Pyrénées (France-Spain border area). Paper number V of the thesis (Martin et al. 2009) is a study on modelling suitable habitats of brown bear in the Cantabrian Mountains (based on field data on presence of brown bear) and potential connectivity or barriers between subpopulation.

Methodology

Bear data were used from systematic investigations on bear presence between 1982 and 1991 and from observations carried during 1996 - 2007. Bear presence was related to grid cells of 5 × 5 km for the global scale study, while to 200 × 200 m grid cells for local scale study.

The habitat data analyses were derived from the ruggedness of terrain (90-m digital elevation model), from the Corine Land Cover 2000; French and Spain human population densities were obtained from respective statistical institutions.

The following descriptive characteristics were used for the ordination analysis at the global level: terrain ruggedness, shrub cover, open areas, forest cover, mast tree cover, forest connectivity (surrounding 5/10/15 km), human population density, agricultural areas, and roads.

The following descriptive characteristics were used for the ordination analysis at the local level: elevation, slope, distance to urban areas, distance to agricultural areas, distance to roads, distance to deciduous/coniferous/mixed/regenerating forests, distance to shrubs, distance to lake, and to natural open areas.

Analyses at the global scale level were carried using the logistic-regression models for dependent variables bear presence and absence. Backward stepwise selection was carried using Akaike Information Criterion (AIC). Habitat quality was classified according to the results into four categories within the two dimensional space (refuge, source, sink, attractive sink).

Analyses at the local scale were carried using the “General Niche-Environment System Factor Analysis” (GNESFA) performing a Factor Analysis of the Niche Taking the Environment as Reference (FANTER).

Habitat suitability model was computed using Mahalanobis distance statistics which give an index of habitat suitability of the environmental variables of the study area (low values means a suitable habitat).

Results

The best general model at the global level contained the following variables: shrub cover (positive effect), terrain ruggedness (positive effect), forest contacting hard-mast species (positive effect), forest connectivity at the scale of 15 km (positive effect), length of roads (negative effect) and human population density (negative effect). The general model was reliable in predicting bear presence (validated in Cantabrian and Pyrenean bear populations).

A map of habitat quality was prepared according to classification of the grid cells into five categories (refuge, source, sink, attractive sink, avoided matrix) – see fig.7.

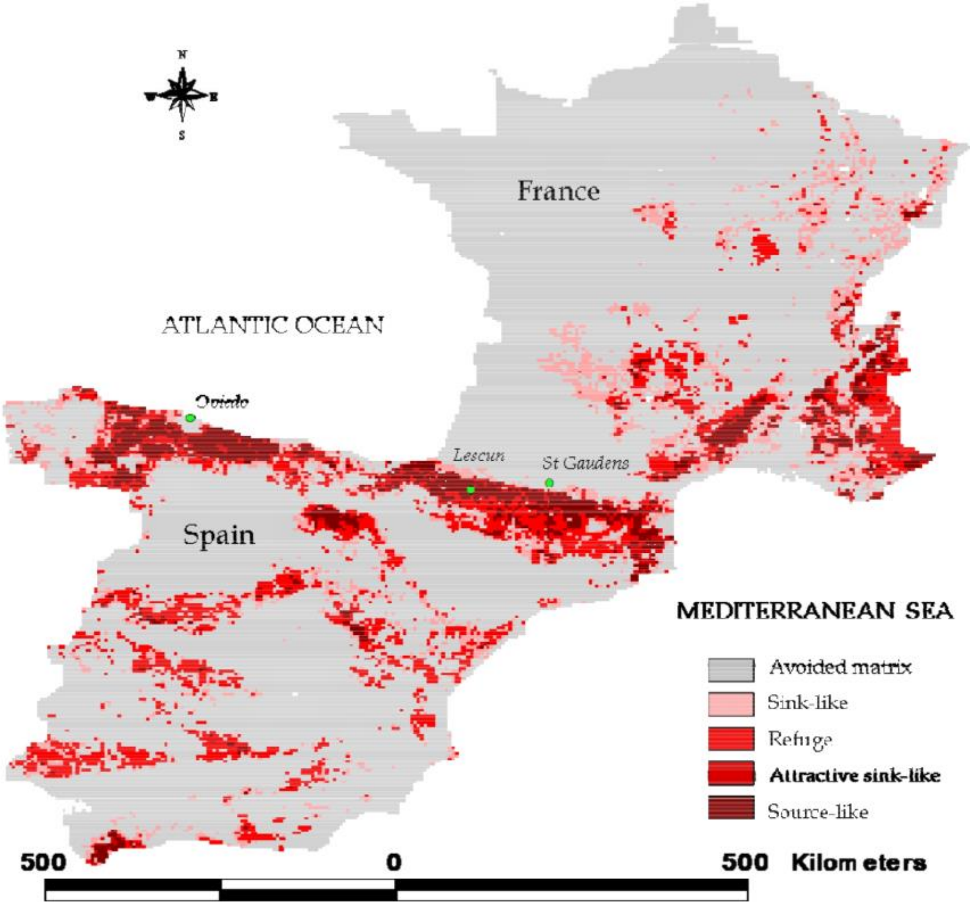


Figure 7. Map of habitat quality for the brown bear in France and Spain. The darker red, the more suitable habitat for the brown bear (Martin et al. 2009).

According the ordination analyses (PCA) carried at the local level, the human areas were separated from the more natural according to the elevation gradient. Using the FANTER, the preferential habitat of brown bear was characterized as the follows: steep areas with forest, far from agriculture and regenerating forests. Paradoxically, roads were associated positively with bear's distribution (lesser extent). Bears preferred medium range of elevation and areas close to lakes. Lesser preference was found for areas far from agriculture and without shrubs but close to deciduous forests.

Habitat suitability map (see fig. 8) was produced using the habitat suitability model. This map was found reliable.

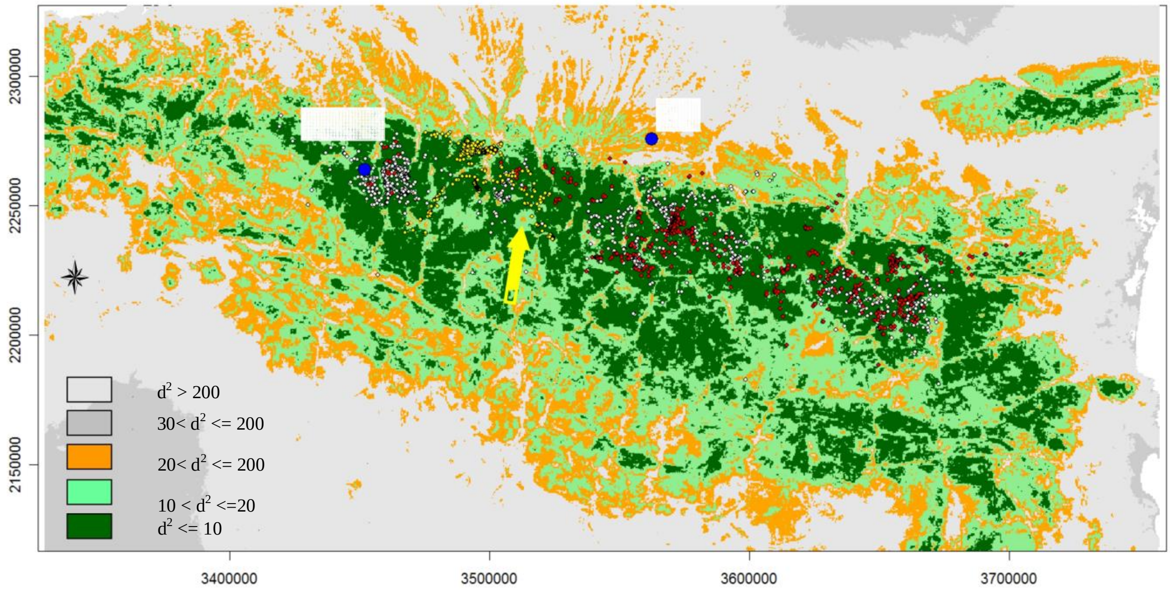


Figure 8. Habitat suitability map of the Pyrenean brown bears in Pyrenees.
The dark green and green areas are most suitable for brown bears. Gray dots – presence of bear used to fit the model, red dots – used to evaluate the model, yellow dots – telemetric relocations of the only female belonging to the western core area, yellow arrow – area between the two subpopulations (Martin et al. 2009).

2.1.3.4. Assessing Highway Permeability for the Restoration of Landscape Connectivity between Protected Areas in the Basque Country, Northern Spain

General overview

Gurrutxaga et al. (2010a) studied fragmentation of the Basque Country by highways. Identification of critical sectors was based on resilience map produced within the study and identification of crossing sites.

Methodology

The study area was the Basque Country. Method was based on detection of possible permeability deficits in highway sectors using difference between available crossing structures, that enable the mobility of large and medium-sized mammals, and recommended density in technical prescription for highway projects – i.e. the deficiency is identified when the density of crossings is lower than the prescribed. The areas important for migration were derived from the core areas of local ecological network (identical with Natura 2000 SPAs excluding those unsuitable for large and medium-sized mammals, e.g. coastal areas; in areas where SPAs had low cover, other core areas were selected). The sectors to be traversed were identified using GIS modelling. Those were divided into sub-sectors depending on the type for habitats they traverse. Those subsectors were analyzed according to their permeability. Density of existing crossing structures was calculated for each sub-sector. Least-cost modelling was used for testing.
The large and medium-sized mammals (functional group) in the study were the follows: *Capreolus capreolus*, *Sus scrofa*, *Cervus elaphus*, *Martes martes*, *Felis sylvestris*, *Genetta ghetto*, *Mustela putorius*, *Meles meles*, *Martes foina* and *Vulpes vulpes*.
A resistance map for functional group was created with a pixel resolution of 20 m. Maps of: land usage from the forestry inventory, residential and industrial land from municipal

planning, rail and road networks, average daily traffic intensity, viaducts and tunnels in highways and dual carriageways; were used at a scale of 1 : 25,000.
Expert estimation of resistance of different land-uses was used (water – 100, urban – 1,000, rock – 40, quarries – 90, meadows – 40, pastures – 30, bushes - 5, wood forests – between 1 and 20: native forests – 1, plantation of medium-term non-native forests – 10, plantations of short-term non-native forests - 20, crops – 60), resistance of roads was according to the traffic intensity (average daily traffic: <1, 000 – 80, 1, 000 to 5,000 – 100, 5,000 to 10,000 – 300, 10,000 to 20,000 not fenced – 700, 10,000 to 20,000 fenced – 900, >20,000 not fenced – 800, >20,000 fenced – 1,000).

Cost distance map and ends of connections (based on the increase in cost gradient) were calculated (see figures).

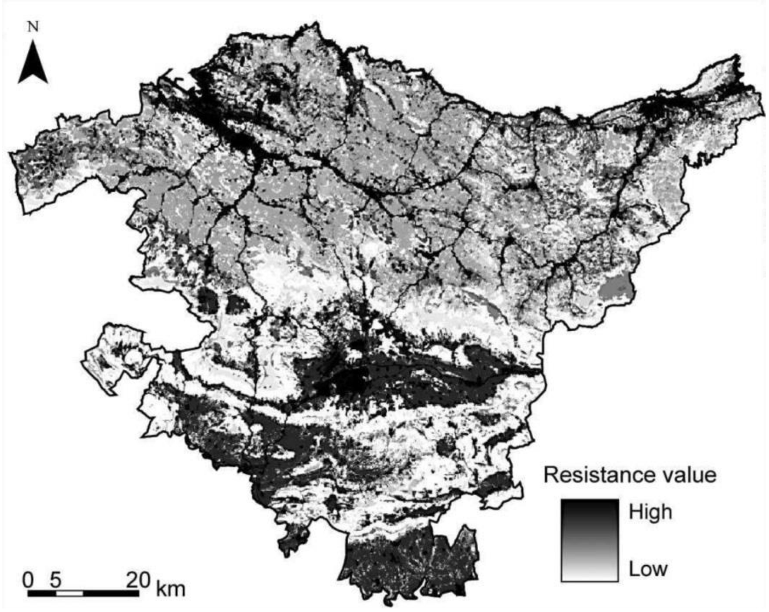


Figure 9. Resistance map of Basque study area (Gurrutxaga et al 2010a).

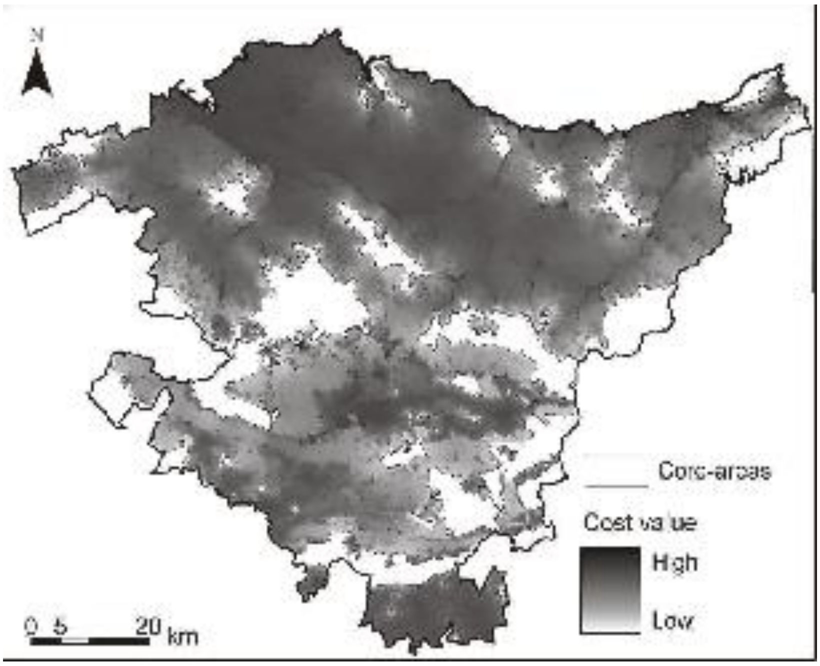


Figure 10. Map of cost surface between core-areas (Gurrutxaga et al 2010a).

At the local level, homogenous sectors were defined at the 1:5,000 scale from the orthophotos.

Structures which enable crossing the road were identified and georeferenced. Inventory of those structures also listed other factors (width and height of the entrances, length of structure, type of structure etc.). Requirements for permeable structure for large mammals and medium-sized mammals were identified (see the paper).

Vegetation around the crossing structure was taken into account and classified as optimal (woodland or wide hedgerows of bushes) or suboptimal vegetation. Other structures, which may influence mobility (such as fences) were also listed. Deficits were identified and corrective measures suggested.

Results

Nine interaction sectors were identified along four different highways. For seven of them, density analyses were carried. Of a total 148 structures, 42 had permeability for large mammals and 78 for medium-sized mammals, 56 had insufficient dimensions. Thirty crossing structures have a certain lack of vegetation coverage in surrounding; further five had stored agricultural machinery within them.
For large mammals inadequate number of crossings was found in all the cases. In case of medium-sized mammals, in half of the subsectors the minimum value was reached.
To optimize permeability, 45 corrective actions are to be done: 30 of them aimed on improvement of vegetation cover, 5 to get rid of fencing, 5 to eliminate of stored objects, 4 enlargements of crossing structures and one of modification of substrate.

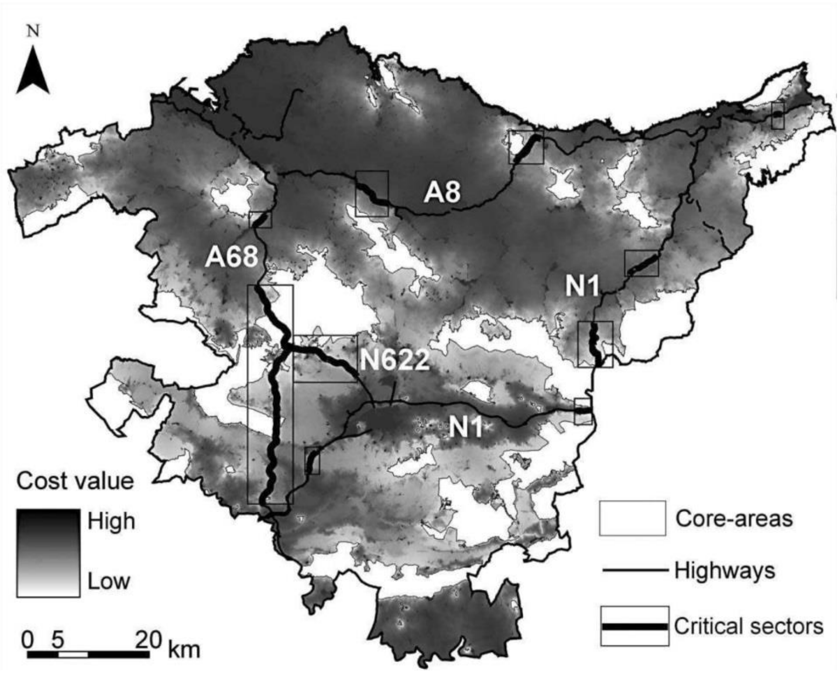


Figure 11. Map of highway critical sectors (Gurrutxaga et al 2010a).

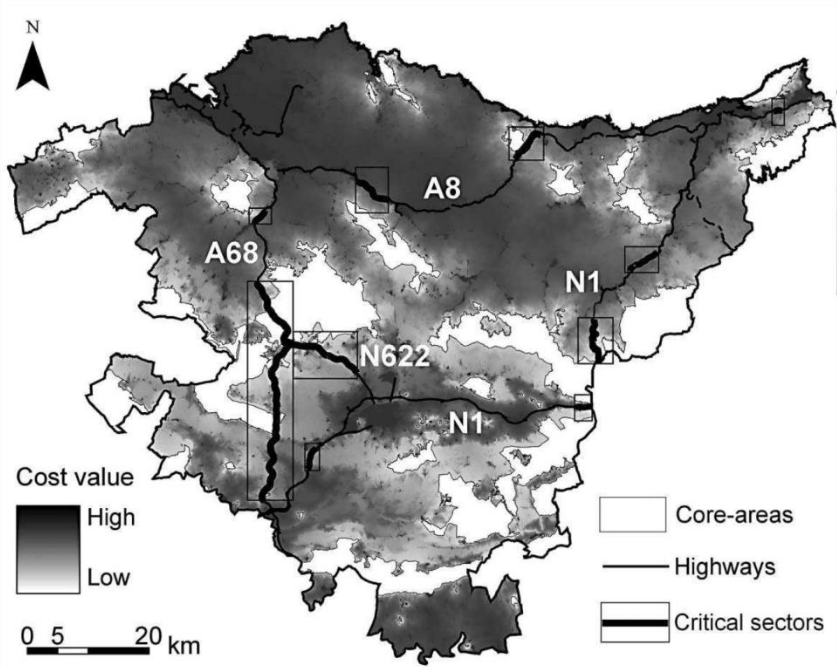


Figure 12. Map of highway critical subsectors for the analysis of the density of appropriate crossing structures (Gurrutxaga et al 2010a).

2.1.3.5. GIS approach for incorporating the connectivity of ecological networks into regional planning

General overview

Gurrutxaga et al. (2010b) using spatial modelling suggested network based on the Natura 2000 network in the Basque Country. The network was designed for large and medium-sized mammals (*Capreolus capreolus*, *Sus scrofa*, *Cervus elaphus*, *Martes martes*, *Felis sylvestris*, *Genetta ghetto*, *Mustela putorius*, *Meles meles*, *Martes foina*) and comprises of core areas, link corridors, link areas and buffered zones. This network was incorporated into the Basque Country regional development plans.

Methodology

Network was designed for large and medium-sized mammals (*Capreolus capreolus*, *Sus scrofa*, *Cervus elaphus*, *Martes martes*, *Felis sylvestris*, *Genetta ghetto*, *Mustela putorius*, *Meles meles* and *Martes foina*).
For core areas, the SPAs of Natura 2000 that contain forests and/or agro-forest mosaics were selected. Additional sites to those Natura 2000 sites were selected.
Same methods of data processing and same resistance values as in the study Gurrutxaga et al. (2010a) were used (see chap. 2.1.3.4.).
Corridors between the core areas were computed using the least-cost modelling. Buffer zones were defined around the core areas and corridors – individual approach was used. Corridors and buffer zones outside Basque Country were clipped.

Results

Maps of ecological network in the Basque Country were produced comprising of core-areas, linkage corridors, linkage areas, and buffer zones (see fig. 13). Forest is a dominating landcover within the network, which is not surprising, because the network was designed for forest species.

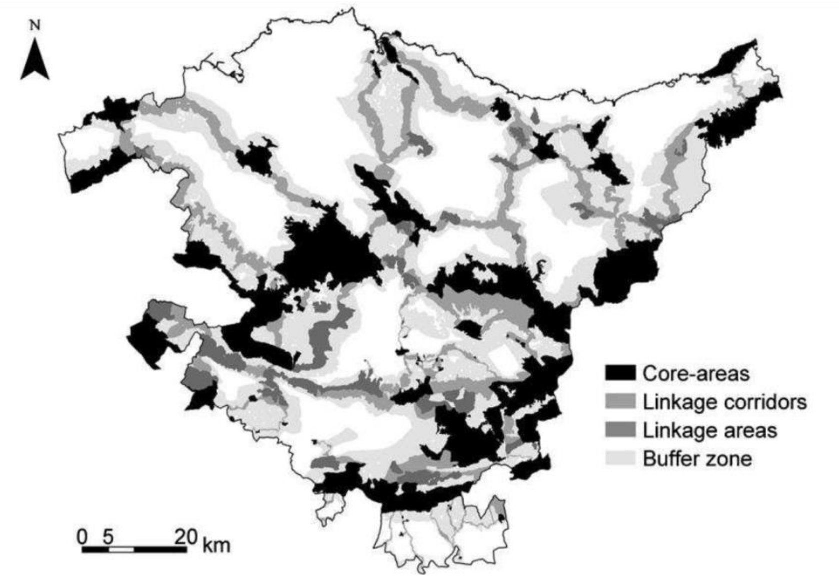


Figure 13. Map of ecological networks structural elements (Gurrutxaga et al 2010b).

Critical areas and critical stretches were identified between the network and urban land and highway network (see figs. 14, 15).

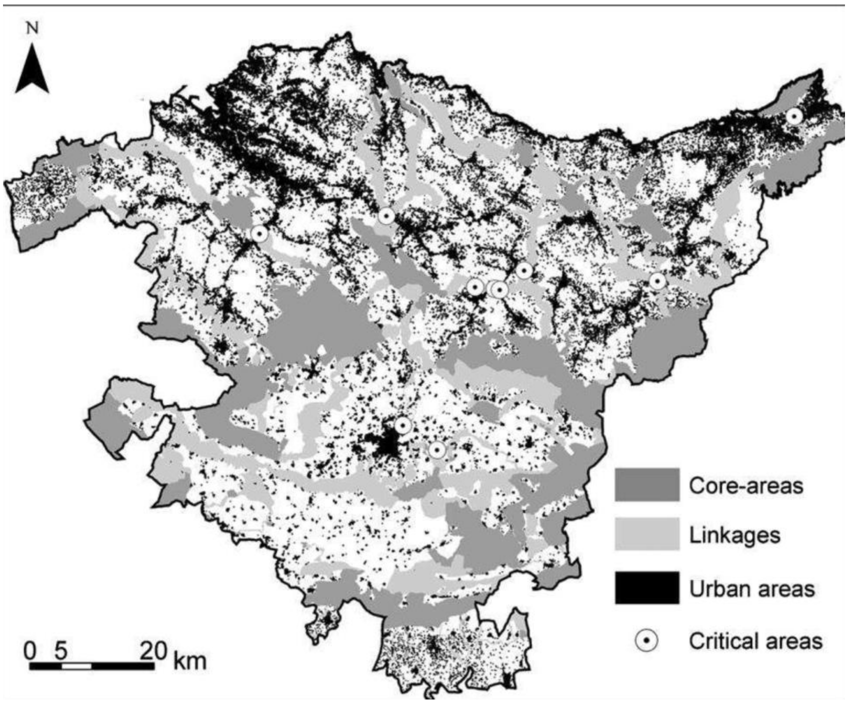


Figure 14. Location map of critical areas of corridors due to urban land (Gurrutxaga et al. 2010b).

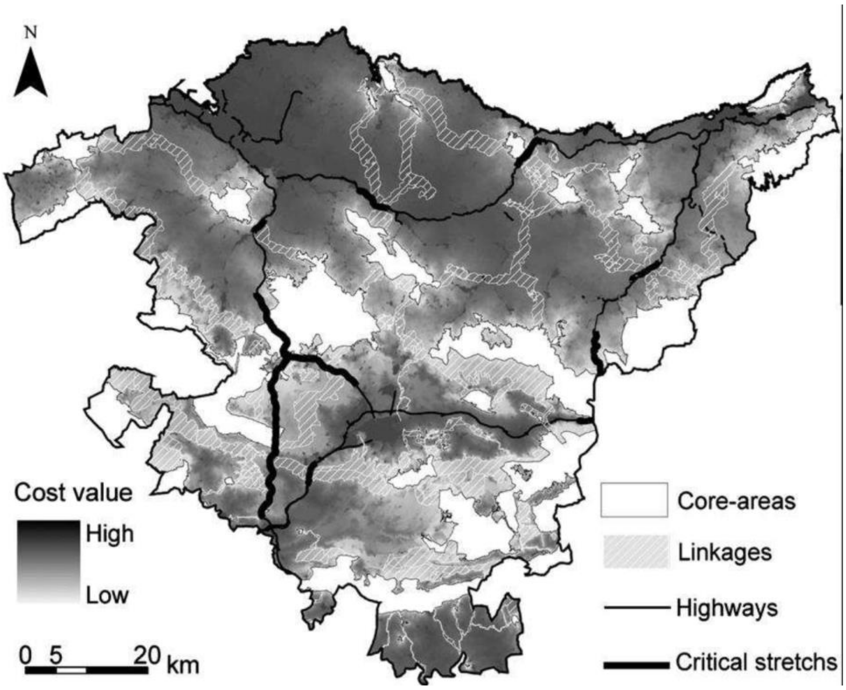


Figure 15. Location map of critical highway stretches (Gurrutxaga et al. 2010b).

2.1.3.6. Protected forest area network - a transnational case study from the Cantabrian Range to the Western Alps

General overview

The case study which goal is to identify key elements within the landscape, that sustain the diversity and long term viability of native biota, considering different dispersal distances of forest mammals and the impact of highways, is covering the forest protected areas from the Cantabrian Range to the Western Alps. Authors show how the proposed approach is useful to identify those protected areas and links that most contribute to uphold functional connectivity in this transnational network, as well as those road sectors where the defragmentation and barrier effect mitigation measures should be prioritized. The Spanish team of scientists from Universidad de Lleida, U. del Pais Vasco and U. Politecnica de Madrid has conducted the study.

Project methodology

The study area comprises the North of the Iberian Peninsula, the Southern half of France and the North West of Italy, yielding a total of 68 provinces. From West to East, the main mountainous areas where forest habitat concentrates are the Cantabrian Range, the Iberian System, the Pyrenees, the French Massif Central and the Western Alps.

The habitat network model, in which nodes in the network corresponded to the protected areas which contained forest, was made. Two or more contiguous protected areas with forests were considered as a unique node. The portions of the nodes, which were intersected by highways, were divided into different nodes so as to adequately estimate the impact of the infrastructures. To allow for a feasible processing of the large study area only nodes with an area of at least 5 000 ha were incorporated in the study. A total of 176 nodes were obtained, which accounted for 91,4% of the total area within the transnational protected forest area network.

The resistance of the landscape matrix for the functional group of focal species (forest mammals) was parameterized into a generic friction surface using the data from bibliographical review and consultation with experts on mammal ecology. The connectivity analysis was carried out in the area of study (with and without highways) taking into account a wide range of median dispersal distances (d) representing medium to large mammals: d = 1 km, d = 5 km, d = 10 km and d = 25 km.

The value of dPCconnector (the importance for the connectivity of the network) was calculated for every node and link in the network. The comparison of the dPCconnector values for individual nodes and links with and without the effect of highways allowed assessing those key landscape elements that might be affected to a larger extent by the impacts of the transportation networks.

Results

First of all, the study identified key nodes (core areas and stepping stones) and key links (corridors) of the network of protected forest areas, covering the area from the Cantabrian Range to the Western Alps. Second, intersections between the key links (corridors) of this network and the highway network were identified. These were concentrated mainly in the transition areas between mountain ranges (fig. 16). Authors suggest that in these intersections the defragmentation and barrier effect mitigation measures should be implemented with high priority.

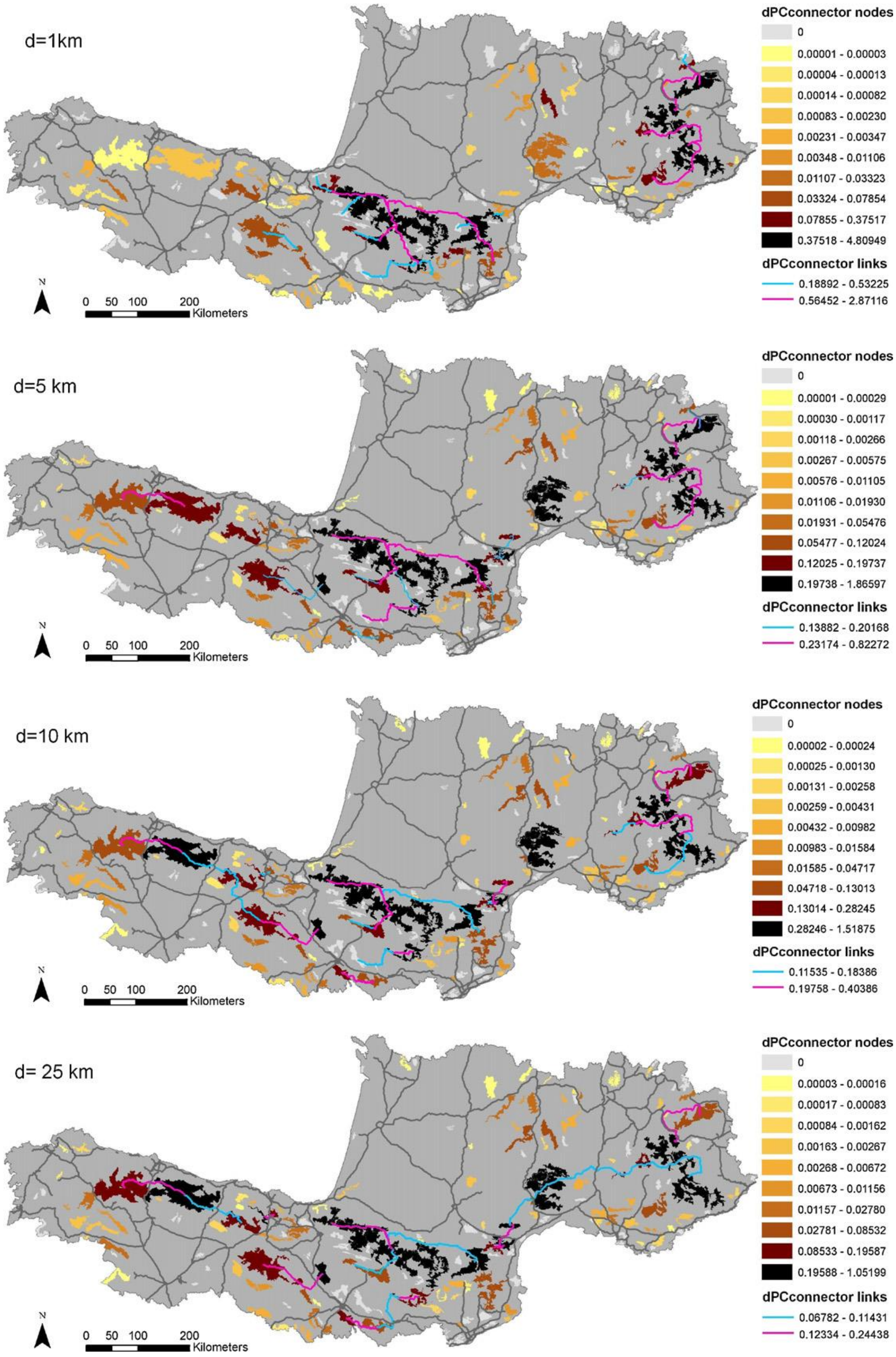


Figure 16. Importance of nodes and links as connectivity providers (dPCconnector values) in the scenarios with highways (grey) for different dispersal distances. The higher the dPCconnector value, the more important connectivity provider the node or link is. Dispersal distances for forest mammals have been set from 1 km (for medium mammals) to 25 km (for large mammals).

The results highlight the importance of the link (corridor) between the Cantabrian Range and the Iberian System, which had not previously been included in the framework of the transnational initiative of the Cantabric - Alps great mountain corridor. Moreover, the number of key link-highway junctions detected in the Cantabrian – Pyrenean transition area is considerable, which agrees with previous studies carried out on this area, and this should be taken into account when planning the defragmentation and mitigation measures.

Other result of the study is that the dPCconnector fraction makes a significant contribution to the detection of key connecting areas and key corridors in the landscape networks.

2.2. Western Europe

2.2.1. Designing a coherent ecological network for large mammals in Northwestern Europe

General overview

The study presents habitat suitability map for potential distribution of the Red Deer in NW Europe and map of habitat connectedness (fig. 17). The authors identified core areas (called key population areas) where the standard minimum population unit was set to 20 as a minimum viable population unit. They also revealed stepping stones and corridors depicted as broad stripes of landscape. The carrying capacity of the landscape and habitat fragmentation has been identified as the most important factors.

Project methodology

The LARCH landscape ecology analysis was used for developing the model including data on Red deer that was selected as an umbrella species. First, the Corine Land Cover database was taken to define habitat categories. Another factor included into the model was the available organic matter for each patch calculated for February condition. Main roads, dual lane roads, major primary and secondary roads and urban areas were taken as a proxy for barrier effect. Spatial connectivity of the habitat network was assessed using connectivity index, which includes the probability of immigration from surrounding patches according to the theory of island biogeography. The connectivity map is based on least cost rule and shows relatively broad areas identified to be suitable for Red deer migration (Bruinderink et al. 2003).

Results

The study focused on modelling suitable habitat and its spatial connectivity for the Red deer in the Western Europe. Main plus of this study is incorporation the availability of food into the model, which was unique factor not previously used in other studies. Identification of core areas, where the minimal size of population could survive when interconnected gave good overview where relatively undisturbed forest areas still can be found. On the other hand, main critical points for migration weren´t described, authors pointed out only those relatively broad areas significantly influenced by urban development and habitat fragmentation caused by major roads.

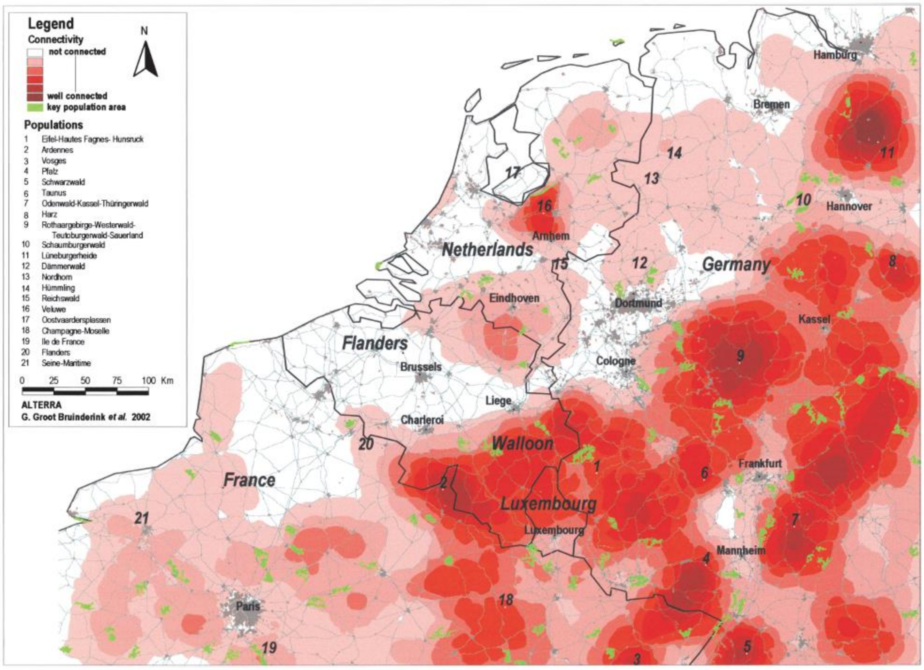


Figure 17. Map shows habitat connectivity potential and core areas (green) for the Red deer in the Western Europe.

2.2.2. SPEN - The Netherlands Report

General overview

Biemans and Snethlage (2008) reviewed present state of ecological networks in the Netherlands. Review is based on interviews with relevant experts who are in charge of ecological network planning. Other sources like policy documents and web pages were also reviewed.

The ecological network in the Netherlands is regarded as a spatially coherent network of existing and newly created nature areas that is being developed and is planned to be ready by 2018 (fig. 18). It is consisted of core areas of national as well as international importance, ecological development areas such high nature value farmland, management areas, connections zones and buffer zones. It is planned that will cover 17% of the total Dutch land area. The key backbone of the network is protected area and other agriculture land is subsidized to be managed under agro-environmental schemes.

The ecological network planning and implementation are integrated in the spatial planning process. The particular ministries are responsible for network implementation, but final implementation into spatial plans is on the regional and provincial municipalities.

Figure 18. Map of the ecological network in the Netherlands.

2.2.3. SPEN – Country study for Denmark

General overview

The information in the report was obtained by interviews which were conducted with planners at central, regional and local level in Denmark. Other sources of the data were collected from internet and various reports by Goldberg (2008). Main part of the report is evaluation of spatial planning in relation to ecological network implementation.

Ecological networks in Denmark are deemed to be wide areas that are strictly protected based on both international and national regulations. Nationally perceived areas of network are protected areas, protection zones, strictly protected nature types and coastal zone protection. From the international perspective the most important sites are included into Natura 2000 network which contains Ramsar sites. Main relevant regulations related to nature protection contains protection of specific areas, corridors and stepping stones in the landscape to maintain ecological networks, and rules on procedures, administration and distribution of responsibility.

Three types of network are regarded:

1. National scale: The Natura 2000 network that includes the designated areas (254 SACs, 113 SPAs and 27 Ramsar sites). The network is divided into core areas – the designated sites – and stepping stones and corridors between them. The stepping stones and corridors are integrated into the planning procedures.

2. Regional scale: network also defines core areas and connection lines and corridors.

3. Municipal and local planning. The core areas and connection lines on the local scale are defined within each municipality.

Altogether, the protected sites cover in the Denmark cover 6-7 % of the whole territory (Golberg 2008).

No other information’s were provided, such as width of corridors or size of the core areas.

2.3. Alpine area

2.3.1. Large carnivores conservation areas in Europe

General overview

The research project, conducted by the Istituto Ecologia Applicata for the Large Carnivore Initiative of WWF International, focused on building habitat suitability models for lynx, wolf and brown bear in the Alpine area and using them for the identification of a network of core areas, buffers and corridors for large carnivore conservation. In the next step, the three habitat suitability models were joined into one summary model of environmental quality for all the three species.

Project methodology

The study covers the entire Alpine area with the only exception of Slovenia, where the data-sets were not provided. Thus, the study encompasses the Alpine area in five countries: Austria, Germany, France, Switzerland and Italy.
Data used for habitat suitability modelling were:
a) species occurrence data (georeferenced species location and territories data): wolf territories in Italy, bear home ranges and locations in Italy and lynx territories from France and Switzerland
b) environmental variables for the area – land cover (Corine Land Cover), digital terrain model (GLCC DTM, other datasets), hydrological network (DCW, GISCO), wild ungulate presence (different data in different countries), protected areas, administrative units
c) expert - made species extents of occurrence

Bear habitat modelling
The land cover categories included in the bear habitat model were: natural pastures and meadows, forests, woods, open spaces, shrub-like vegetation, buildings, farmland and human population density. Occurrence of Red deer and Chamois was also included in Italy, Switzerland and France. The virtual territory of 71 km^2 was used.

Lynx habitat modelling
The land cover categories included in the lynx habitat model were: natural pastures and meadows, forests, woods, open spaces, shrub-like vegetation, buildings, farmland and human population density. Occurrence of Red deer, Chamois and Ibex was also included in Italy, Switzerland and France. The virtual territory of 165 km^2 was used.

Wolf habitat modelling
The land cover categories included in the wolf habitat model were: natural pastures and meadows, forests, woods, open spaces, shrub-like vegetation, buildings, farmland and human population density. Occurrence of Red deer, Chamois and Ibex was also included in Italy, Switzerland and France. The virtual territory of 103,8 km^2 were used.

Summary of environmental quality model

The original ecological suitability models were standardized subtracting the average value of the ecological suitability observed within the known territories of the species and dividing by its standard deviation. The resulting models had exactly the same characteristics of the original ones except for the fact that they averaged to zero (within the areas of the known territories) and that suitability was measured in terms of standard deviation from each one's average. The three standardized models were then used to perform a principal components analysis (PCA). Finally the summary variable has been partitioned to produce a map depicting joint environmental suitability for the three species.

Results

For each species, the potential distribution model was made, with and without prey density to be taken into account, important corridors and barriers in the Alpine area were identified and the efficiency of large scale protected areas for the species' protection (the protection of the areas with the most suitable habitat for the species) was evaluated.

No details regarding the potential width or other corridors/core areas/buffer zones characteristics were mentioned in the study. The study was focused mainly on identification and description of the major corridors for each species separately.

The result of the Summary model of the environmental quality is a map showing joint habitat suitability of Alpine area for all three LC species (fig. 19).

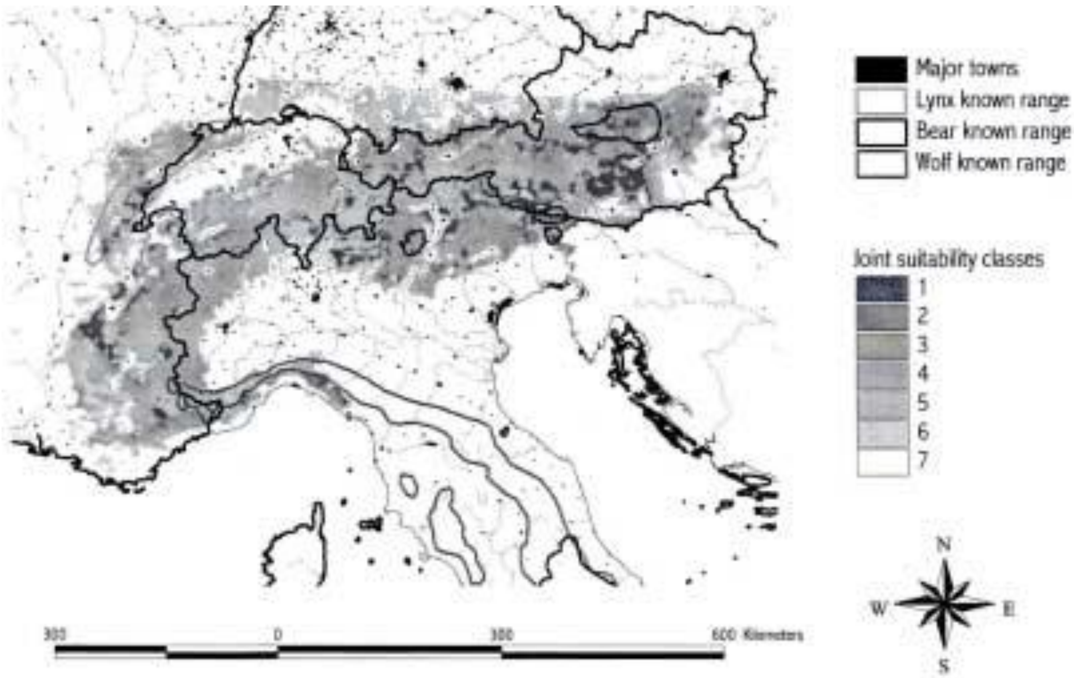


Figure 19. Results of the principal component analysis of the joint habitat suitability of the Alpine area for Lynx, Wolf and Brown Bear (areas outside the study area are masked in white). The first three habitat suitability classes are considered to be respectively the core areas of the species distribution and its connecting matrix. The rest of the classes represent areas of decreasing quality reaching down to intensive agricultural sites and densely populated areas (Corsi et al 1998).

2.3.2. Econnect

General overview

The Econnect project, which goal is to implement a Pan-Alpine Ecological Network has been implemented by the Ecological Continuum Initiative: Alpine Network of Protected Areas (ALPARC), International Commission for the Protection of the Alps (CIPRA), International Scientific Committee for Alpine Research (ISCAR) and WWF European Alpine Programme. As a part of project's work package 5 „Barriers and Corridors", the analysis of the distribution and connectivity of the populations of large carnivores (Brown bear, Lynx and Wolf) and Red deer in the Alpine area has been made. Using habitat modelling, potential distribution maps of all four species has been created and core areas, corridors and main migration barriers were identified.

Project methodology

The study covers the entire Alpine area as defined by the Alpine convention. This encompasses an area of approximately 190 000 km^2. All models were conducted in a resolution of 1 km^2 with the exception of Red deer, where the resolution was one hectare.

Brown bear

To model the potential distribution of *Ursus arctos* in the Alps a logistic regression model developed for the bear in the eastern Alps (Güthlin 2008) was used in a refined, yet unpublished version. Data used for habitat suitability modelling were:
environmental variables for the area – coniferous forests, land cover: agriculture, broadleaf, mixed, scrub, open habitats (Corine Land Cover), distance to roads, distance to settlement, slope and elevation (DEM). When the habitat suitability model was created, the morphological spatial pattern analysis (GUIDOS) was used to classify a map of suitable bear habitat in different categories from unsuitable areas (grey) to core areas (green) and corridors (red) – fig. 20.

Wolf

A first habitat suitability model was developed, based on wolf occurrence data using a multi-season occupancy model, extending the work from Marucco (2009) to the Alps, which considered wolf detection-nondetection data following Mackenzie et al. (2006). Second, this model was used as the habitat layer for building a spatially explicit, individual-based model (SE-IBM) based entirely on information collected through a 10-year intensive study of the wolf population in the Italian Alps (Marucco & McIntire 2010). The model was developed based on demographic processes, social structure, spatial information, and habitat selection of wolves. When the habitat suitability model was created, the morphological spatial pattern analysis (GUIDOS) was used to classify a map of suitable wolf habitat in different categories from unsuitable areas (grey) to core areas (green) and corridors (red) – fig. 21.

Lynx

To model the potential distribution for the lynx in the Alps a logistic regression published by Zimmermann & Breitenmoser (2007) was used with some minor adaptations. All areas above 2500 m were considered to be unsuitable for lynx and set as no data values. The shrub and forest layers, the ecological variables included in the model, were obtained from CORINE Land Cover, declivity and altitude were obtained from SRTM (Shuttle Radar Topography Mission - digital topographic data). When the habitat suitability model was created, the morphological spatial pattern analysis (GUIDOS) was used to classify a map of suitable *L. lynx* habitat in different categories from unsuitable areas (grey) to core areas (green) and corridors (red) – fig. 22.

Red deer

For the analysis of potential habitat distribution of red deer an expert-based approach was used due to a lack of observation records and suitable species specific models. The main factors for suitable habitat of red deer were defined by experts and this information served as baseline for the cartographic implementation. These were: forests, non-forest as potential habitat areas for red deer (minimum habitat area, maximum slope, maximum altitude and minimum distance from settlements, industrial or commercial units, from road and rail networks and associated land, from airports and associated land and from construction site) using Corine Land cover, JRC Forest map, digital elevation model and other GIS-data like ski areas, or river segments. When the habitat suitability model was created, the morphological spatial pattern analysis (GUIDOS) was used to classify a map of suitable *C. elaphus* habitat in different categories from unsuitable areas (grey) to core areas (green) and corridors (red) – fig. 23.

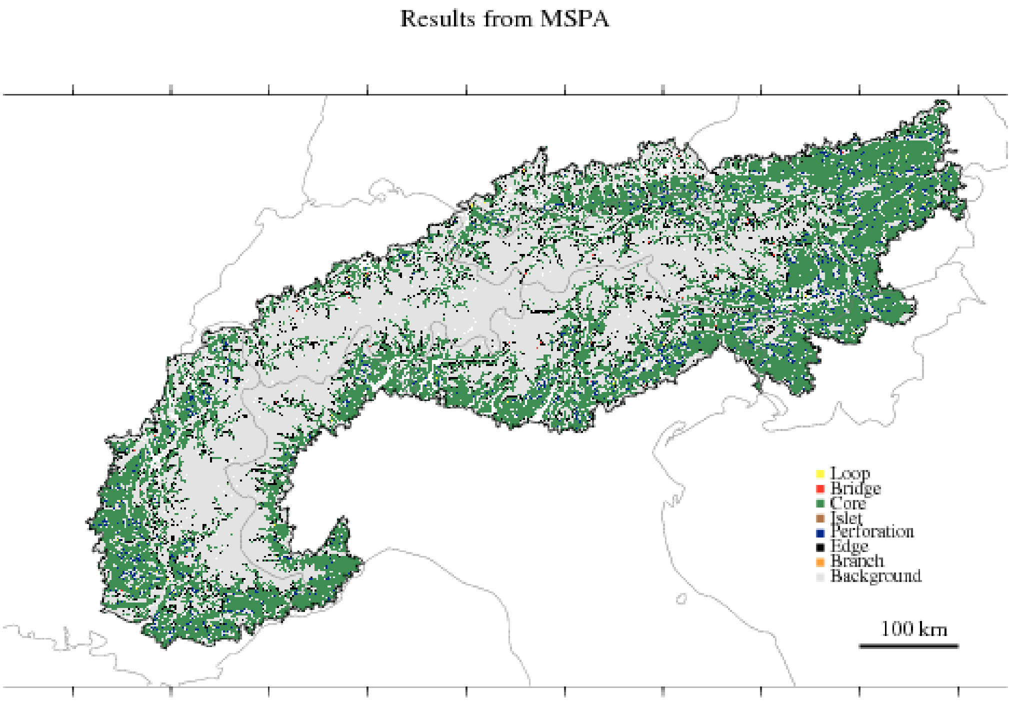


Figure 20. The results of a morphological spatial pattern analysis based on the potential distribution of *U. arctos* in the Alps. Background (grey): Pixels that are classified as unsuitable for bear, Core (green): Pixels that are classified as forest or suitable bear habitat and pixels are surrounded by habitat, Branch (orange): Branches of 1 pixel width that originate in core area and terminate in background, Edge (black): Edges have on one side core area and on the other side back- ground, Islet (brown): Suitable pixels that are surrounded by background, Bridge (red): Corridors that connect

core areas, Perforation (blue): Pixels that are edges in forest wholes, Loop (yellow): One pixel wide corridor that originate in a core area and terminates in the same pixel.

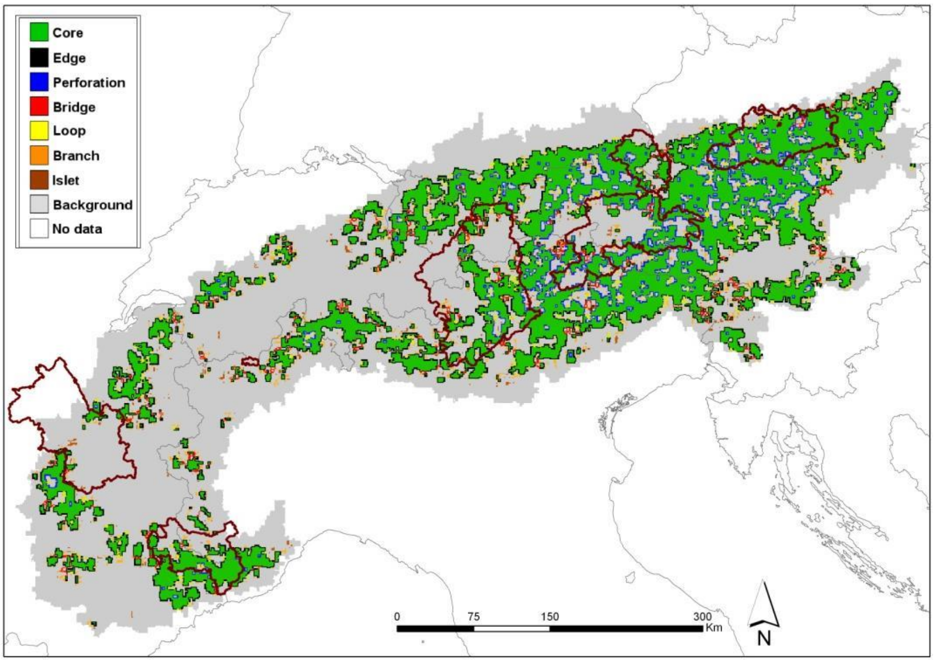


Figure 21. The results of a morphological spatial pattern analysis based on the wolf packs (*Canis lupus*) habitat suitability map in the Alps, where the threshold value was set at 0,8. Colors are the same as in previous figure.

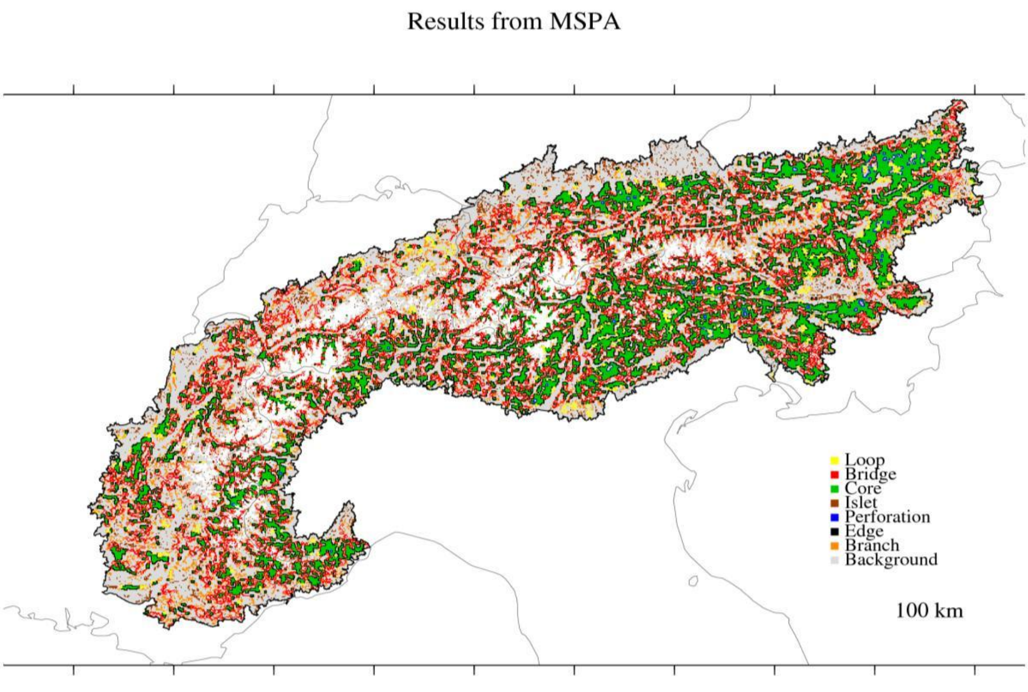


Figure 22. The results of a morphological spatial pattern analysis based on the potential distribution of *Lynx lynx* in the Alps. Colors are the same as on above figures.

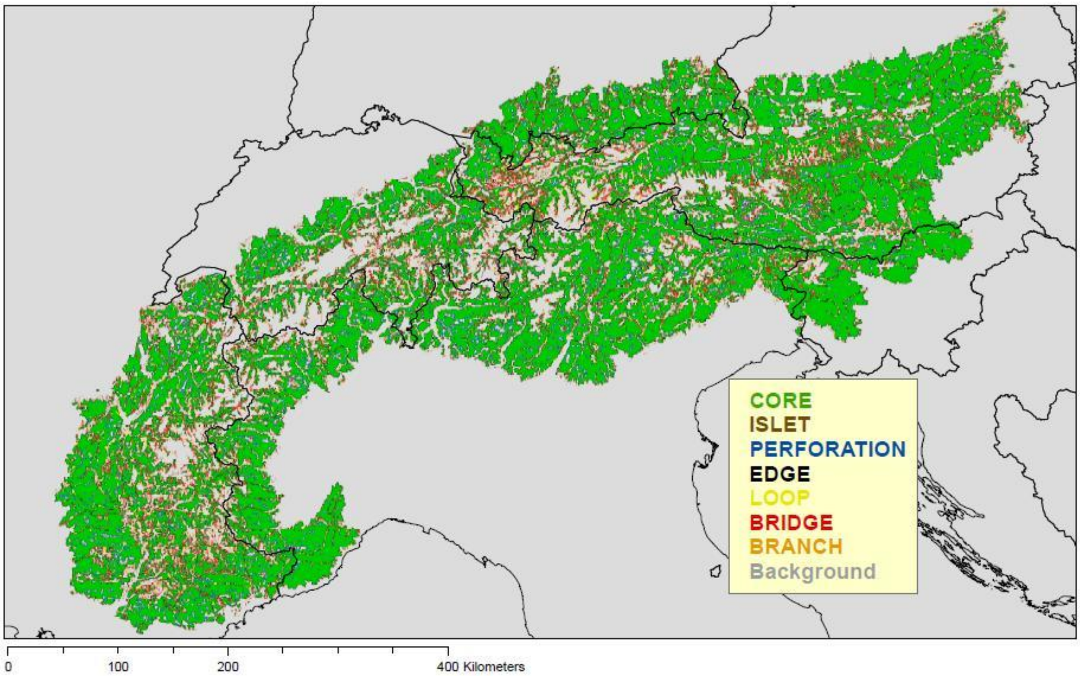


Figure 23. The results of a morphological spatial pattern analysis based on the potential distribution of *Cervus elaphus* in forest as well as non-forest habitats in the Alps. Colors are the same as on above figures.

Results

The main result of the analyses are the maps of classified areas with identified core areas (green) and corridors (red) for all four focal species in the Alpine area (figs. 20-23). However, no suggestions regarding core areas and corridors characteristics and protection has been made by the authors.

Brown bear

The current distribution of *U. arctos* in the Alps is very spare and limited mainly to the eastern Alps. This is the result of human driven persecution and extinction of bears. The potential distribution model for the Alps shows, that there is potential for bears in the western Alps. Regarding the legal status of potential bear habitat, the morphological spatial image analysis revealed that more than 60 % of potential bear habitat not classified. From a nature conservation view of perspective, it would be desirable to protect all bear habitat not yet protected. Results from GUIDOS provide a first step towards a spatially oriented evaluation of bear habitat. For example pixels that are connecting core areas, like bridges, should be given preferences.

Wolf

The MSPA analysis was based on the SE-IBM wolf pack habitat suitability map to identify core areas and bridges, which are the most important areas to protect to maintain wolf connectivity over the Alps. However, there was a significant difference if we considered 0.5 or 0.8 thresholds. If the threshold was set at 0.5, the authors documented a big connected area over the Alps. If the threshold was set at 0.8, authors documented a more fragmented area, especially in the Western-Central Alps. Major barriers for wolf dispersal were identified as from anthropogenic and landscape origin. In particular, the lowest levels of connectivity were found between source areas in the Pennine and Lepontine Alps, between Switzerland and Italy.

Lynx

Approximately 41 % of all bridges that connect core habitat fall within an Econnect Pilot region or are protected. It would of course be desirable to ensure the protection of all connecting pixels (i.e. bridges). This analysis revealed that motorways have a significant impact on the distribution of *L. lynx* in the Alps. While the approach maybe too simplistic because not all motorways are fenced and tunnels and bridges are connecting the habitat patches, the fact that linear impenetrable features have a negative impact on lynx seems to emerge. The resistance value for motorways is sensitive towards the results of the analysis. Values for the resistance should be carefully chosen and possibly be supported with empirical studies. Settlements as they are at the moment seem to have little negative impact on the *L. lynx* in the Alps, as it reduced the overall graph density by less than 1 %.

Red deer

The current distribution of *C. elaphus* in the Alps is probably strongly influenced by the human management. The datasets on the species occurrence from the several Austrian provinces and from Bavaria and Northern Italy show that the red deer free zones are suitable as habitat but this species is excluded from these areas. Therefore, it is very difficult to evaluate the role of anthropogenic and landscape barriers on the species.

2.3.3. Lynx corridors in Jura Mountains

General overview

The team of scientists from University of Lausanne and University of Bern has taken up their lynx research. Zimmermann & Breitenmoser (2007) recalibrated a previously developed GIS probability model for lynx distribution in order to estimate the population size based on knowledge of the land tenure system of resident lynx and assess possible corridors between the Jura Mountains and adjacent 'lynx areas' (the Vosges Mountains, the Black Forest and the Alps).

Project methodology

To estimate the potential population size of the Eurasian lynx (*Lynx lynx*) in the Jura Mountains and to assess possible corridors between this population and adjacent areas (the Vosges Mountains, the Black Forest and the Alps), authors adapted a previously developed Geographic Information system (GIS) probability model for lynx distribution and extrapolated it over the entire mountain range. The model was based on knowledge of the habitat use and land tenure system of resident animals from the central part of the Jura Mountains, where lynxes were followed by means of radio telemetry. Corridors were computed in the GIS using a friction grid and a cost distance function. The friction value attributed to each land use variable was assessed from previous observations of lynx dispersal.

Results

The model predicts a lynx breeding population in the Jura Mountains of 74 - 101 individuals and 51 - 79 individuals when continuous habitat patches of 50 km^2 are disregarded. The Jura population lies within the range of a viable population if only demographic aspects are taken into account, but is rather small from a genetic point of view. Genetic viability would be assured if the Jura lynx population was part of a larger metapopulation. Potential corridors (fig. 24) exist from the Jura Mountains to the Vosges Mountains, the Black Forest and the Alps (Chartreuse and Saleve, respectively). The length of these corridors range within 7,3 – 37,3 km, and their costs are all within the range of radio-collared lynx roaming outside their prime habitat. The best corridor leads south to the Chartreuse, an isolated part of the French Alps, which is connected to the rest of the Alps by two corridors of 4,5 and 6,5 km long, respectively.

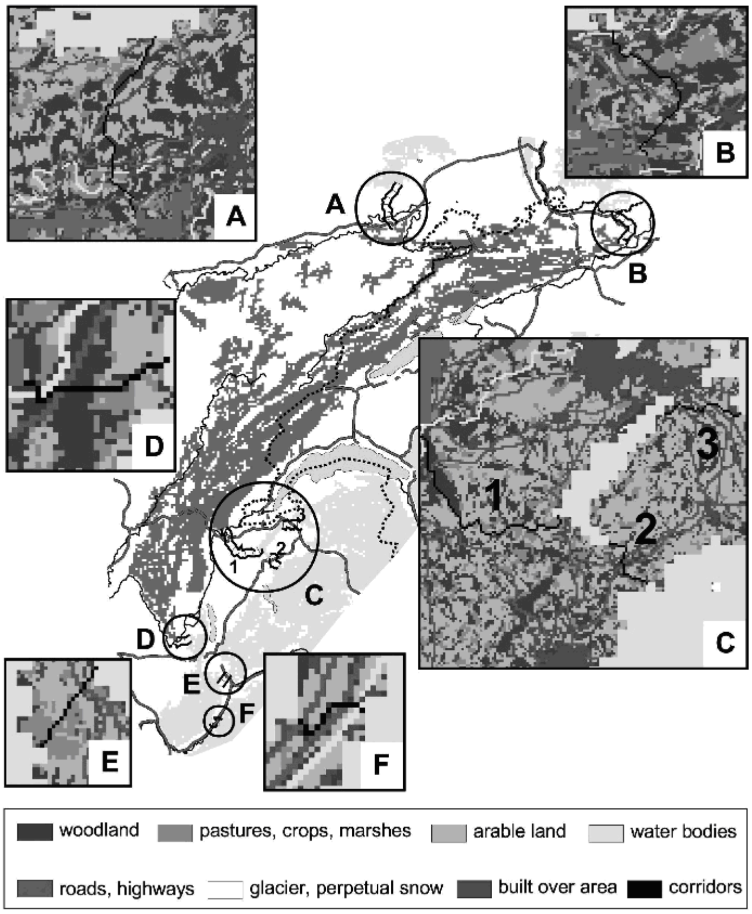


Figure 24. Potential corridors between the Jura Mountains and the adjoining areas Vosges Mountains (A), Black Forest (B) and French Alps (C-F). Continuous areas of 50 km^2 with habitat probability greater than 0.35 (Popt) are shown in dark grey for the Jura Mountains and light grey for the adjacent areas (1 x 1 km grid).

2.3.4. Switzerland

2.3.4.1. Bears suitable habitat and corridors in Switzerland

General overview

One hundred years ago, the brown bear was extinct in Switzerland as in most other parts of the Alpine region. During the last few years, the remaining populations in Slovenia and especially in the Trentino, northern Italy, have been increasing once more. Thus, thanks to legal protection and reintroduction programs, bears are expanding and reclaiming areas of their former distribution. Since southeastern Switzerland is very close to the Trentino, a natural return to this country seems possible. This study, conducted by the KORA organization, deals with the basic question of whether there is any suitable habitat in the densely populated and intensely used landscape in Switzerland. Further, the study gives a first insight into potential migration routes for dispersing bears and possible conflicts that could arise, if the bear should indeed return.

Project methodology

The study area comprises the Alpine region from the Trentino to the southeastern parts of Switzerland. In order to examine suitable bear habitat authors used the Ecological Niche Factor Analysis (ENFA) (Hirzel *et al.* 2002). This multivariate analysis used only presence data (bear presence data gained from Trentino area) in order to compute a habitat suitability model by comparing the environmental niche of the species to the environmental characteristics of the entire study area. Thus the resulting habitat suitability map shows areas where the environmental conditions correspond with those of areas where the species was actually observed. The habitat suitability map also represents a map of the potential distribution.

Results

Areas of suitable bear habitat were found in the southern and northern parts of the Swiss Alps, namely in the Engadin, the northern Grisons and in the region of Glarus. Dispersing bears from the Trentino could reach the core areas of suitable habitat in Switzerland along several corridors (fig. 25) with the longest corridor having a length of 87 kilometres. Since no insurmountable obstacles block the way, the return of the brown bear is highly possible in the near future.

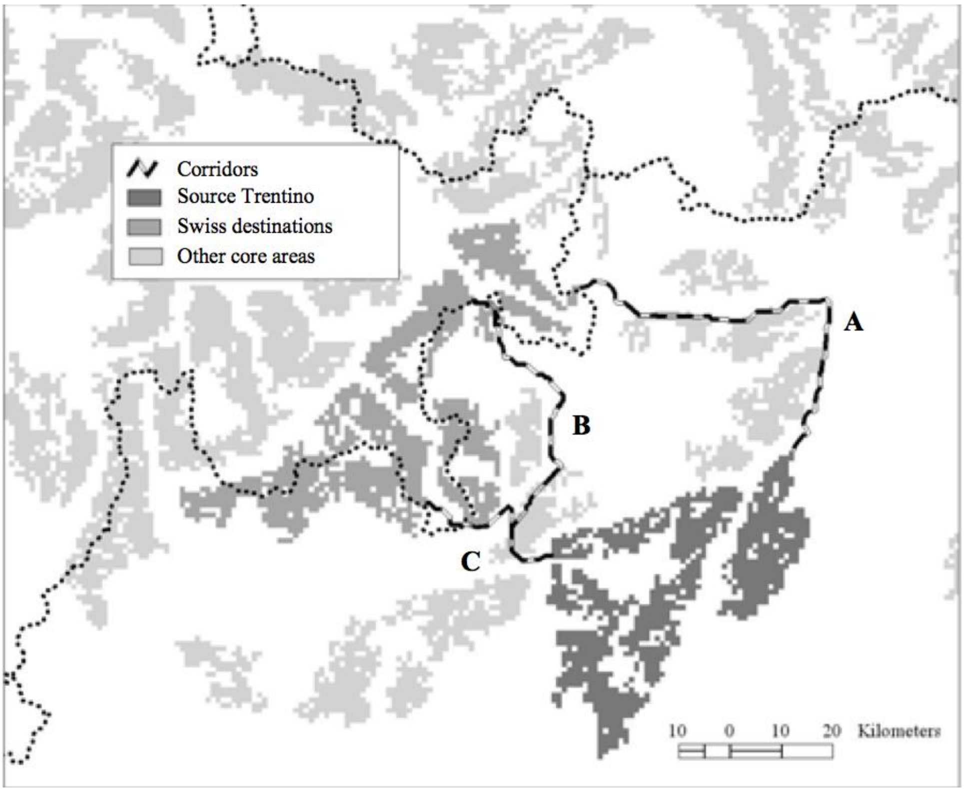


Figure 25. The three main corridors connecting Switzerland with the Trentino (according to the median). **A:** Trentino – Val Müstair (87.0 km), **B:** Trentino – Zernez (74.4 km), **C:** Trentino – Poschiavo (37.5 km).

2.3.4.2. Corridors for forest animals in the Switzerland

General overview

The team of experts from Bundesamt für Umwelt, Wald und Landschaft; Schweizerische Gesellschaft für Wildtierbiologie and Schweizerische Vogelwarte Sempach have compiled the study devoted to international corridors for wild forest animals in the Switzerland. Each identified international corridor has been briefly described, the species which will use the particular corridor were also mentioned and if needed the protection measures and recommendations were stated.

Project methodology

The questionnaire survey among hunter associations about species distribution, migration and core area identification was first method used. The second method - habitat permeability model (Durchlässigkeitsmodell) has classified landscape into five categories according to its barrier effect (from 1 – impermeable highway and settlement to 5 – forest and protected landscape). The final grid with permeability scores were visualized using GIS method. Unfortunately, linear barriers such highways weren't included into the final model. For selected cantons also hunting statistics and information about killed animals due to vehicle collision were taken into account.

Proposed corridors were delimitated primarily for forest dwelling animals such as Red deer, Roe deer, Wild boar and Chamois. Other animals that can utilize corridors are Red fox, European badger and House marten. Also European Pine marten and large carnivores (Lynx, Wolf and Bear) were mentioned to be potentially migrating along these corridors. Axes of corridors were classified on three levels: international, regional and local.

Results

Authors presented map (fig. 26) of corridors relevant for international importance. They described each corridor section and whenever needed the recommendation how to mitigate barrier effect was proposed.

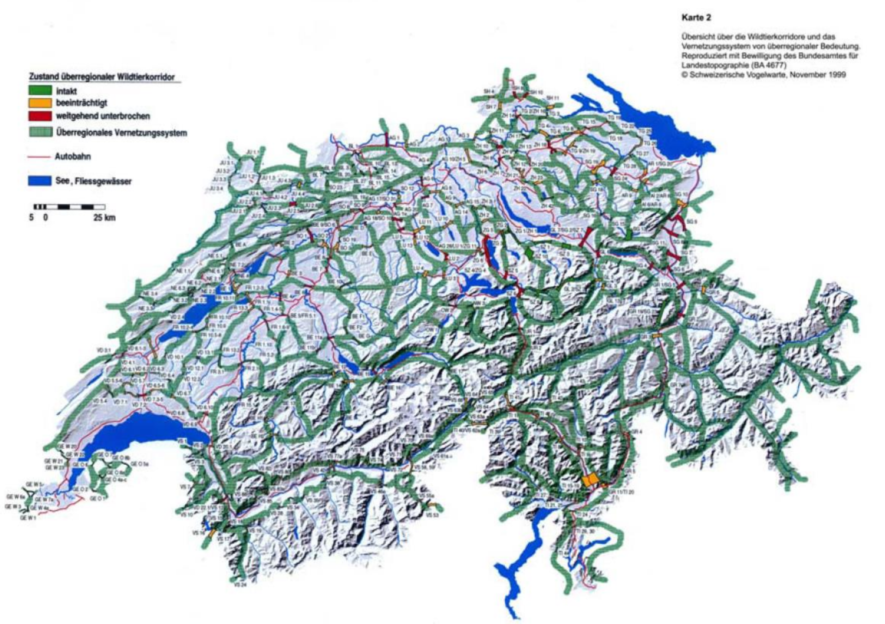


Figure 26. Wildlife corridors of international importance in the Schwitzerland.

2.4. Central Europe

2.4.1. Germany

2.4.1.1. Ecological network in the Germany

General overview

Germany offers a well-elaborated nationwide network of biological corridors; see (Hänel & Reck (2009), Schumacher & Schumacher (2009), Reck et al. (2010). This concept equally counts with three principal interaction elements of a migration network, which includes core areas with both recent and potentially future (based on habitat models) occurrence of the species of interest, namely of the Eurasian Lynx, Wildcat, Grey Wolf, Eurasian Elk, Chamois, and the Red Deer. In addition to core areas, stepping stones with favourable habitats are considered to be connected by individual corridors. Biological corridors are designed based on models of habitat preferences in individual species and on models simulating connectivity between core areas.

Project methodology

Data sources used for ecological network elaboration were: Digital Kartographic map (1 : 200 000), Digital landscape map Basis-DLM (1: 250 000), and Corine Land Cover 2000. Main forest categories from Corine Land Cover were merged and accompanied by a group of shrubby and herbaceous vegetation. The inclusion of shrubby and herbaceous vegetation (eg 324 - "forest-shrub-transition stage ') integrated nature rich undergrowth formed as a particularly suitable area for lager mammals (e.g. areas of military training sites, landscapes with surface mines etc.). Large forest core areas (of national importance) were determined by the 2,5 km distance rule. About 400 forest areas were not connected with the whole network, because they did not reached the area limit for inclusion or were surrounded by the settlements. Moreover some other areas were identified according to the unfragmented area by traffic method (area bordered by roads with traffic flow higher than 5 000 cars per day). The data from areas known to be hosting permanent occurrence of focal species as well as data on migration (e.g. place of traffic collision) were included.
The Least cost path method was used as a basis for corridor modelling between selected core areas. However, the method was modified. The presented corridors have to be understood as a symbolic axes linking system of the regions, by the best possible way through forested areas, which serves as appropriate living spaces. The core areas were further classified according to their surface area (up to 100 km^2 - nationally important areas, up to 500 km^2 - internationally important areas). The final corridor model was validated using species occurrence data. It was found that some areas potentially suitable for Red-deer were not included, especially in southern Schleswig-Holstein as well as in North Rhineland-Westphalia (Westmünsterland / Niederrhein). Other important corridors have been integrated into the national map (dashed line on fig. 27) using regional information (Hänel & Reck 2011).

Results

Based on above mentioned data, the comprehensive ecological network for forest mammals was proposed for whole Germany (fig. 27). All possible conflict hot spots with areas of settlement and areas with high accumulation of transport routes using detailed data and knowledge of experts were also taken into account. The corridors in Germany are planned throughout the country as a line with an unchangeable protection zone along their full length. They are protected as habitats of protected fauna species by the EU legislation and by the German act on nature conservation. Every *Bundesländer* has the own responsibility for corridors planning and is obliged to establish ecological network on at least 10 % of state territory.

Figure 27. Ecological network for forest animals in the Germany. Connectivity axes and core areas are depicted.

2.4.1.2. Project BUND Wildkatzenprojekt (Wildcat Rescue Project)

General overview

The project of non-governmental organization BUND (Friends on Earth) was initiated in 2004 by establishing corridors for the Wildcat (*Felis silvestris*) between the Thuringian Forest and National Park Hainich. Its main objective is to create a network of corridors at the national scale with will be connected also to bordering countries.

Project methodology

The main data source for habitat modelling was Corine Land Cover with its general categories. Two statistical model types were used for resultant habitat model – the model from telemetry and the model from observational data. Statistically significant factors in first model were distance to forest, distance to settlements and distance to nearest watercourse. By using logistic equation, the prediction on wildcat occurrence on landscape scale can be made. The model was also checked against independent telemetry data collected in another region in Germany (forest Bienwald). The second method was applied on the Rhineland-Palatinate territory, where the grids boxes with wildcat absent/present were marked and logistic regression was created. The best model showed proportion of settlements and forest within a radius of 5 km. Logit link formula was used to predict the probability (from 0 to 1) for the wildcat occurrence on whole German territory in each 10 x 10 m grid net. The probability 0,4 and higher was considered to be suitable for wildcat occurrence in selected grid.

The next step after habitat modelling was to identify starting and ending points for corridor modelling in between them by using the cost distance analysis. This method uses resistance values, which are assigned to each landscape category. Resistance values were determined from habitat model for wildcat, which was developed based on telemetry data and thus gave more precise outputs in comparison to arbitrarily set values by experts (Klar et al. 2008).

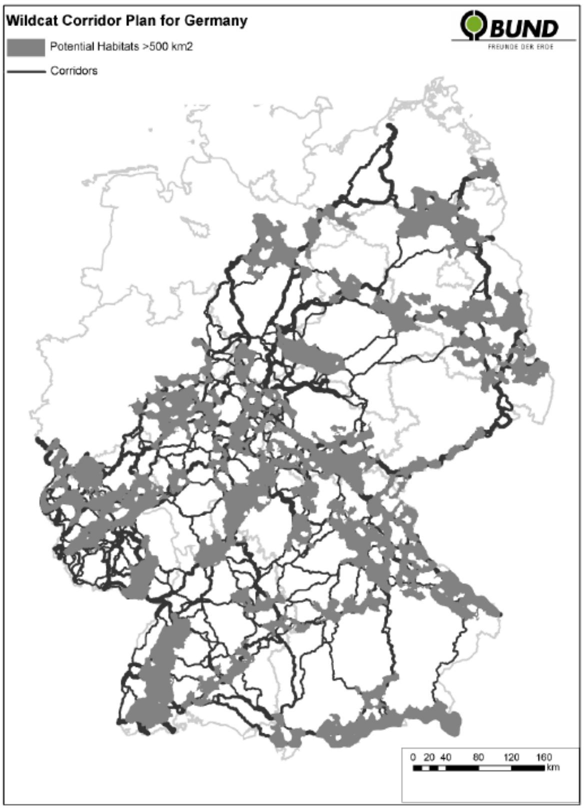


Figure 28. Wild cat corridor map in Germany (BUND).

Results

One of the main disadvantages of habitat modelling is the resolution of the Corine Land cover (CLC), which is 25 ha. This is the reason for not inclusion of the small scale woodlands and linear hedgerows, which could be used for migration in non-forested areas. This fact was partially compensated for some federal states using ATKIS (Amtlich Topographisch-Kartographisches Informationssystem), which has more precise data resolution. However, the resolution of CLC is sufficient to define large forested areas as core areas and stepping stones with suitable habitat for wildcat occurrence. Another disadvantage of the corridor model is not inclusion potential migration barriers such as high traffic volume highways and large rivers. Authors suggested making appropriate mitigation measures in the crossing points, where the highway intersects the proposed corridor. They also considered roads to be significant barrier from traffic volume above 10 000 vehicles per day, which is questionable.

In spite of that, the concept of migration corridors for wildcat in the Germany is one of the most comprehensive. Its uniqueness is supported by the fact that some parts of proposed corridor network have been applied and implemented in the field already. The area between National park Hainich and was the first, where the trees along the proposed corridor were planted. The project is already being implemented beyond Thuringia, namely in Bavaria, Hesse, Lower Saxony, Baden-Württemberg, Rhineland Palatinate, and other states of Germany. Moreover, the GIS shapefiles of proposed network are available for download at http://wildkatzenwegeplan.geops.de/.

2.4.2. Poland

2.4.2.1. Ecological network in Poland

General overview

The network of corridors for the Grey wolf (*Canis lupus*) in Poland may be considered as one of the best prepared (Jędrzejewski et al. 2005). Its added value is based on documented occurrence data of focal species supported by relevant GIS techniques such as habitat suitability modelling. Researchers and collaborators to the Polish Academy of Sciences, Mammal Research Institute, Białowieża have been working on the issue for a long period of time in cooperation with the Association for Nature "Wolf" and also with forest managers and national park employees, who collected data in the field. The network is formed by the corridors themselves, but also by stepping stones (i.e. areas with a habitat suitable for the temporary occurrence of the species during migration), and by core areas, which provide conditions for long-term occurrence of the wolf populations. Corridors usually copy vast forest complexes. Three main categories of migration corridors may be distinguished according to their level and character: international, national, and local. Their legal protection is grounded on the EU directives (conservation of species of Community interest, environmental impact assessment) but not on national level.

Methodology

The GIS analysis of biological corridors used the following databases:

1) Topographic maps at a scale of 1:50 000. The scale maps made it possible to locate objects with high accuracy (eg, the level of individual belts and roadside woodlots, individual trees and free-standing buildings).

2) Digital maps of forest within each Regional Directorate of State Forests, including descriptive data on the ownership and use of forest area. Database created on test. LANDSAT satellite images, topographic maps and forest data Directorate General of State Forests. Forest digital maps were used to update the data on the scale topographic maps of forests and used to supplement the database.

3) Land use data - Corine Land Cover (CLC) 2000, layers of information on land use in 44 categories.

4) Digital maps of protected areas included in the National System of Protected Areas, which was collected 4 layers: national parks, landscape parks, protected landscape areas, nature reserves.

5) Numerical Map of Natura 2000 sites: Special Protection Areas (Birds Directive) and Special Areas of Conservation (Habitats Directive).

The basic criteria for the designation of corridors were:

1) Forest cover.
It was the most important criterion for demarcation corridors. Large forest areas were all included. The corridors were proposed in the shortest distance between large forested areas, especially through smaller afforested patches and belts. In situations where the shortest path between afforestation was impermeable barrier for animals, another alternative route was proposed. The basis for the demarcation of corridor sections was topographic map.

2) Type of land use on non-forest areas connecting forest fragments with preference to landscape structures potentially providing temporary shelter for moving animals, such as trees, vegetation along river banks and water bodies. Also the areas suitable for the future afforestation possibility were searched. These structures were located on the basis of topographic maps 1:50 000.

3) The watercourses and reservoirs.

4) Avoidance of anthropogenic barriers. In some situations, however, this was not possible (e.g. the southern Poland, in a densely populated area of foothills). In such cases, the chosen sections are proposed through the loosest possible connection between settlements.

5) Data on the occurrence of species bison, moose, red deer, bear, wolf and lynx in Poland were considered (also some migration routes and the wolf genetic results).

Results

The greatest importance, when planning the ecological network, was paid to interconnect the most valuable Polish natural areas, especially those populated by rare or endangered species and also try to avoid densely human populated and built-up areas. Entire forested areas with lower population density and infrastructure that seem to have the best prospect for maintaining the landscape connectivity were included into network. The areas that are already covered by some form of legal protection were prioritized. Corridor width is variable, depending on local conditions. The result is relatively dense network of corridors, occupying a large area of the country (fig. 29). Most of this area is already covered by various forms of protection, and only about 18% of the area would require legislative changes.

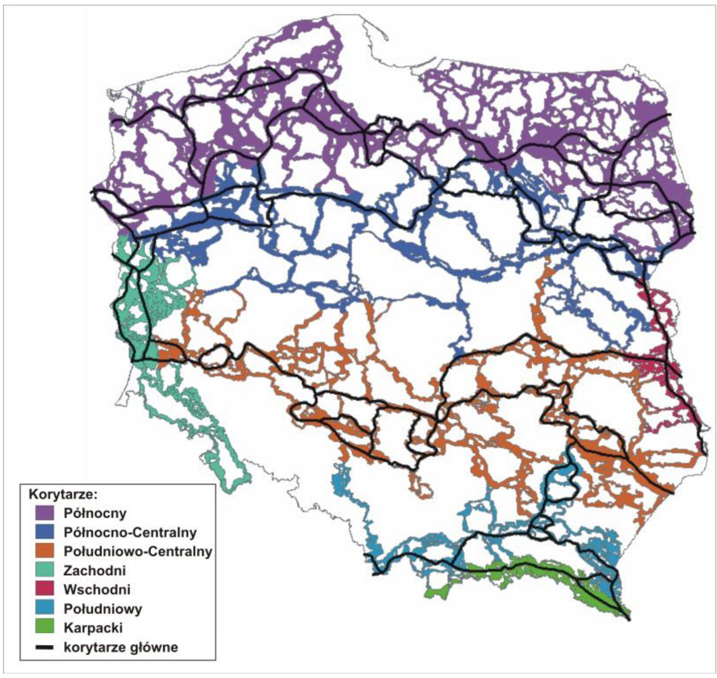


Figure 29. Biological network of corridors for large mammals in the Poland.

The adjustment of the proposal of ecological network in Poland during recent years was also supported by following studies.

2.4.2.2. Habitat suitability model for Polish wolves based on long-term national census

General overview

This work devoted to habitat suitability modelling preceded the proposal and delineation of corridors for large mammals on whole Polish territory. Study is based on large-scale data set of wolf occurrences originated from years 2000 - 2006, when large scale census was conducted.

Project methodology

Habitat suitability model (HSM) was based on habitat classes taken from Corine Land Cover and divided into five general categories: 1 – forests, 2 – wetlands and marches and 250 m buffer around water reservoirs and river banks, 3 – meadows and pastures, 4 – arable fields, 5 – cities and other industrial and rural area. Occurrence data for wolves were collected during National wolf census that was conducted by State Forest districts and national parks (2000 - 2006). Density of roads has been considered as a main factor for barriers. Density of main wolf prey namely ungulates (roe deer, red deer, wild boar, moose) was recalculated to biomass. Finally, whole territory of Poland was divided into 10 x 10 km square grids (core area of annual wolf territory). Than to each cell in the grid was assigned whole set of above mentioned factors. A set of multiple regression models with the relative probability of wolf occurrence as a dependent variable and most important habitat features (Forests, Wetlands, Meadows, Roads) as explanatory variables was ranked by the corrected Akaike information criterion (AICc), and the most parsimonious model was chosen.
The mean probability of wolf occurrence increased with growing forest cover, ungulate abundance and per cent area of wetlands and marshes in a cell.
In the final step, it was searched for the adjoining patches using size criterion to reach at least 400 km^2 continuous suitable habitat. This method identified 24 potentially relevant

areas for wolf permanent occurrence with predicted relative probability of wolf occurrence ≥ 30%, six of them already inhabited (fig. 30). HSM model was also validated by comparing patches predicted by the model with cumulative distribution of wolves from years 1950-2006.

Results

Authors have showed that more habitats suitable for the Wolf can be found especially in the Western part of Poland, that is actually uninhabited by stable population. Except of forest also meadows and wetland habitats are frequently utilized by wolf in the areas where the forest cover is scarce. Roads and density of human population were identified as most important factors hindering dispersal opportunities.

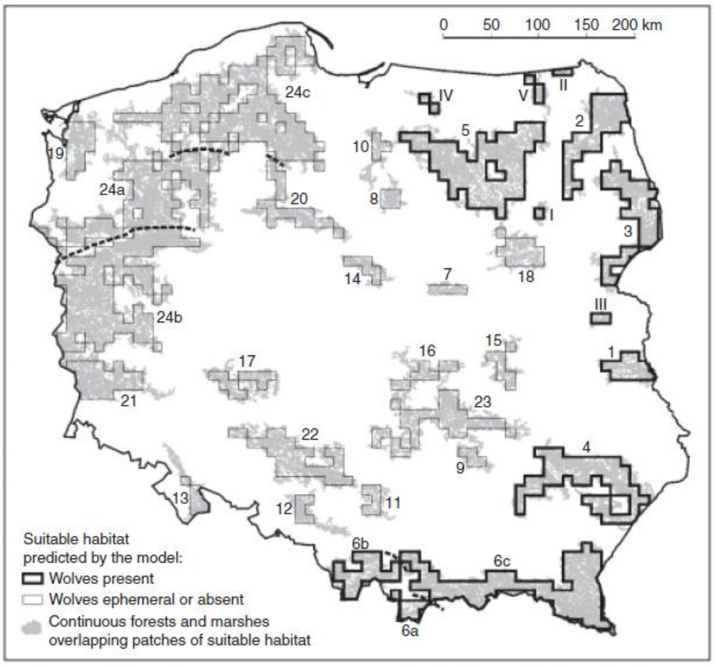


Figure 30. Patches of habitat suitable for wolves (*Canis lupus*) in size ≥ 400 km^2 (Jędrzejewski et al. 2008).

2.4.2.3. Analyses of least cost path for determining effects of habitat types on landscape permeability: wolves in Poland

General overview

This study continuously follows the previous mentioned work (Jędrzejewski et al. 2008), where the core areas (suitable patches) for wolf were identified for entire Poland. Main aim of this study was to create and compare corridors between those patches using GIS modelling methods (Fig. 31).

Project methodology

Huck and colleagues created habitat suitability map for wolf in entire Polish territory based on Ecological Niche Factor Analysis (ENFA) method (Hirzel et al. 2002). This method also predicts marginality values for all eco-geographical factors used in spite of values that are arbitrarily set by expert opinion. These values were also used to define costs of movement in defined grid matrix later on. The variables taken from Corine Land Cover (CLC) were grouped together into main categories as in above mentioned study (Arable, Forest, Meadow, Water, Wetland and Human – towns and settlements). Primary (highways and international roads) and secondary roads were also taken as a proxy for barrier effect. Finally, only five main categories (Arable, Forest, Meadow, Wetland and Human) were used in the analyses due to the fact that factor Water was highly correlated to Wetland and variable Road to Human. The wolf occurrence map was created using whole set of observations (presence / absence data) collected during National wolf census (2000 - 2006). The least cost paths (LCP) analyses were performed taking into account combined cost map for habitat types and roads (cost values resulted from ENFA). They computed also length and distance between connected patches. Moreover, to assess percentage area of different habitat types, the total 1 km width buffer was created and the total length of roads within the buffer was calculated.

Results

This study confirmed that a lower proportion of cities and roads surrounds the most densely populated patches, forest being the most important factor predicting wolf occurrence, on the opposite roads and settlements being the factors explaining why patches are unpopulated by wolfs. Unpopulated patches were also separated by corridors with maximal distances over open landscape. Authors of this study also showed that LCP can be used not only for visualization the direction of corridors, but can also predict most important factors that hinder or facilitate dispersal by comparing different subsets of LCPs.

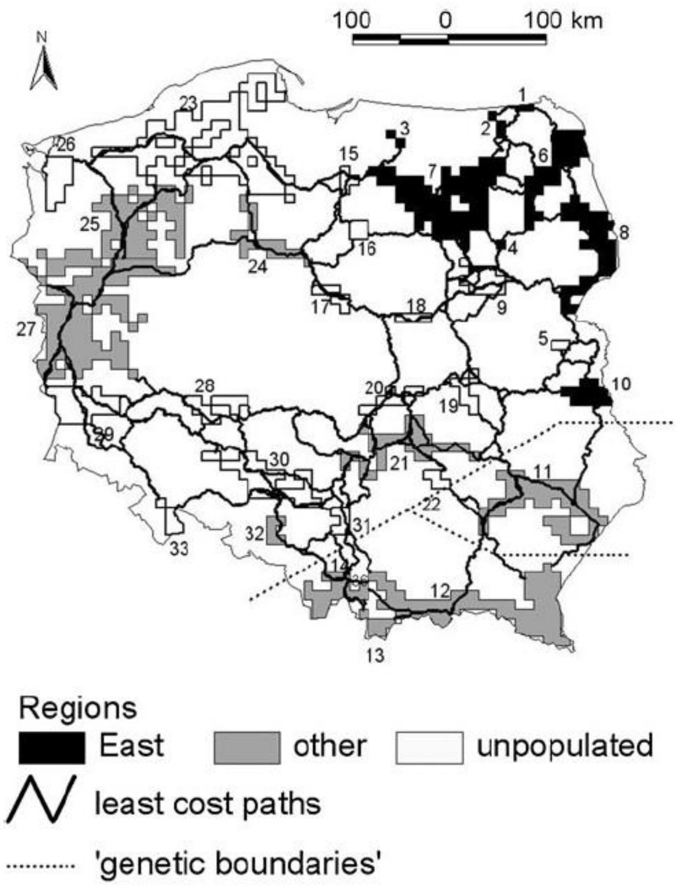


Figure 31. Suitable wolf patches within Poland and least cost path (corridors) connecting these patches (Huck et al.2011).

2.4.3. Austria

2.4.3.1. Habitat suitability and migration permeability models for forest animals in the Austria

General overview

Clemens Köhler has presented in his thesis habitat suitability model and interregional corridors for the bear in the whole Austria. The resultant GIS based model had very good predictability of bear and lynx occurrence as it was validated using field occurrence data of the species. The model also used to identify the most likely road crossing sites for animals, which would indicate the best placement for passages.

Project methodology

The resistance model of the landscape considering the values from 0, 01 (forest) and 1 (impermeable barrier) was created using ArcInfo software at first. The 18 land cover classes from SINUS databank were reclassified into nine categories using expert based principle as follows: vegetation free area, ice and snow area, water surface, forest, green land, wetland, arable land, settlements and other non defined area. The subsequent buffer area of 500 m around large settlement (> 90 ha) and buffer area of 100 m around small settlement (< 13,5 ha) were considered to belong to the urban area (the area affected e.g. by noise and light of the settlement is not equal). Also to the category forest were assigned with different resistance values according to different size of the forest area (see the thesis for values).
The following step was to perform cost distance and corridor analyses using previously prepared resistance layer. The corridor command in the ArcInfo identifies the least-cost path from one source to another defined source (core area).

Results

According to the above mentioned GIS procedures, the model of interregional migration area in the Austria was prepared (fig. 32). Even though the model was based especially on expert based assumptions and criteria, whole model was afterwards successfully validated using 4185 records of brown bears of which 81,15 % was found within area with very low resistance (good permeability of the landscape). Moreover, validation of the lynx occurrence data confirmed that all grid cells laid within designated area for migration. Unfortunately, it was caused due to the fact that not precise data on localizations of the lynxes were available. The model is very useful for prioritizing the places, where the road mitigation structures should have been built in the future.

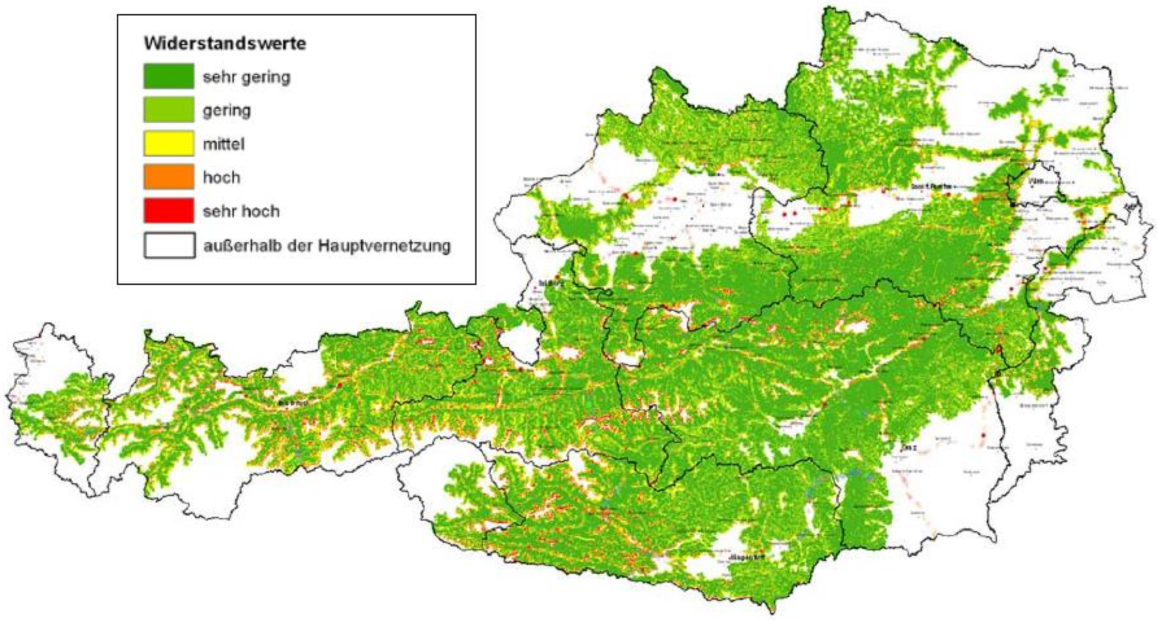


Figure 32. Habitat suitability model and international corridors for bear in the Austria (Köhler 2005).

2.4.3.2. Ecological network in Upper Austria

General overview

The three institutions Oö. Umweltanwaltschaft, Oö. Landesregierung and Oö. Landesjagdverband cooperated on preparation of ecological network composed of core areas and stepping stones consisted by suitable habitat, which are connected through corridors. The width of international corridor was determined to be at least 1 km and the lynx was selected to be the target species. All corridors are designed in three categories, i.e. of a regional, national, and international significance. As there is no specific legislative rule aimed at the protection of corridors at the national level, it is currently secured only through the EU directives (conservation of species of Community interest).

Project methodology

At first, the potential core areas and stepping stones for the lynx were selected based on GIS habitat suitability study (Köhler 2005) and expert opinion. In the next step, the corridors were proposed between core areas through stepping stones, using Austrian map 1: 50 000. Actual route of corridor was adjusted accordingly, using orthofoto map inspection. The final step was to evaluate resulting maps according to different spatial data (forest, water surface, roads, railroads, type of land use, elevation, protected areas) in order to proper divide the corridor zones.

Moreover, the model of landscape permeability for large mammals was prepared taking into consideration the cell resolution 50 x 50 m. Movement through the landscape was assessed on five degree scale from non permeable to free movement depending on land cover and barriers. Three levels of corridors are recognized: local (width 250 m), regional (width 500 m) and interregional (width 1000 m). Above that, the corridors were also classified into three categories (red, orange and green zone) with different landscape permeability, which was set according to the presence of different barrier types and their negative co-occurrence (Birngruber et al. 2012).

Results

The final migration network for large mammals, which is based on landscape permeability model, is obvious from fig. 33. It is obvious that large core area for permanent occurrence is situated to large forested area in the Alps. The second area with suitable habitats is also in northern part of Upper Austria close to the Czech borders. Due to this fact most corridors are proposed in the north south direction with the aim to provide and sustain the landscape permeability for persisting populations of the lynx between South Bohemia and the Apls. The most problematic sites are located in the lowlands where the cities, roads and railways are located, as obvious from fig. 34. The added value of this study is that provides thorough corridor zone description and proposes the mitigation measures, whenever needed.

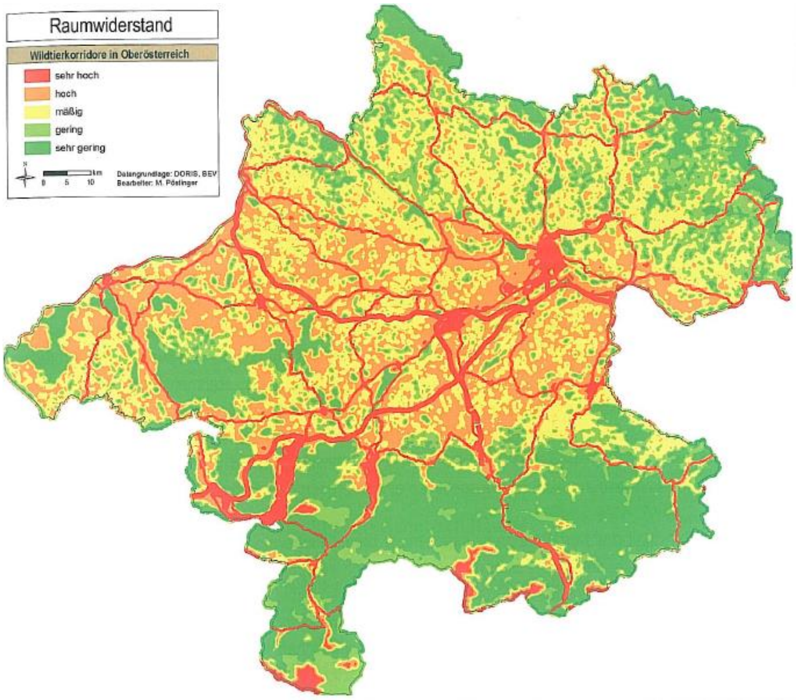


Figure 33. Landscape permeability model for large mammals in the Upper Austria.

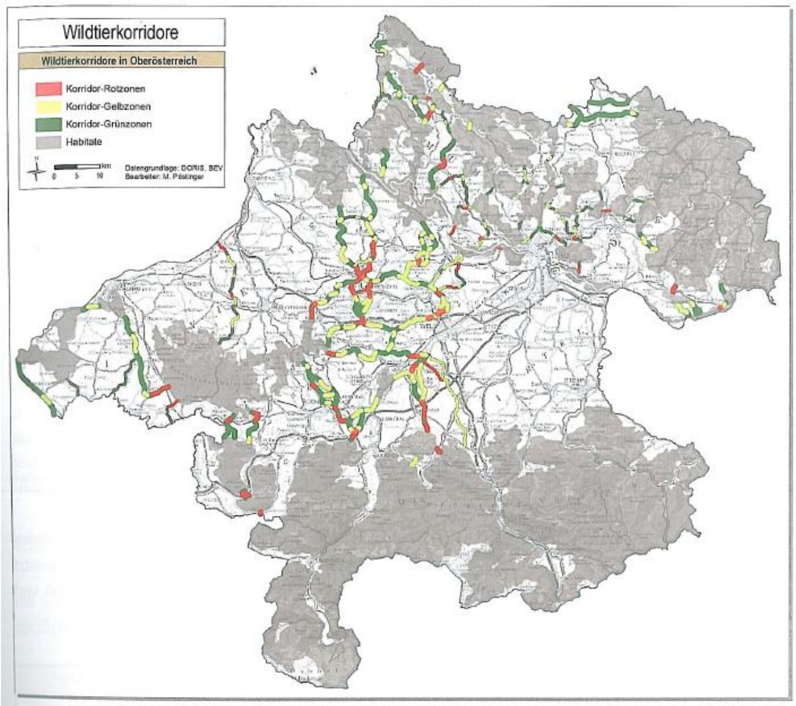


Figure 34. Map of core areas and corridors and their sections that are divided according to barrier effect for migration (red – high barrier effect, green – low barrier effect).

2.4.3.3. Ecological network in Styria

General overview

Biological corridors on regional level in Styria were proposed by Wieser and colleagues within NATREG project financed by Transnational cooperation programme South east Europe in 2011.

Project methodology

First of all, the core areas were proposed by experts within the landscape sufficiently covered by forest with good connectivity, preferably in alpine regions well distant from cities and highways. The Red-deer was regarded as a main umbrella species. The Roe-deer played this role in areas where Red-deer was absent. Core area covered significantly high proportion of land. The axes of corridors were modelled using GIS least cost path analysis method, between so called connectivity points that were set within core areas. Due to this fact more axes of modelled corridors leads very close to each other almost in one synergy. The buffer around corridor axis has variable width and should be minimum 1 km.

Results

Biological corridors were proposed in the highest frequency (every 10 or 20 km) especially in the valleys, where the cumulative effect of barriers such as roads and settlements is the highest. In some parts of the country the number of corridors is much higher on local level. The permeability of the corridors was also evaluated by local experts throughout the regions. We did not include this concept to case study (chapter 3) because different method was used as described above (see fig. 35).

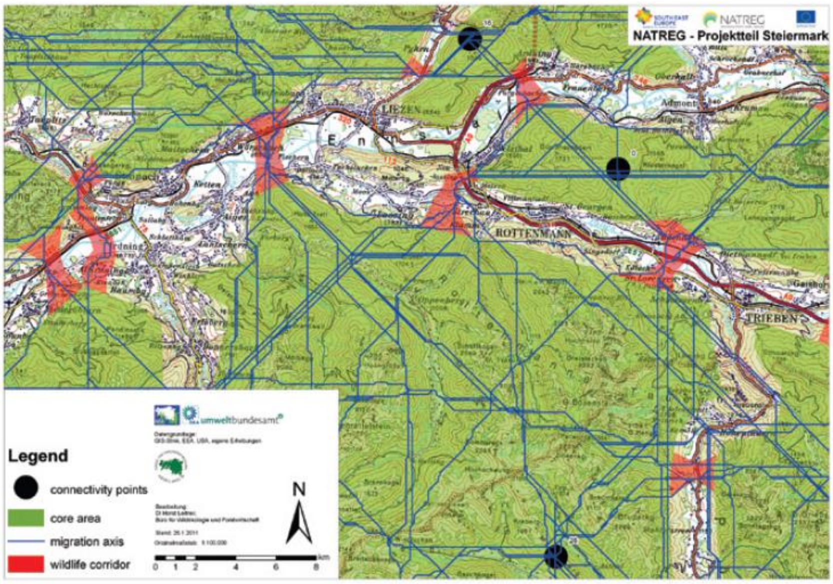


Figure 35. The example of migration corridors in Styria (Wieser et al. 2011).

2.4.3.4. Ecological network in Carinthia

General overview

The ecological network in Carinthia is defined and consisted of core areas, buffer zones and stepping stones. Corridors have been also taken into consideration in the designation of the network.

Project methodology

The ecological network in Carinthia is based on following data, especially regarding landscape structure: the spatial landuse, vegetation mapping (biotope types), road network, and settlements. The corridor width was obtained from a recommendation from wildlife expert opinions and should be at least 500 m – 1 000 m when leading close to settlements. Between years 2001 – 2003, the intensive monitoring of presence and migration of focal species (roe deer, red deer, wild boar, bear and lynx) was carried out as a support for corridor planning. The graphical implementation of the corridors was carried out in ArcView with the aid of the national map (ÖK 50), digital photos with 2,5 m resolution and Google Earth. Main core areas were identified in the north and north-western Carinthia. The work presented by Köhler (2005) was one of the important materials on which was the network in Carinthia based, especially from the methodological point of view (see chap 2.4.3.1.).

Results

The most intensively used areas are the Klagenfurt basin and the Großraum Villach and the Lavant Valley and the Drautal ranging from Spittal an der Drau. There can be found most barrier places that hinder the possibility for migration. Twenty core areas were proposed in the Carinthia in total (area from 22 km^2 to 1 120 km^2). The corridors were proposed solely in the valleys, where the barriers are accumulated. In total 280 corridors with the area 670 km^2 were delineated. Barriers such as highways, settlements and large lakes are depicted in the fig. 36. The very bad situation is especially in central and lower Carinthia, where is the highest barrier effect caused by multiple barriers co-occurrence. Due to this fact, corridors are planned on each third kilometre (Leitner et al. 2009).

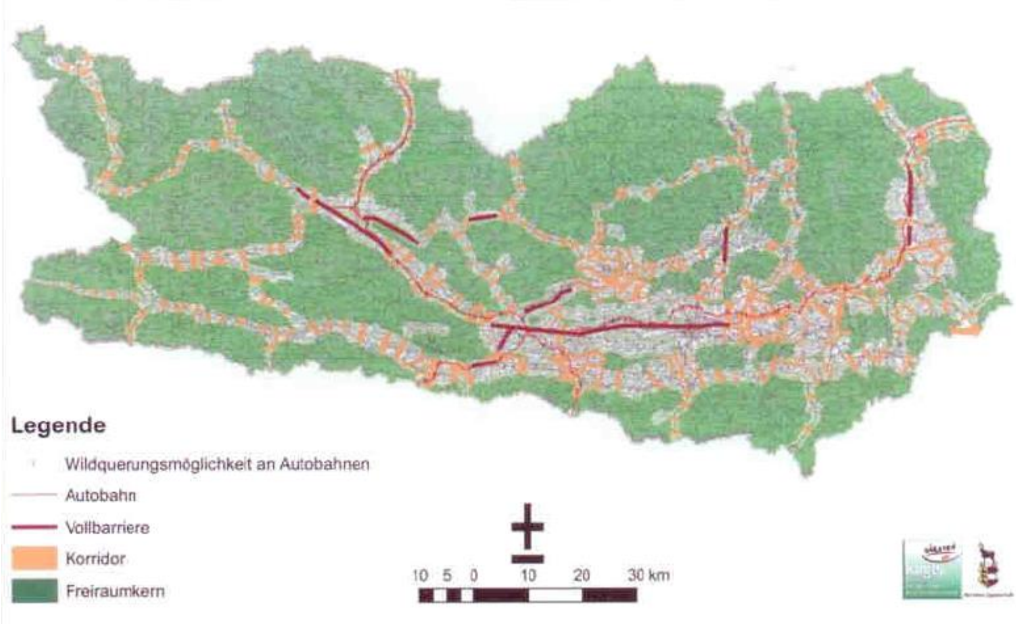


Figure 36. Map of core areas (green) and corridors (orange) in Carinhia.

2.4.4. Czech Republic

2.4.4.1. Assessment of landscape migration permeability for large mammals and proposal of protective and optimization measures

General overview

The ecological corridors and significant migration area for large mammals were prepared as a part of the project: Assessment of landscape migration permeability for large mammals and proposal of protective and optimization measures, which was financed by the Ministry of Environment during 2008 - 2010. Three main outputs in ESRI shapefile were produced: 1) significant migration areas (SMAs), 2) corridors and 3) critical and barrier sections of corridors, where the mitigation measures were recommended.

Project methodology

The basis for ecological network proposition was the development of two models of landscape permeability for the focal large mammal species, which were the lynx, the bear, the wolf, the moose, and the red deer. First model aimed at habitat suitability modelling using focal species occurrence data gathered between years 1985 – 2010 in species occurrence data database managed by Nature conservation agency of the Czech Republic. Other important sources of abiotic data were elevation, vertical heterogeneity, type of habitat taken from Corine Land Cover 2006 database, distance from settlements and road density weighted by traffic flow. Habitat model was based on calculation of Mahalanobis distance used in extension Land change modeller for ArcGIS. Habitat model for the lynx was verified by telemetry data from Šumava national park. The next step was to model core areas and stepping stones with suitable habitat. The potential corridors were modelled between core areas using least-cost path method.

The second model assessed the landscape potential for the lynx and the red deer by incorporating the set of criteria evaluated by experts. Set of indicators for habitat and anthropogenic disturbance was characterized with four parameters. Habitat parameters –

characterize the natural conditions of the sites. These involve the habitat type, elevation, heterogeneity of the terrain and extent of continuous territories. Anthropogenic disturbance parameters were roads and railways in four categories according to traffic flow, settlements based on extent in four categories, non-forest areas in four categories according to distance from forest edge, fences in two categories with respect to potential occurrence of fencing.

Based on the above mentioned materials, the corridor delineation was adjusted above orthophoto map in GIS environment using scale 1:10 000 and lower taking into account landscape structures such as e.g. tree lines or scattered bushes, riparian vegetation along water streams etc. These supportive materials were used for preparation of field map with expected corridor situation. The added value of this project is that the intensive field barrier monitoring along each corridor was performed. Main barrier sections (e.g. highways and railways with high traffic volume, large settlement and large forest free area) along the corridors were checked in the field in order to adjust and finalize the best possible corridor permeability for large mammals. The methodology is thoroughly described in publication Protection of landscape permeability for large mammals (Anděl et al. 2010).

Results

Three main data outputs were produced in shapefile form. The significant migration areas represent areas necessary to ensure long-term existence of populations of focal species of large mammals (fig. 37). They comprise areas providing conditions for the permanent occurrence of the species as well as those securing sufficient connectivity for their migration. They connect all areas where the permanent occurrence of the mentioned species was documented (e.g. national parks, protected landscape areas = core areas). They are of linear character only where they pass through a highly fragmented landscape containing just remains of suitable habitats. They form a continuous network and do not comprise small isolated areas (if these cannot be functionally connected to the main network).

The corridors connect core areas that are significant for the permanent and temporary occurrence of large mammals (fig. 38). They are conceived as a vital minimum (not as an ideal situation) to retain the permeability of the landscape for large mammals at present and with the view to long-term sustainability. These are designed as linear structures in the landscape tens of kilometres in length and on average 500 m in width (buffer zone is defined to be 250 m on each side from the corridor axis). Urban areas are not included in corridor area, even when they are situated within the given zone. They represent locations with a higher probability of occurrence of large mammals and are designed to achieve maximum permeability along their entire length. They are components of significant migration areas (SMA). In case SMAs extend over a vast area (mostly mountain ranges, areas of permanent occurrence), corridors represent only one of the numerous potential migration corridors. By contrast, they provide the only opportunity for migration of large mammals through the landscape on sites with limited migration permeability and narrow linear SMAs. Protection of the last existing permeable routes is, in fact, the key role of corridors.

The last significant result of the project was to identify individual spots of currently existing impermeable barriers during intensive field survey. These spots are viewed as “critical sites” where mitigation measures and solutions to acquire permeability were proposed (28 identified sites). In the future, the critical sites have to be addressed in detail, i.e. by delimiting precisely the migration routes. Spots with multiple migration barriers (128 identified sites) or with an otherwise significantly reduced or complicated permeability are viewed as “limited barrier sites”. From beginning of the year 2012, all shapefile outputs of the project are provided through the web database and serve as a recommendation material which can be used during spatial planning process.

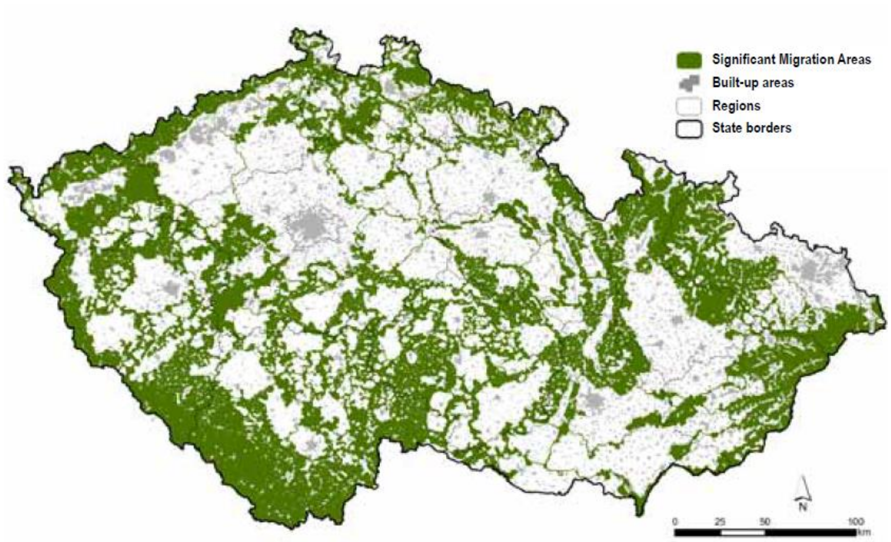


Figure 37. Map of significant areas for migration of large mammals in the Czech Republic.

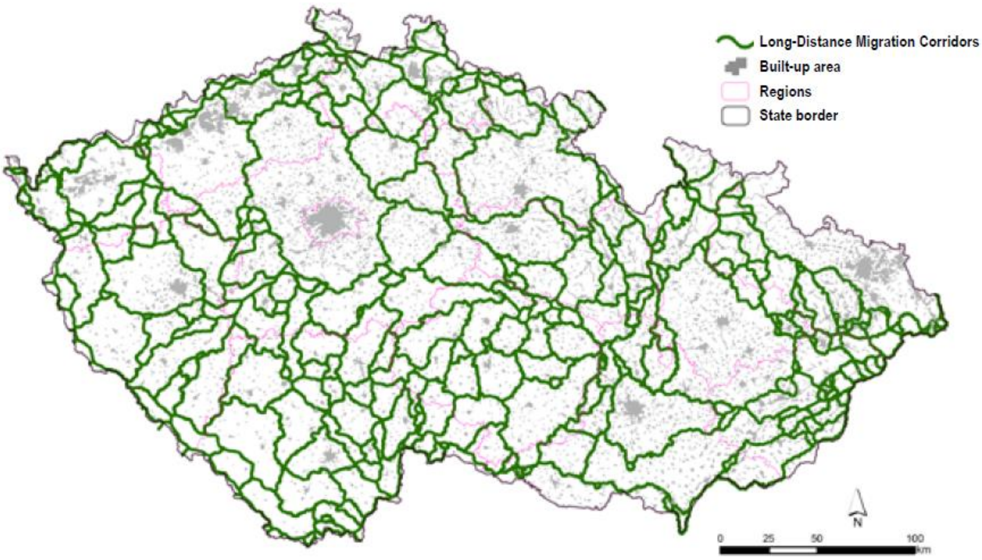


Figure 38. Map of corridors for large mammals in the Czech Republic.

2.4.5. Slovakia

2.4.5.1. Alpine - Carpathian corridor

General overview

This project funded by the European Regional Development fund (2008 – 2012) facilitated the transboundary cooperation between Slovakian and Austrian representatives. One of the aims was to enhance and re-establish migration permeability for the red deer between the Alps and the Carpathians and connect protected areas. The lead partner was Amt der NÖ Landesregierung and project partners were: ASFINAG Autobahnen- und Schnellstraßenfinanzierungs-Aktiengesellschaft, Nationalpark Donau-Auen GmbH, NDS a.s., Slovenská technická univerzita, fakulta architektúry, Štátna ochrana prírody SR, Správa CHKO Záhorie, Umweltverband WWF Österreich, UNEP - Interim Secretariat of the

Carpathian Convention, Daphne, Universität für Bodenkultur Wien, Institut für Vermessung, Fernerkundung und Landinformation and Institut für Wildbiologie und Jagdwirtschaft.

Project methodology

By means of GIS - modelling and remote sensing the actual situation and possible scenarios were explored to refine the permeability of the landscape for wildlife migration. The Alpine Carpathian Corridor project model was therefore conducted in four steps, starting with an "overview model" considering the whole study area. The basic input data for modelling were information on land use, satellite images, digital cadastral maps, road network, expert based resistance values and terrain surveys.
First step was to model landscape potential within proposed corridor area without considering positive or negative factors. The second scenario was modelled with added landcover classification derived from satellite images plus additional information of land use and regional planning from Land Niederoesterreich, Burgenland, Slovakia and Hungary. Fenced features and highways with existing wildlife passages were also included into the second model (fig. 39). In Austria two main roads (not highway or express road) are considered due to their intensive traffic density. The third and fourth model scenario had the aim to explore landscape connectivity when three landscape bridges were added into identified bottleneck sites located near to Arbesthal/Goettlesbrunn (A4), Muellendorf (A3) and Moravský Svatý Ján (D2). The last model scenario was the same as the previous, the only difference was location of the bottleneck site to Zohor (SVK) instead of Moravský Svatý Ján (SVK).

Results

Main result of this project is that three underpasses located in bottleneck sites were planned with close cooperation with companies responsible for highway planning and building in order to enhance migration permeability of these sites.

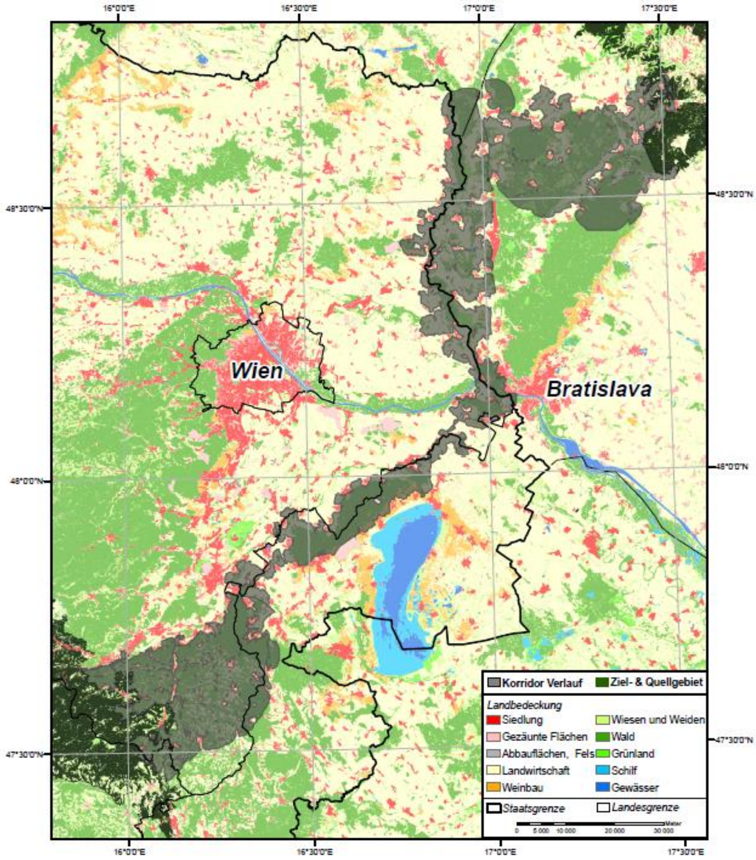


Figure 39. Alpine-Carpathian corridor planned between Slovakia and Austria.

2.5. Eastern Europe

2.5.1. Potential habitat connectivity of European bison (*Bison bonasus*) in the Carpathians

General overview

Main aim of this study was to prepare model predicting potentially suitable corridors connecting five Carpathian areas, where European bison herds were reintroduced. This work is based on habitat suitability index (HSI) map that was developed by Kuemmerle et al. in 2010 (fig. 42).

Project methodology

First of all, range maps for five free-ranging bison herds from Poland (derived from GPS collared animals), Slovakia and Ukraine (derived from topographic maps) were prepared. All analyses were carried out using habitat suitability map prepared by Kuemmerle et al. in 2010 or 2011. This map was modelled using maximum entropy method of modelling. The factors used as landscape variables were: forest fragmentation, land cover and distance to forest. Factors describing barrier effects were highways, main roads and rivers, lakes and settlements, distance to roads and distance to settlements, other topographic variables were aspect and slope (for more detail see Kuemmerle et al. 2010). Potential habitat patches were defined to have habitat suitability index above 0,6 and be larger than 200 km^2 (area for 50-60 animals). Next step was to delineate corridors using least cost path modelling, which was prepared with the usage of different barrier cost surfaces (CS 0, 100, 200, 500, 1000). Further than only cost surface 0 and 100 were compared in the figure. Least cost paths were prepared between bison present home ranges and potential habitat as well. Different costs of dispersal distances were also tested.

Results

This study identified potential corridors between five European bison herds in the Carpathians. There were identified 36 connections between suitable habitat patches based on cost surfaces 100, 200, 500; 35 connections based on cost surface 1000 and 38 connections based on cost surface 0. It was stated that almost half of connections in the habitat network based on the CS100 were blocked by at least one total barrier, thus fully inhibiting dispersal along these connections. The largest blocks of continuous suitable habitat were found in the Eastern Carpathians in the Gorgany and Czornohora Mountains. One of the important finding was the fact that none of the present Ukrainian herd was released inside suitable habitat identified within the study. Another important areas identified to hosts suitable habitat were Rodna and Maramures Mountains in the eastern Romania, Fagaras Mountains in the southern Carpathians and areas in the Bieszczady and Bukovske Mountains. The different dispersal distance turned out to be significant factor for predicting connectivity estimates. Because of that fact, three areas being identified as well connected between each other with high probability of bison movement: ranges located close to the Polish–Slovak border, (two in the Bieszczady Mountains and one in the Bukovske Mountains), range of the Skole herd and range of the Bukovynska herd. On the opposite a weak connection exists between the Eastern Bieszczady herd and the Ukrainian Skole herd, despite the close proximity of these herds. The migration probability between ranges of two other Ukrainian herds (Skole and Bukovynska) is very low so they seem to be isolated from each other (see figs. 40, 41).

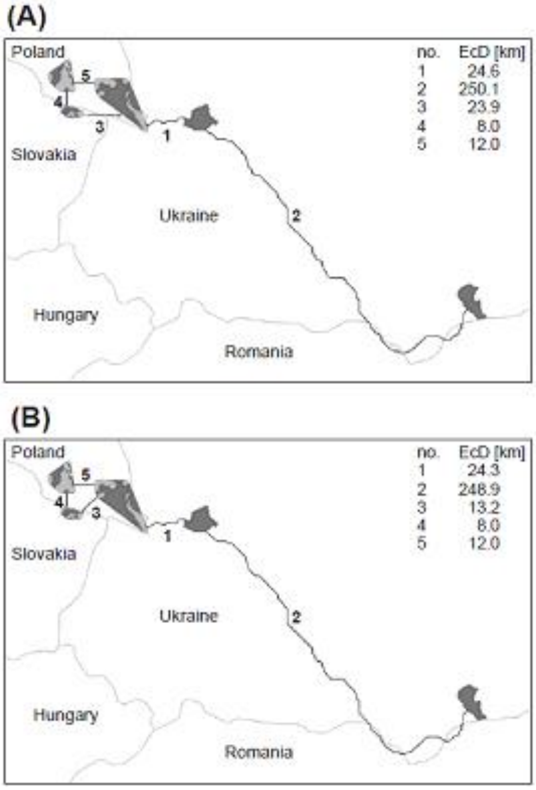


Figure 40. Ranges of existing bison herds in the Carpathian Mountains (light gray – minimum convex polygons, dark gray – expert-based bison herd range delineation) and potential connections: (A) based on different cost surfaces: CS100, CS200, CS500 and CS1000, (B) based on CS0; and their Euclidean distances (Ziółkowska et al. 2012).

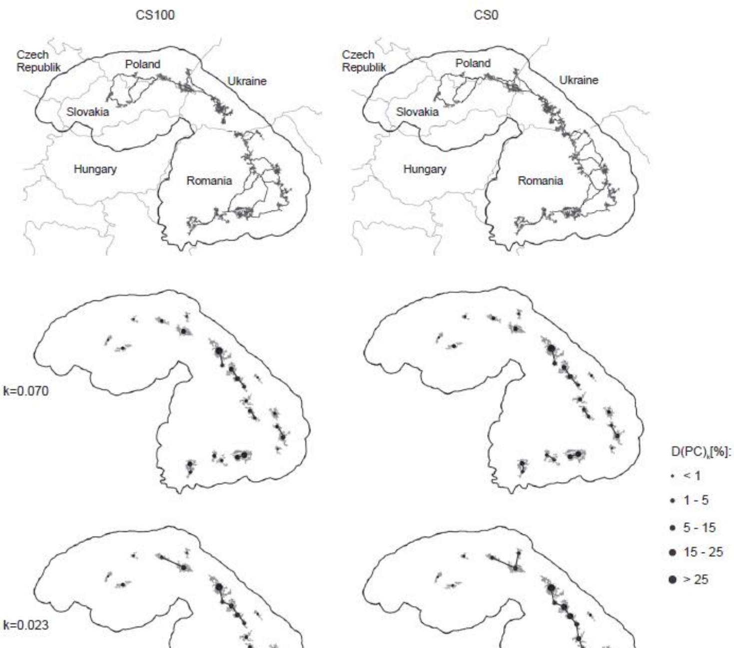


Figure 41. Potential connections between bison habitat patches for cost surfaces CS0/CS100 and two different k values, which is a cost distance-decay coefficient (Ziółkowska et al. 2012).

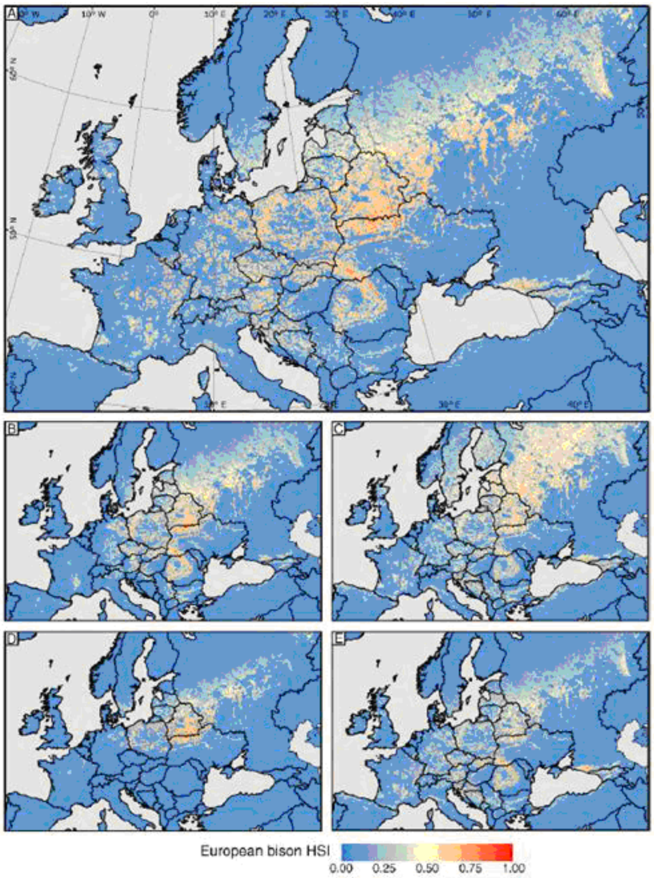


Figure 42. Map predicting potential European bison habitat in Europe (Kuemmerle et al. 2011).

2.5.2. Mapping conservation areas for carnivores in the Carpathian Mountains

General overview

The phd thesis of Valeria Salvatori gives a comprehensive overview to habitats suitable for large mammals in the Carpathian area. The habitat potentially suitable for bear, lynx and wolf was modelled using GIS predictive methods.

Project methodology

All data were adjusted for four following Carpathian countries: Slovakia, Ukraine, Poland and Romania. All GIS layers were transformed into the UTM WGS84 projection system.

The following variables were selected as input for the environmental suitability classification: vegetation type, altitude and human disturbance (human settlements and roads). Terrain roughness wasn't used; the altitude data were used in the form of a digital elevation model and expressed as continuous values.

Vegetation type was expressed in the form of land cover classes originated from Corine Land Cover (CLC) and merged from 36 categories present in the area into following seven categories: urban areas, roads, agriculture, forest, grassland, barren land and water. These categories were divided according to large carnivores and prey species ecological demands.

Data describing altitude (Digital elevation model) were derived from isopleths for Slovakia, Romania and Ukraine and standardized to match country lines and coordinate projection. The cell size of the layer was set to that of CLC grid. There were difficulties in obtaining altitudinal data for Poland. Due to this fact it was decided to do two separate analyses, first for Poland only without altitude data and second for the rest of the Carpathians with layer derived from isopleths.

Another crucial data source used has been data on large carnivore's occurrence. The input data were mainly transformed from tourist and sketched maps into GIS point layer. Exact radio-telemetry data were obtained only from Poland and Slovakia. Romanian data on carnivore's locations from 27 regions were digitized from forestry maps. Final GIS layer contained 234 findings for bear, 258 findings for lynx and 224 findings for wolf. After that the circular moving window method (with the diameter of a size equal of the home range) was applied to gain raster layer with the information about species perception of the space. The raster image was reclassified by adding values representing the proportion of given factor (e.g. human disturbance) within the moving window.

Finally, the Mahalanobis distance, a multivariate technique was used to measure the distance of a single multivariate observation from the centroid of its multivariate population. This means that the Mahalanobis distance was used as a proxy for environmental suitability for large carnivores. Following this procedure the mean and standard deviation (SD) of the Mahalanobis distance values at the large carnivore locations were calculated and used for the slicing process that resulted in establishing 7 classes of habitat suitability.

Results

The main objective of the present study was to produce maps that showed the geographical distribution of suitable areas for the conservation of large carnivores (bear, lynx and wolf) in the Carpathian Ecoregion. The bear distribution was predicted over mountainous areas with the occurrence no lower than 200 m a.s.l. Mureş river valley was identified as a main natural migration barrier to central part of Bihor massif, which is more or less isolated (fig. 43). The area with the highest suitability for the bear was estimated to 36 384 km^2 in the whole Carpathians.

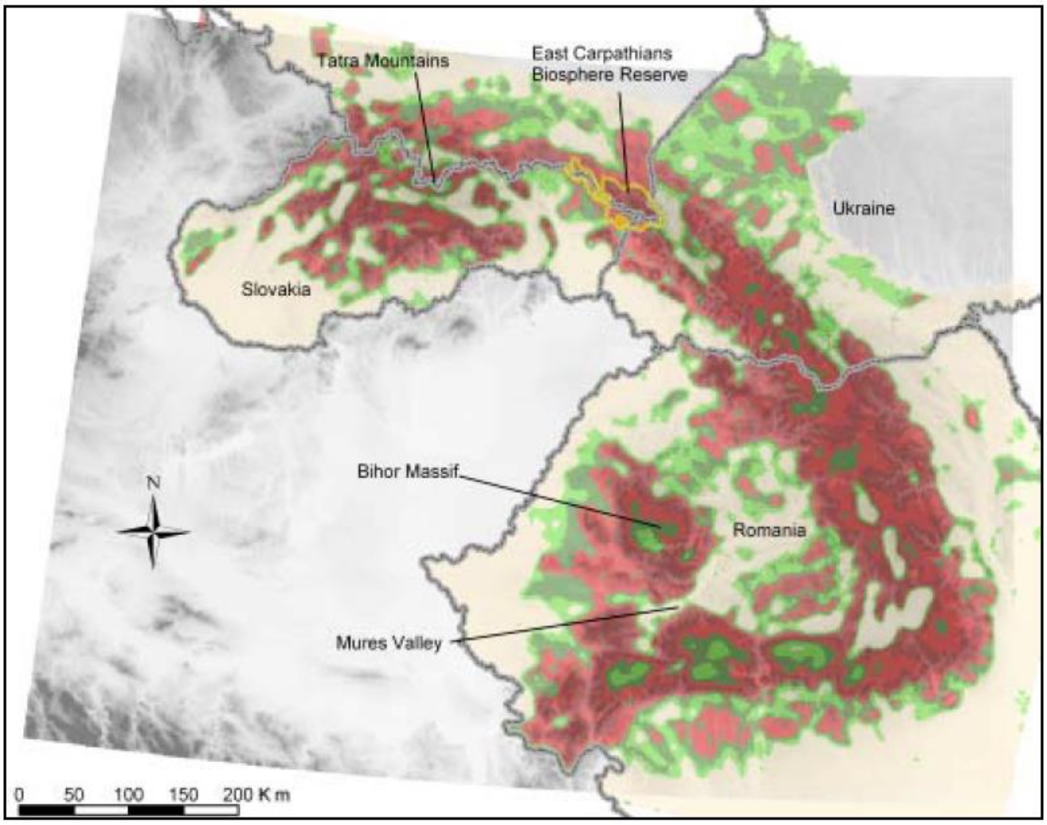


Figure 43. The habitat suitability map for the Brown bear (*Ursus arctos*) in the Carpathians.

The Lynx potential distribution was estimated to nearly half of the Carpathian region (fig. 44). Two most suitable classes were located in Romania and Slovakia. Two best suitable classes cover 58 % of the whole Carpathians.

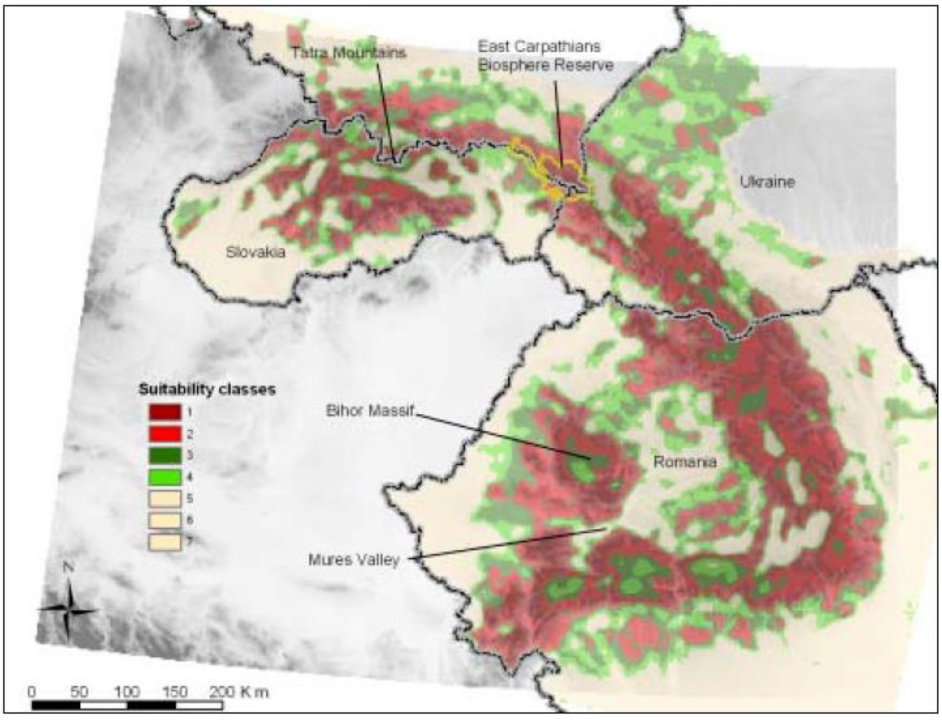


Figure 44. The habitat suitability map for the European lynx (*Lynx lynx*) in the Carpathians.

The first and second suitability classes of wolf habitat cover areas of 124 056 km^2 that is 65 % of the Carpathians (fig. 45). Only 14 % of Carpathians is not suitable. It is especially due to wolf broad ecological niche which is able to utilize during the migration.

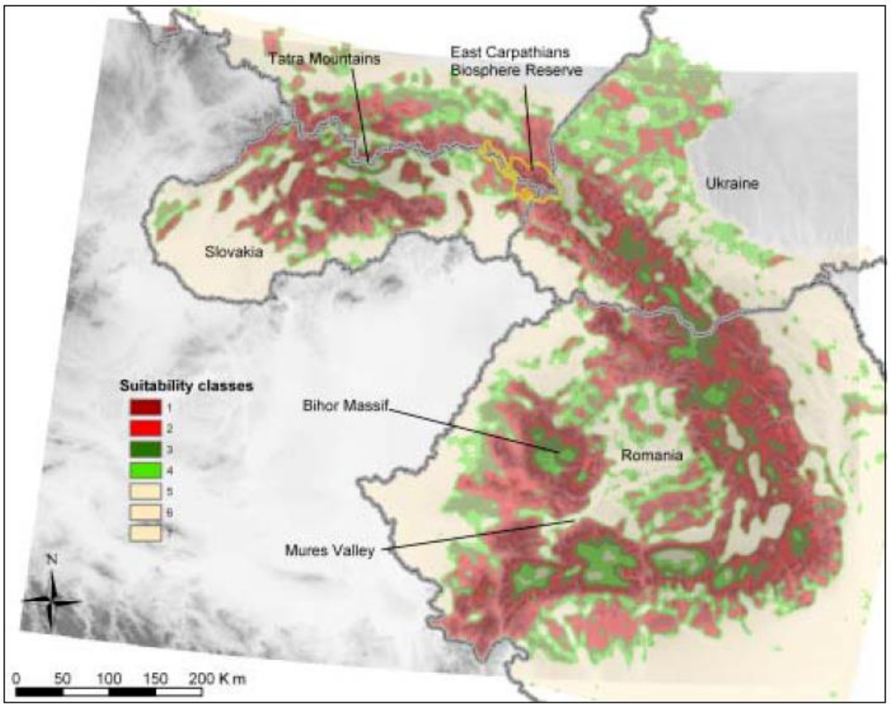


Figure 45. The habitat suitability map for Wolf (*Canis lupus*) in the Carpathians.

2.5.3. Romania

2.5.3.1. Identification and assessment of the potential movement routes for European bison in the North-East of Romania

General overview

The author focused on identifying possible migration routes for European bison (*Bison bonasus*) from Vânători Neamt Nature Park to other five neighbouring parks. One herd of about five animals is planned to be reintroduced to Chitele area in Vanatori Neamt Park. This study took into account simply landscape characteristics to define large scale areas called corridors, which are free from migration barriers and possibly suitable for movement of bison herd.

Project methodology

The methodology wasn't described into the detail. It is mentioned that Corine Land Cover data were used for evaluating the corridors. Other characteristics were the altitude and relative elevation that represented roughness of the terrain, which was calculated as a relative elevation per square km. No other thorough details such as corridor width were stated.

Results

This study depicts the possible situation that will favour migration of European bison in small scale area in NE Romania (fig. 46). Several possible corridors were proposed from Vânători Neamt Nature Park connecting other five protected parks: Călimani, Ceahlău, Cheile Bicazului-Hășmaș, Rodnei Mountains and Maramureș Mountains, that are from 55 to 140 km far from European bison releasing area. Main migration barriers and threats within identified corridors were described. This includes mainly rivers, national roads and settlements. The corridor heading towards Rodnei Mountains was identified as the most suitable for bison movement. The biggest disadvantage of this study is the lack of detailed methodology that wasn't described into detail.

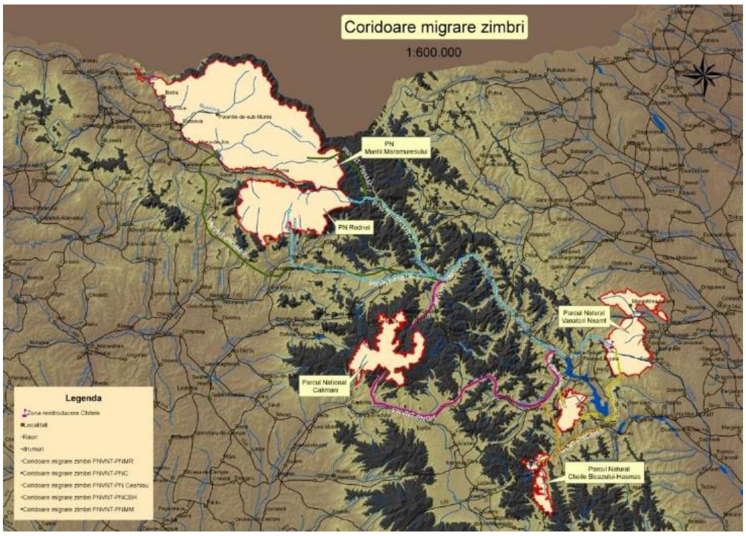


Figure 46. Map of potential corridors for European bison movement in NE of Romania.

2.5.4. Ukraine

2.5.4.1. Creation of ecological corridors in Ukraine

General overview

Three institutions have cooperated on this study: State agency for protected areas of the Ministry of Environmental Protection of Ukraine, Altenburg & Wymenga Ecological Consultants and InterEcoCentre. Corridors were proposed in two regions: Turkivskyi eco-corridor between Skolivski Beskydy National park and Polish border and Bukovynskyi eco-corridor between Vyzhnytsky National park and Romanian border.

Project methodology

The Brown bear, European bison, Lynx and Wildcat were selected as umbrella species for corridor modelling in two pilot regions. Land use variables and topography assumed to be affecting biology of selected species were used such as: Land cover, global digital elevation model, hydrography, road and railway network, settlements. The Corine Land Cover dataset is not available for Ukraine so main classes of land cover according to Hostert et al. (2008) were used with additional merge of some categories: 1) coniferous forest, 2) mixed and broadleaved forest, 3) managed grassland + unmanaged grassland + succession areas and bare rocks, 4) dense and open settlements, 5) plough land (polygons initially classified as settlements beyond polygon limits) – plough land category was further reclassified using elevation and slope (pixels from settlements at elevation above 600 m or on slope over 5 degree were classified as grassland), 6) water bodies, 7) Railways, 8) Highways, 9) Main roads and 10) Secondary roads.

Final dataset that was prepared for corridor modelling in GIS interface contained: 1) 10 land cover classes, 2) Forest / open area ratio within 250 m radius (%), altitude, relative elevation (terrain roughness) within 250 m radius (m) and human proximity.
The land cover suitability values of 10 main classes for each four umbrella species were established by the expert's opinion (so called restrictive values with the score 1-100). The same scoring based on expert opinion was undertaken also for forest / open area ratio, suitability of altitude, suitability of roughness. After that, the integral GIS modelling of the habitat suitability was done using five geo-datasets comprising land cover classes, forest / open area ratio, altitudinal belts, terrain roughness and human proximity, using weighted additive overlay procedure. This procedure was repeated for each species. The bison was assumed to be the least sensitive to human presence, the Lynx the most on the opposite.
The proper corridor delineation was processed using ArcGIS software and its extension Corridor Designer. The separate corridor was modelled for each species. Habitat suitability threshold score was defined in order to distinguish between breeding and non breeding population patches (core areas / stepping stones).

Results

Final maps were drafted manually, taking into consideration modelled corridors and expert field experiences. In the final step the verification took place in the field with the aim to check out the corridor bottlenecks and to map already existing barriers and to assess the land use with stakeholders and real connectivity.

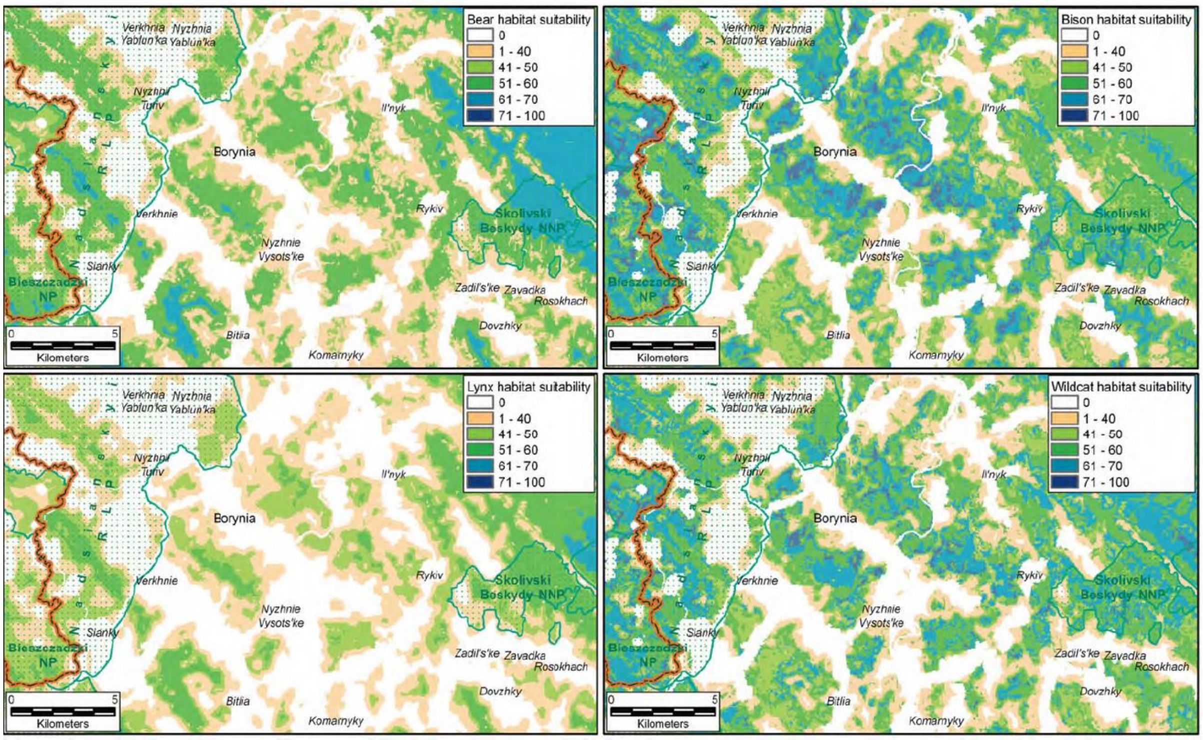


Figure 47. Habitat suitability classification of the Turkivskyi corridor area for four umbrella species (Deodatus & Protsenko 2010).

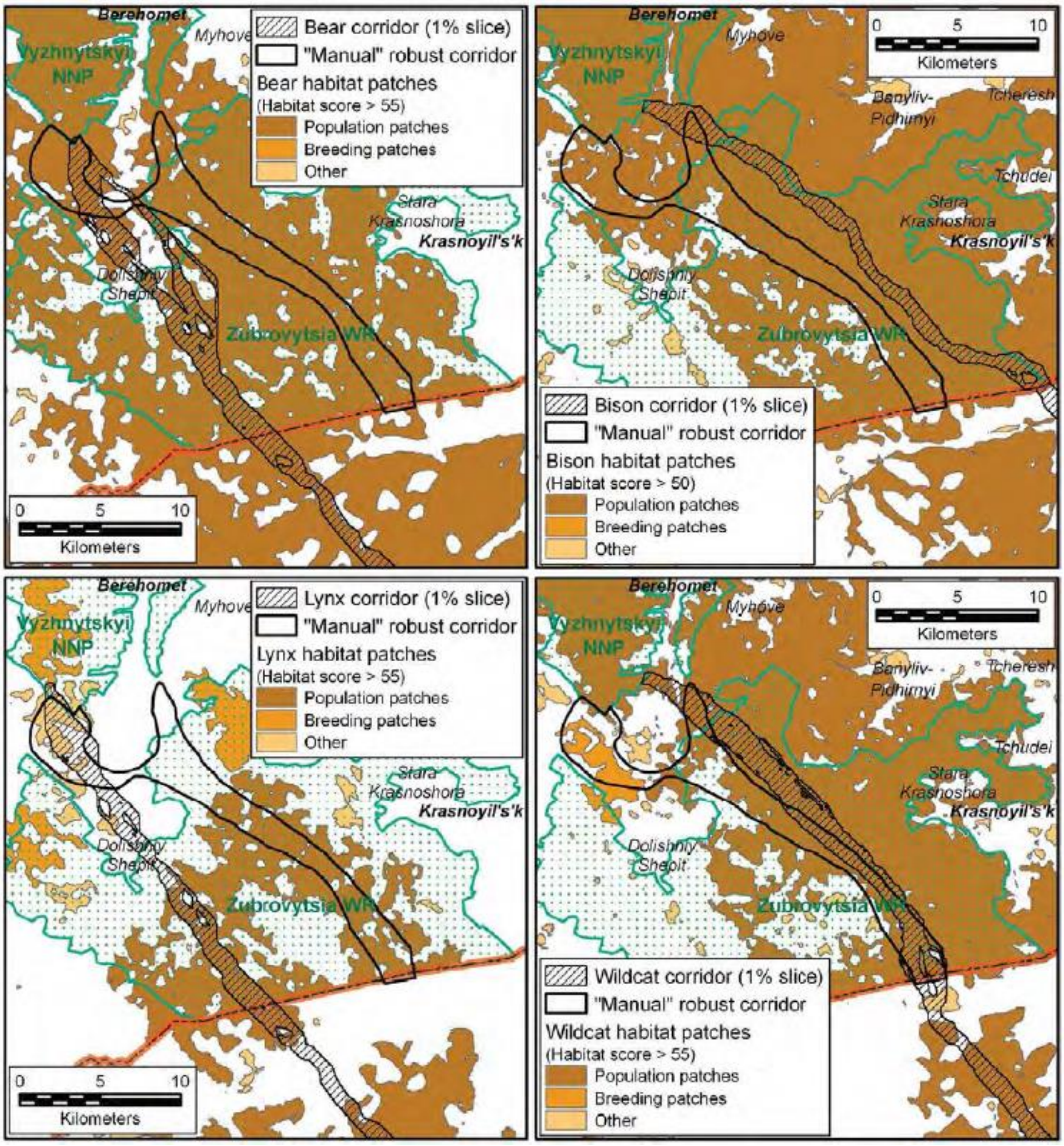


Figure 48. Corridor models delineated by Corridor designer software for four umbrella species in the Turkivskyi corridor area. Preliminary robust corridors were also drawn manually (Deodatus and Protsenko 2010).

2.5.5. Bulgaria

2.5.5.1. Restoring ecological networks across transport corridors in Bulgaria. Identification of bottleneck locations and practical solutions

General overview

This study funded by the Dutch Ministry of Agriculture and carried out by Alterra in cooperation with the Bulgarian Academy of Sciences and seven other project partners had the aim to identify bottleneck (conflict) sites on existing and newly proposed roads, highways and railways for 12 selected target species: bear, wolf, red deer, wildcat, pine marten, otter, marbled polecat, souslik, aesculapian snake, blotched snake, tortoises and common toad (Alterra 2008). Where needed the mitigation measures were proposed.

Project methodology

Two methods were combined when searching for bottlenecks. GIS model LARCH for viability analysis of the population was performed using expert based criteria. This model was used in two different situations – with or without mitigated road / railroad barriers.
Second, the experts were asked to identify problematic sections of the transport network for selected animal species based on local experience. The resulting model was afterwards re-evaluated by experts twice. Each bottleneck site was categorized into one ecological benefit class on the scale 1 to 5 (e.g. class 1-3 refers to immediate positive shifts in population viability due to defragmentation measures). Moreover each site was assessed again by experts as highly urgent or less urgent for mitigation measures. Less urgent site for mitigation was identified when more than 75% of the species habitat supported for population viability. The bottleneck critical sites were prioritized according to number of identified species. The more species were assigned to critical site the more priority the site gained.

Results

The analyses resulted in identification of 283 critical bottleneck sites (130 on main roads and 125 on regional roads) from which 30 % were classified as high priority site. Altogether 67 sites for the bear were identified as critical with about 40 % of current population still regarded as highly viable. Most bottlenecks can be found in central and southwestern Bulgaria. The most important sites for mitigation were in Struma river valley and between central Balkan and Rila mountain ridges (fig. 49). Only 25 % of wolf population is regarded as highly viable (fig. 50) with 80 sites identified as bottlenecks. The sites for mitigation are found also in central and southwestern Bulgaria, on road between Rila and Vitosha and between Eastern Rhodopes and southeastern part of the country. The number of bottleneck sites for the red deer was identified to be 71, which are found mainly in western part of the country. The great portion (75 %) of the population was assessed as highly viable (fig. 51). Regrettably, the present wildcat population was identified as not viable (fig. 52). The analyses have found 52 bottleneck sites especially in western part of the country that to the large extent overlap with sites for bear and wolf. Other region for mitigation was located along the Black Sea coast.

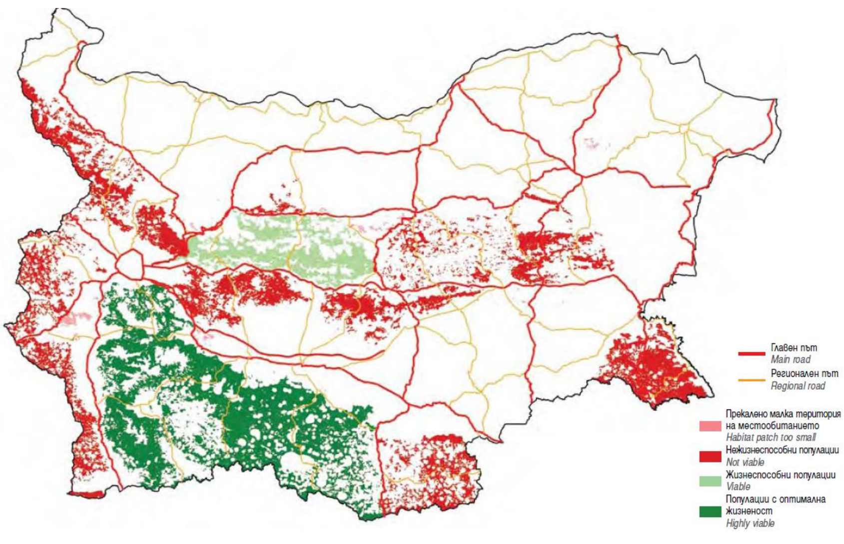


Figure 49. Population viability of bear before road mitigation.

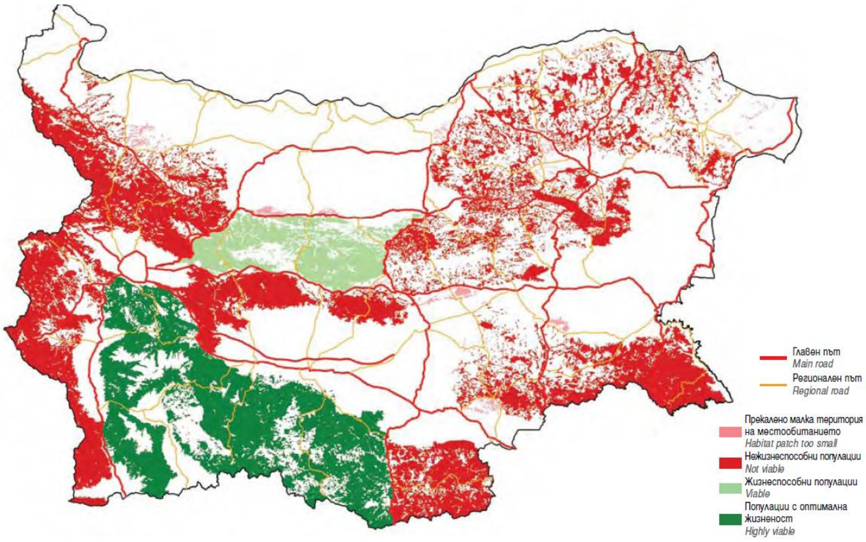


Figure 50. Population viability of wolf before road mitigation.

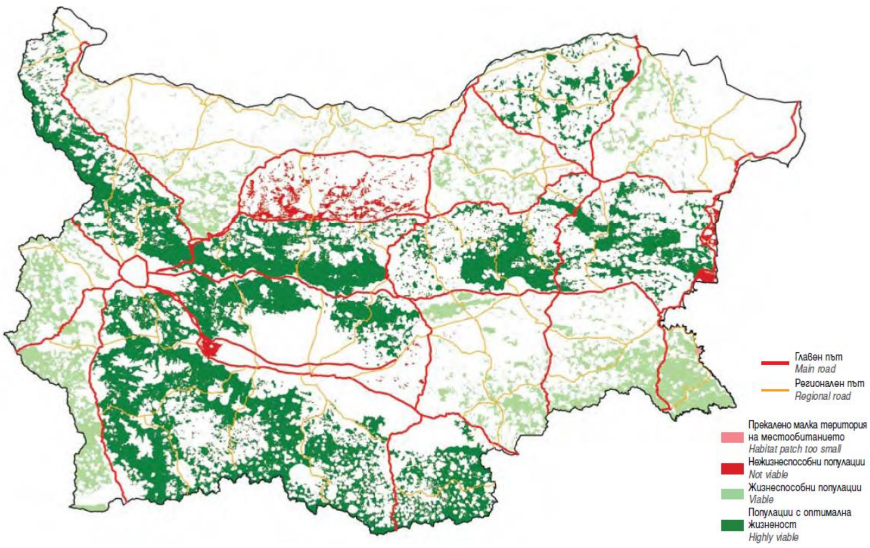


Figure 51. Population viability of red deer before road mitigation.

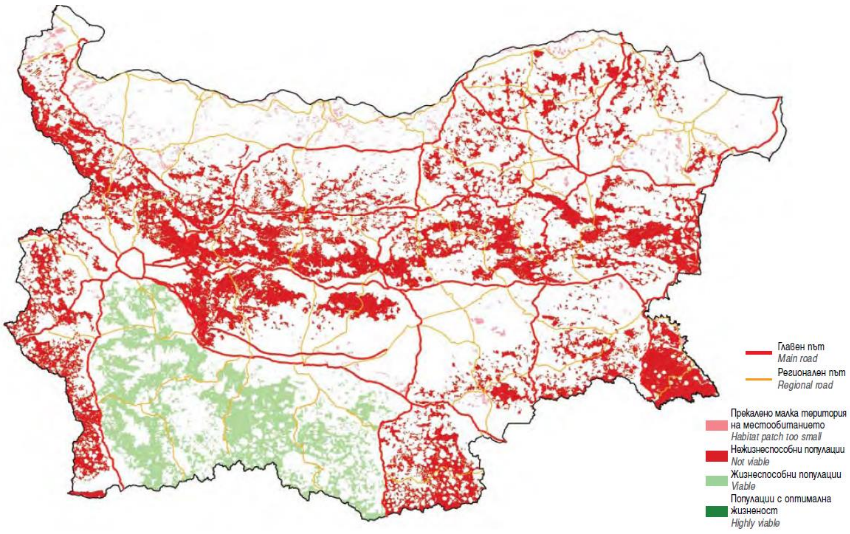


Figure 52. Population viability of wildcat before road mitigation.

2.5.5.2. Application of GIS Model for Assessment of the Habitat Quality and Prediction of the Potential Distribution of Carnivorous Species in Local Scale - Lynx (*Lynx lynx* L.) in the Strandzha Mountain as an Example

General overview

The study presents habitat suitability map for potential distribution of the Lynx in the south-eastern part of Bulgarian Strandzha Mountains.

Project methodology

GIS habitat suitability model was developed using deductive approach that used habitat scores taken from neighbouring countries and expert opinion due to lack of the Lynx presence or absence data. Final model was validated by field research aiming to gather data on Lynx presence (searching for tracks). The second part of this work was to question local policeman, shepherds, foresters and hunters about possible Lynx presence in the area.
Input variables into the HSM were Corine land cover (6 categories: forest, grass and shrubs, agriculture zones, water, urban zones, bare areas plus roads from Bulgarian database); digital elevation model and spring counts of red deer, fallow deer, roe deer, wild boar, hare and pheasants as a proxy for prey base.
The GIS layers were analyzed altogether with weighted overlay function and resulted raster was processed with nearest neighbourhood function, mean, circle of size 18 pixels to simulate Lynx perception of space. This window was equal to the average home range size (93,6 km^2).

Results

The results of this study are shown in the fig. 53. The whole territory of Strandza mountain was divided into five habitat suitability classes. First and second most suitable class encompasses nearly half 49,6 % of the study area which is 575,1 km^2. The southern part turned out to be well connected with the neighbouring territory in the Turkey.

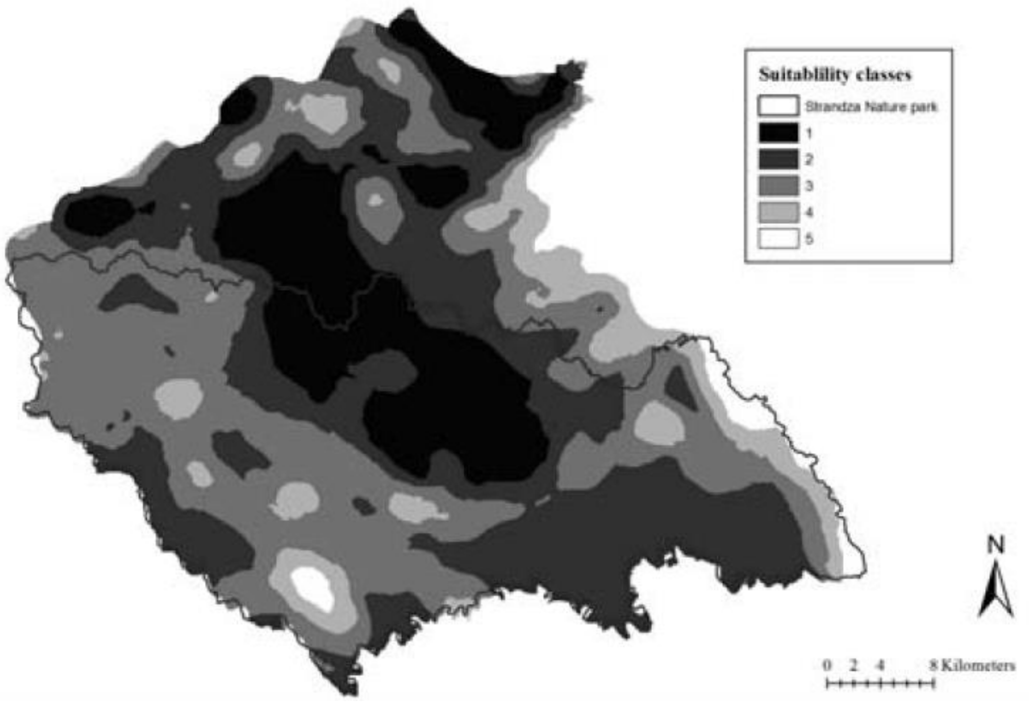


Figure 53. Habitat suitability map for the Lynx in the Strandza mountains.

2.6. Northern Europe

2.6.1. Latvia and Lithuania

2.6.1.1. Ecological network in Latvia and Lithuania

General overview

The comprehensive report written by Sepp & Kaasik in 2002 summarizes the status and development of ecological networks in the Baltic States. The principle of ecological network planning is very similar among the countries. The broad based approach was used for defining areas that should be included into the network. Basically, all protected areas designated according to the national or international legislation, that hosts endangered fauna and flora, were incorporated into the ecological network proposal.

Project methodology

The designation of ecological networks and their structural elements was based on GIS inspection of existing digital databases by identification areas from thematic map overlapping.

Estonian datasets were follows:

Valuable bird areas, Important Bird Areas, Ramsar sites, valuable wetlands I-III category, Corine biotope sites, map of heritage conservation, forest conservation area network, map of valuable landscapes, hydrological net, belt around inland waters, salmon rivers, valuable meadow communities, key biotopes of valuable forests, basic map, topographic map, information on particularly protected species and biodiversity important habitat areas, Corine land cover and spatial planning maps.

Latvian datasets for planning of national and international level were follows:

Landscape map, specially protected nature territories, Ramsar sites, map of HELCOM BSPA, Important Bird Areas, Corine biotopes sites, protected belt around the Baltic sea / Riga gulf, hydrological net, belt around inland waters, salmon rivers, valuable wetlands, information on particularly protected species and biodiversity important habitat areas, Corine Land Cover, basic map, topographic map.

Lithuanian datasets were follows:

Base maps in different scales, forest site maps, map of relief, protected areas, Corine Land Cover, nature frame maps, wetland and peatland maps (Sepp & Kaasik 2002).

Results

Latvian ecological network is consisted of relatively broad areas divided into following categories (fig. 54): Biocentres of national and international level and their core areas, corridors of national and international level, stepping stones, Nature development areas located in the biocentres and corridors.

Lithuanian ecological network is consisted also of large scale areas divided into following categories (fig. 55): National and European core areas and biocentres, national and international corridors, buffer zones, stepping stones and renaturalization zones.

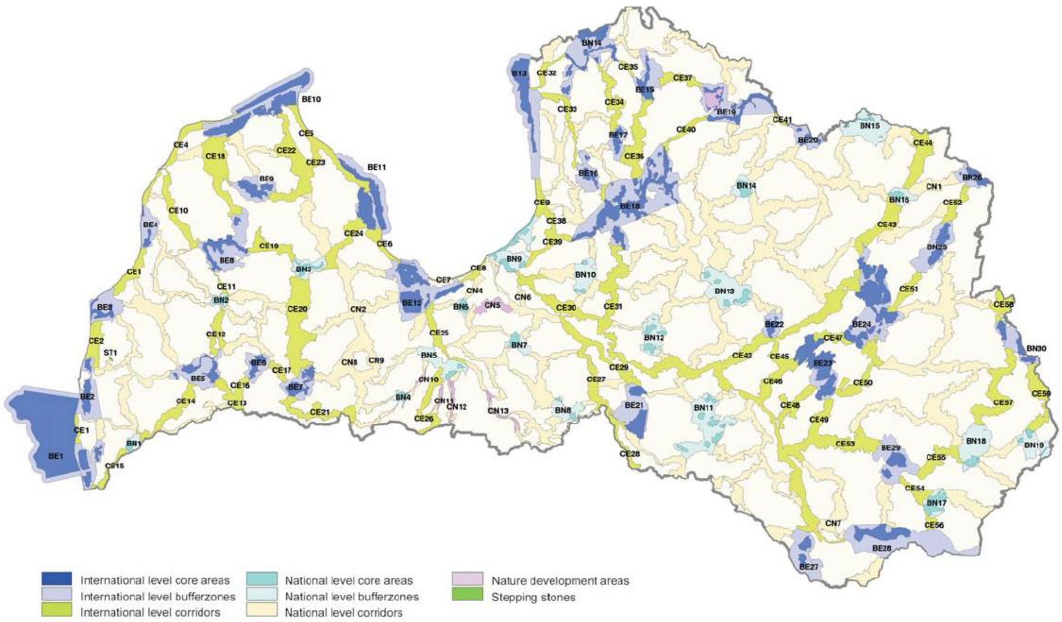


Figure 54. Map of the ecological network in Latvia.

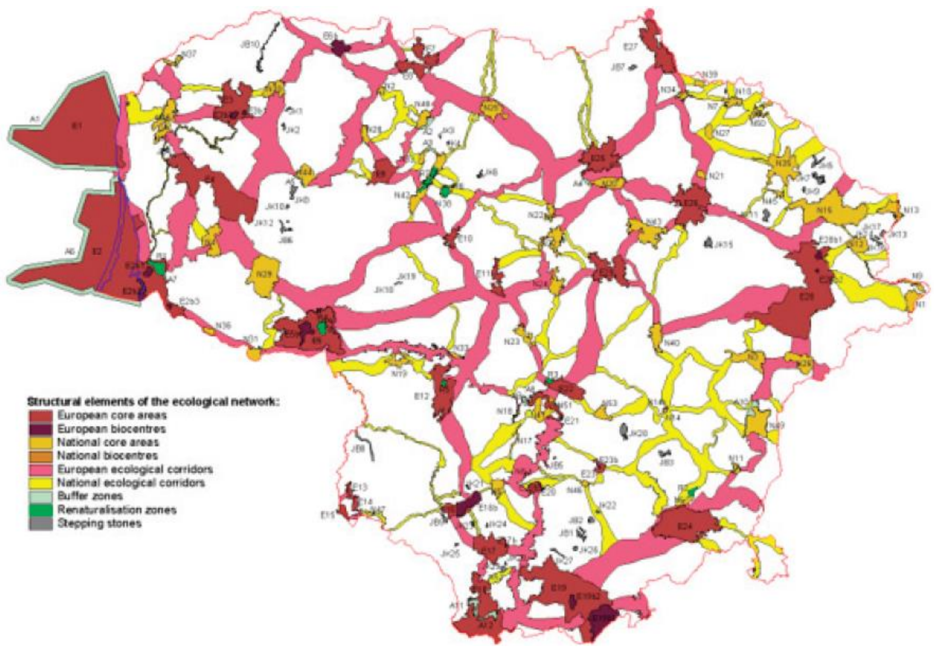


Figure 55. Map of the ecological network in the Lithuania.

2.6.2. Estonia

2.6.2.1. Distribution of the Green Network of Estonia

General overview

One of the goals of the Estonian Green Network was to spatially incorporate the Natura 2000 sites as areas of European importance. Results demonstrated that in 10 of the 15 counties, this goal can be considered to have been achieved, as a minimum of 95% of the Natura 2000 sites within these counties have been incorporated into the Green Network. The Green Network of Estonia is supposed to complement the network of protected areas, combining them into an integrated spatial system of natural and semi-natural areas. One of the goals mentioned in the methodology was to incorporate all the Natura 2000 Network sites as areas of European importance. The legal process of the county thematic plans of the GreenNetwork started in Estonia in 1999.

Methodology

One single layer was created using data originating from all county governments (15 countries). The data from different counties varied greatly in terms of structure and detail (levels of corridors etc.). Arranging data to cover the whole Estonia was necessary and more precise data from some counties were not included. The layer of the Estonian Green Network was composed in the GIS programme MapInfo Professional.

Land use data were inspected and assessed on the Estonian Base Maps 1:50 000 and 1: 10 000. The main selected criterion for inclusion to the network was “forest” class that contained three basic map classes: forest, young forest and bushes. The class “field” incorporated three basic map classes: grassland, field, garden. The class “yard” contained yard areas and buildings.

Results

The ecological network concept in Estonia is regarded to integrate land use with landscape functions. Selected areas cover at about 50 % of the Estonian territory. The model was developed especially for the purpose of incorporating into spatial planning processes on regional as well as national level. One of the main goals is to establish network of protected and natural areas, promote the protection outside protected areas and to protect migration possibilities through the landscape. Suitable national core areas were selected according to the size and conservation value. The Natura 2000 sites were also included to the map, but specific corridors weren´t proposed or described (see fig. 56).

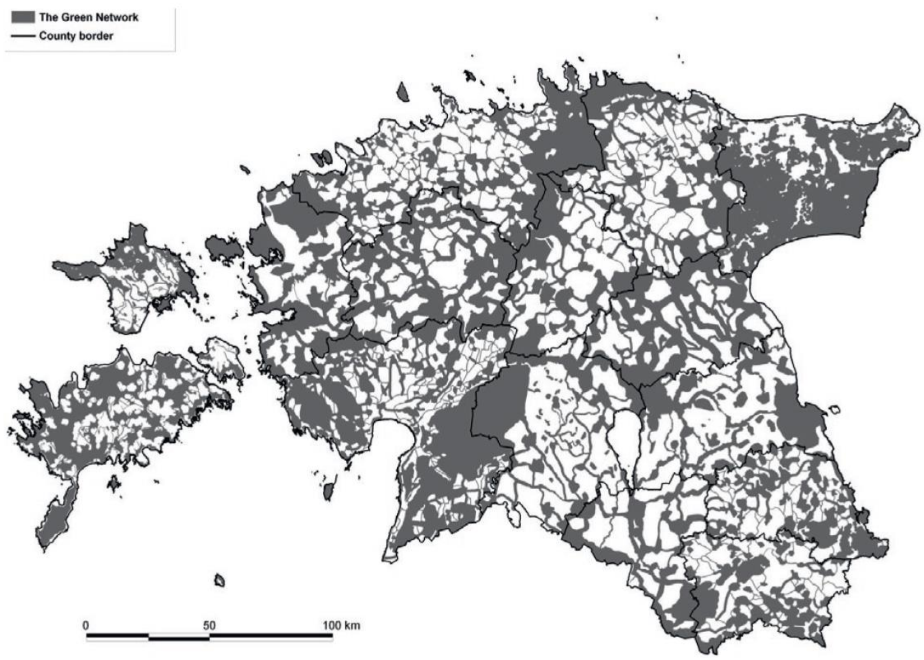


Figure 56. The ecological network in Estonia (Raet et al. 2010).

2.7. Analysis of methods used in ecological network planning

Species survival is dependent on habitat quality, food availability and for most species the ability and opportunity to move through the landscape. The industrialization of agriculture, change of land use, building of transportation infrastructure and urban areas has caused a serious fragmentation of natural areas, deterioration of ecosystems, loss of natural habitats, significant changes to their structure and functions and consequently extinction of species.

There is obviously a lack of knowledge, and limited time and funding for creating such knowledge, on species behaviour in landscape. Since species dispersal and survival is hardly predictable, and the facilitation of one species dispersal might not be sufficient for dispersal of other species, scientific evaluation of impact of landscape changes on biodiversity is very challenging. Diversity of species using the respective ecological network therefore strongly depends on an overall area and quality of habitat types in core areas, stepping-stones and the length, width and structure of interconnecting corridors.

Planning of ecological network includes several phases:

1. Species selection

The first crucial step is a decision for which target species is the network being planned. The right choice would be to select such umbrella species that will also cover ecological demands of wider spectrum ecologically similar species. Usually, major groups of forest species, aquatic species, and grassland species are being distinguished.

The landscape fragmentation processes in Europe mostly affect groups of species restricted to the well-preserved natural environment (wildlife), those with great requirements on the size of their home range, or regularly or occasionally migrating species. In this study we focus on ecological networks created for forest species, mainly large carnivores (Bear, Wolf and Lynx) and large ungulates (Red Deer, Eurasian Elk and Eurasian Bison).

These species have all very similar environmental demands, i.e. they are restricted to vast forested areas with minimum human disturbances. Long-distance migration is inseparable part of their biology. In many cases, this migration may involve dispersing subadults that are being pushed away from their parents' home ranges, but we may also record vagrancy of adult animals. Animals can migrate tens or even hundreds of kilometres.

Considering the above-mentioned facts, large carnivores and large ungulates provide ideal umbrella species for the projects focused on preservation and restoration of the landscape connectivity. Except the Red Deer and Eurasian Elk, these species are rare and strictly protected under Habitats Directive and member states' national legislative. The high requirements of all the mentioned species as to the size and quality of their habitat and their biology relate to long-distance migration. Their high requirements on the quality and structure of the habitat cover the demands of a number of other species restricted to a well-preserved forest environment (e.g. Red Fox, Badger, Marten).

In the Alpine area and Italy, the Brown Bear has been the most used focal species in forest ecological network planning. It is mainly because its conservation importance for Alpine countries, Italy and Slovenia. Recently re-introduced population, successfully growing, is the centre of concern of intensive research and monitoring. These provide high quality species occurrence data, which can be used for habitat modelling and corridor identification. Brown Bear has also been often used as a focal species in ecological networks in Carpathians (Romania, Ukraine, Czech Rep.), that host important Bear population (approx. population size: 8 100 animals) and in Spain (Linnell et al. 2007).

The Grey Wolf has been selected as a main focal species mainly for the areas with its significant populations: Italy (500–800 animals), Iberian Peninsula (2 500 animals) and Baltic countries (3 600 animals) (Linnell et al. 2007). In other areas, when present, it has usually been selected as one of the focal species for its conservation importance.

The Eurasian Lynx is an important focal species mainly in ecological networks of Central and Western Europe (Austria, Czech Rep., France, Germany) where other large carnivores are absent or present only occasionally (Linnell et al. 2007). Here it is a centre of a number of conservation efforts, including intensive population monitoring that provides data on species habitat preferences and migration abilities.

Red deer, Roe deer and Chamois are preferred focal species in the countries with long hunting/wildlife management traditions when there is a sound knowledge on the species biology and ecology and management of the populations is being accepted as a necessary part of biodiversity conservation (Alpine countries, Germany). Also, Red deer is an important focal species in ecological networks of Western Europe where other large mammals are absent.

In some European states, ecological networks or single corridors has been proposed also for the European Bison, European Elk and Wildcat. Although rare, these attractive species are serving as a flagship species for the connectivity of forest ecosystems and forested protected areas.

2. Selection of area, scale and type of network

Second step in ecological network planning is selection of area of interest and the scale on which the network will be proposed, this resulting in the network structure.

In most studies the **area of interest** has been defined either by geography (single or more forested areas/mountain ranges) or by its conservation importance (Natura 2000 sites or national protected areas designated for the forest species) or politically (e.g. area of one or more European states, area of Framework Convention on the Protection and Sustainable Development of the Carpathians etc.).

The scale of the study must be selected according to the biology of the focal species. The bigger the animal, the bigger its home ranges and therefore the larger core areas are necessary to host at least small viable population. Also, the length and width of corridors must be adjusted to species migration demands and its sensitivity to human disturbances.

Ecological networks for forest mammals are delineated on three basic scales:

- **Regional level:** the smallest scale, usually being used when planning an ecological network for medium sized forest mammals (wildcat, wild boar, red fox, marten, badger, polecat) or birds. It is also used when the distribution area of a species is restricted to a certain isolated area (region) for which it is sensible to prepare specific ecological network. Example of regional level network is an ecological network proposed for medium sized mammals (*Capreolus capreolus*, *Sus scrofa*, *Cervus elaphus*, *Martes martes*, *Felis sylvestris*, *Genetta ghetto*, *Mustela putorius*, *Meles meles*, *Martes foina*) in Basque, Spain (fig. 13)

- **National level:** the intermediate scale, used mainly when designing ecological network for large carnivores and ungulates within one country. E.g. national ecological network in Poland has been delineated preferentially for Grey Wolf to facilitate its large distance migration from source Eastern populations to the newly originating Western ones. Following these migration routes, wolves have to overcome a number of national highways (fig. 29).

- **Supranational/European level:** although the majority of large carnivores' populations in Europe are shared by more than one country (Linnell et al. 2007), the proposals of supranational ecological networks are more an exception among the studies reviewed. The good example of a transnational study is a proposal of ecological network connecting Cantabrian Range, Pyrenees, Massif Central and Alps (fig. 16).

Also, the structure of proposed ecological network can vary significantly, according to the geography of the area of interest and species habitat needs:

- **The simplest case** is a single corridor interconnecting two core areas. This approach has been applied e.g. in the proposal of Alpine-Carpathian corridor (fig. 39). Both core areas are forested mountain ranges hosting significant large carnivores' population, divided by less forested, lowland urban areas that create great barrier for

LC migration. Therefore, the countries of Austria and Slovakia joined in a common project to map, propose and implement the protection of a single major migration corridor for large mammals.

- **The more complex solution** is an ecological network consisting of more core areas and corridors. An example of such approach is proposed ecological network in Lombardy (Bani et.al. 2002, fig. 3). The authors identified core areas of given size (larger than 25 ha for birds and 50 ha for small forest carnivores) and these connected by the corridors with the best available habitat. Here no stepping-stones were proposed to facilitate movement of species.

- **The most complex solution** is delineation of ecological network consisting of core areas, stepping stones and corridors. Although this is methodologically most suitable approach, it is not so often used. This is mainly because the resolution between core areas with permanent species occurrence and stepping stones with only temporary occurrence can be very intricate. However, there are examples of such approach, e.g. ecological network for forest animals in Germany (fig. 27).

3. Theoretical modelling

When the basic inputs are known, the next step in the network preparation is identification of the key network components (core areas, stepping stones, corridors) in the landscape of given area. For this phase, a variety of statistical and GIS instruments are being used.

The widely used method for ecological network planning is habitat suitability modelling (HSM), which is useful for predicting areas with potentially usable environment for permanent (core areas) or temporal occurrence (stepping stones) of selected species. Method of habitat suitability modelling requires computer based GIS software environment, which has often high demands on data harmonization. The quality and predictability of the final output (habitat model) is fully dependent on the resolution, quantity and relevance of up to date data that will enter the analyses.

Basic data used for habitat suitability modelling (HSM):

The preparation of environmental variables is, to a certain extent, limited also by the availability of the required information. While some of the principal factors of the natural and anthropogenic impact can be expressed easily, a number of other environmental variables can be neither conveyed as data nor visualized in the GIS environment. Two methods for HSM modelling has been broadly applied: 1) The Ecological Niche Factor Analysis (ENFA) - this multivariate analysis uses only presence data in order to compute a habitat suitability model by comparing the environmental niche of the species to the environmental characteristics of the entire study area; 2) The Mahalanobis distance incorporated in extension Land change modeller for ArcGIS. The main results from HSM maps should be identification of core areas and stepping stones for selected species.

A) species occurrence data

The very good knowledge about species occurrence and permanent distribution over landscape is crucial requirement especially for further model validation (e.g. moving window method – could be used). The best option would be to collect GPS telemetry data, which will provide precise localized data, describing species utilization of the landscape during longer time span. Another useful method is mark – capture – recapture or data from long term monitoring, which has same methodology over years. The importance of recording absence data should be highlighted. All data should be provided in the ESRI shapefile form and georeferenced into common projected coordinate system. Nevertheless, there has been often lack or complete absence of data on species occurrence and distribution in the reviewed studies and projects. This lack of the data is often substituted by extraction of literature data and expert based opinion, which is subjective and not always accurate.

In most European countries, the mapping of biotic and abiotic resources and conditions has been carried out and the results have been used in different ways and different scales as criteria for location of the ecological network. Monitoring of particular species and its habitats in core areas is basic requirement that is fulfilled in several countries. However, there is generally lack of information on forest species occurrence in non-forested areas. This includes stepping stones: patches of suitable habitat that does not provide enough space and resources for species reproduction, but play an important role in facilitation of migration. There is also need to learn more about the behaviour of the species during migration and answer how they approach and perceive the barriers.

B) environmental and landscape variables that that are used as facilitators of migration:

1) Elevation – expressed as a mean elevation above sea level in individual cells
2) Slope and aspect
3) Vertical heterogeneity – expressed as a standard deviation in elevation within individual cells of a regular grid. (e.g. this variable could predict the occurrence of Lynx better than elevation).

4) Corine Land Cover (CLC) and variables derived from this data source

Almost every study utilized this data source for creating merged CLC categories such as: forest, agricultural land, area influenced by human, meadows and pastures or water bodies. However, CLC has been mapped with the resolution accuracy 25 ha. This is the reason why the small scale woodlands, linear hedgerows or riparian vegetation along river banks and water bodies, which animals use for migration through non-forested areas, were in some cases not included into forest variable. This fact was partially compensated in some projects (e.g. Wildcat project 2.4.1.2.) by using federal topographic and cartographic maps, which has more precise data resolution. The usage of other map sources (orthophoto) should be highly recommended preferably when dealing with regional level, where more precise data could be available. However, on the national and supra-national level is the resolution of CLC sufficient to define core areas and stepping stones.

5) Nationally protected areas, Natura 2000 sites and other protected areas

6) Factors of potential landscape productivity

It would be worth to note that incorporation of variables such as food availability is dependent on various unpredictable factors, such as temperature, rainfalls etc. Anyway the use of variables like mast tree cover or wild ungulate presence or abundance will introduce another dimension useful for establishing core areas. Especially the estimation of ungulate abundance should be carefully considered and verified when preparing ecological network for large carnivores.

C) environmental and landscape variables that hinder migration of species (barriers):

1) distance from the forest: expressed as a Euclid distance of cells of a regular grid from the nearest forest complex (usually derived from the CLC database).

2) distance from agriculture areas

3) distance from settlements: expressed as a Euclid distance of individual cells from the nearest settlement (usually derived from the CLC database).

4) settlements: also commonly derived from CLC, categories are divided according to size of the settlement.

The buffer zone around the settlement has been sometimes introduced and is recommended in order to show existing human pressure on the landscape. Another factor associated to human disturbation is human population density that should be also used to better describe supposed negative human influence.

5) water bodies

The great importance should be paid to classify water reservoirs according to presence / absence of artificial banks.

6) transport infrastructure: commonly used datasets were roads and railroads.

Commonly used category for description of the impact of transport infrastructure on landscape permeability was road and railway density. Highways, main roads, dual lane roads, major primary and secondary roads were usually regarded. Unfortunately, some of the reviewed projects does not incorporated road variable into the habitat suitability model. This obvious lack should be consistently compensated by field verification of actual permeability of identified corridors' crossing with the road. Also, mitigation measures should be proposed to compensate barrier effect of roads. Moreover, different road categories weighted by traffic flow should be incorporated above the simple road / highway categories, into habitat suitability model.

7) other infrastructure

Generally, we miss the absence of incorporating other infrastructure occurring in the landscape, such as gas – pipelines and photovoltaic power stations (wind mills with respect to birds). These facilities are very often newly built on agricultural land and they are not included in the Corine land cover database.
Another problem is the lack of digitized source of data on fenced areas in agriculture landscape (pastures and vineyards). Also the present status of fenced sections of highways and main roads are not reported and the digital data are absent.
The locations of structures that support migration through roads (underpasses, overpasses, tubes), were not broadly used. This data source is fundamental and its incorporation into models should be required in further studies. This applies also to ski resorts, which can be regarded as a barrier in mountainous regions.

Corridor modelling:

The **Least cost paths** (LCP) method was broadly used for corridor modelling between selected core areas. Analyses are dependent on quality and quantity of variables that enter to HSM modelling. The LCP method should take into account combined costs for movement through the modelled landscape (values resulted often from ENFA) for different habitat types and barriers. In the next step, so-called connectivity points (the beginning and the end of modelled corridor) have to be selected within core areas or stepping stones.

Field verification:

After the LCP, the additional inspection of corridors on topographic maps (scale 1:10 000 or lower), LANDSAT satellite images, other orthophoto maps and forest maps is highly recommended. The map examination on lower scale will favour the possibility to locate objects with higher accuracy (e.g. free-standing buildings, linear vegetation and scattered bushes). The final corridor orientation and delimitation should be adjusted according to inspection of relevant barriers and supporting vegetation structures. Based on reviewed examples, the corridor width for large mammals ranged from 250 m (chap. 2.1.2.1.), through 500 – 1000 m (chapters 2.4.3.2., 2.4.3.4.) to 2000 m buffer zone with at least some scattered vegetation which was proposed for short distance corridor between parks (chap. 2.1.2.1.). The corridor width 250 m was proposed rather for smaller mammals, so the best recommended optimum for large mammals is 500 – 1000 m. The corridor area should not include urban areas. In such places the corridor area can be narrowed according to current spatial situation.

The final significant step is to verify actual migration permeability in the field, where main barrier sections were identified. Following barriers should be taken into account: highways and railways with high traffic volume (from 10 000 vehicles per day), large settlements and narrow bottlenecks between cities, wide rivers and water reservoirs and large agricultural areas (where the fenced plots can be expected).

In these identified corridors, activities like roads construction should always go with mitigation of their impacts on the landscape permeability according to proposed compensation measures (via EIA process).

2.7.1. SWOT analysis of methods used for ecological network delineation

A SWOT analysis is a subjective assessment of data which is organized by the SWOT format into a logical order that helps understanding, presentation, discussion and decision-making. The SWOT analysis headings provide a good framework for reviewing strategy, position and direction of a company or business proposition, or any other idea. The four dimensions of analysis: Strengths and Weaknesses (internal traits/factors); Opportunities and Threats (external factors) are an extension of a basic two heading list of pro's and con's. We have applied this method for simple assessment of different methods used for planning of ecological networks (see tables 1-4).

Table 1. SWOT of the method when habitat analysis is based on literature data.

Internal	**Strengths**	**Weaknesses**
	Exact method	Limited by quality and amount of literature data on species habitat preferences
	Objective	Unrealistic results when data from different geographical or climatic area used in the analysis (highlands vs. lowlands, forested Scandinavia vs. deforested Western Europe).
		Sensitive to data interpretation
		Dependent on the quality of geographical data available: some migration barriers needn't be identified and vice versa
External	**Opportunities**	**Threats**
	Easily repeatable	Lower acceptance of result by experts, since the analysis is not hard data based
	Cheap implementation	

Example	**Protected forest area network – a transnational case study from the Cantabrian Range to the Western Alps**

Table 2. SWOT of the method when habitat analysis is based on species occurrence data.

Internal	**Strengths**	**Weaknesses**
	Exact method	Limited by quality of species occurrence data
	Objective	Limited by amount of species occurrence data: two types of data needed: a) data for the creating of the habitat model, b) data for the model evaluation
	High quality results, geographically accurate	The accuracy of the model strongly dependent on the amount of species occurrence data available (broad ecological spectrum is favourable)
	New results: based on the occurrence data, habitat suitability and ecological preferences are modelled, these results can be used in other analyses	Dependent on the quality of geographical data available: some migration barriers needn't be identified and vice versa
External	**Opportunities**	**Threats**
	Higher acceptance of results by all stakeholders: based on the real data on species occurrence in the area, individual home ranges and migration events (hard data)	Expensive implementation
External	**Large carnivores conservation areas in Europe**	

Table 3. SWOT of the method when habitat analysis is based on expert opinion.

Internal	**Strengths**	**Weaknesses**
	Partly exact method	Limited by the expert knowledge on species habitat preferences
		Opinions on species habitat preferences may differ among experts
		Unrealistic results when habitat preferences from different geographical or climatic area are used in the analysis (highlands vs. lowlands, forested Scandinavia vs. deforested Western Europe)
		Subjective method and sensitive to data interpretation
		Dependent on the quality of geographical data available: some migration barriers needn't be identified and vice versa
External	**Opportunities**	**Threats**
	Cheap implementation	Acceptance of results may vary by experts, but probably low acceptance by other stakeholders
Example	**ECONNECT (Red deer)**	

Table 4. SWOT of the method when the corridors are mapped in the field.

Internal	**Strengths**	**Weaknesses**
	Partly exact method and data	Limited by the expert knowledge on species habitat preferences
	All corridors very well documented, habitat types, structure and permeability of corridors known in detail	Limited by the expert knowledge on species migration routes, dispersal abilities and barrier effects
	All barriers identified and documented in detail including those not readable from GIS layers/maps (e.g. fenced pastures).	Subjective
	Combination of barriers can be evaluated based on onsite data	Time consuming
	Opportunities	**Threats**
	Easy implementation of the protection of ecological network since all the barriers known in detail	Acceptance of results may vary among experts and probably lower acceptance by other stakeholders
	Stakeholders involvement	Very expensive
		Analysis cannot be repeated and easily updated
Example	**Assessment of landscape migration permeability for large mammals and proposal of protective and optimization measures (Czech Republic)**	

Conclusion of SWOT analysis:

The best methodological approach is preformation of habitat analysis using species occurrence data. This approach produces highly accurate results accepted by experts and also other stakeholders. The quality of the results can be significantly increased by performing field mapping and evaluation of the barrier effects on site. However, this method is very expensive and therefore can be used only on regional/national level.

2.8. Methodological recommendations for delineation of ecological networks for large mammals at the European level.

2.8.1. Focal species

- The landscape fragmentation processes in Europe mostly affect groups of species restricted to the well-preserved natural environment (wildlife), those with great requirements on the size of their home range and species migrating for long distances. Therefore, these species should be selected as focal species for pan-European network.
- Species that serve as an umbrella species of forest ecosystems should be preferred since by protecting their habitats and migration routes we help other forest species.
- Due to their biology large carnivores (Brown Bear, Grey Wolf and Eurasian Lynx) and large European ungulates (Red Deer, Eurasian Elk and Eurasian Bison) meet all the above-mentioned criteria.
- The original continuous European distribution of these species is now seriously fragmented with large carnivores being absent in large part of Western Europe. Therefore, combination of more focal species, similar in ecology and migration demands is recommended. This enables planning of common ecological network using same methodology for the whole European territory.

2.8.2. Network characteristics (area, scale, structure)

- According to Linnell et al. 2007 "From a biological point of view a population of large carnivores extends of hundreds, thousands and often tens of thousands of square kilometres. On the scales that we are talking about here there are few administrative units (states) that are able to contain a viable population of any large carnivore species on their own. Therefore, it is vital that conservation planning for large carnivores occurs in a coordinated and cooperative manner between all the administrative units that share populations."
- Situation with large ungulates is quite similar: the fragmented population of European Bison is shared by Poland, Lithuania, Belarus, Russian Federation, Ukraine, and Slovakia, European Elk population extends from Scandinavia to Central Europe (Poland, Czech Rep.) and Red Deer is found throughout much of Europe.
- Therefore ecological network for these species should with no doubt be prepared on pan-European level.
- The network should include all major European forested areas, mainly mountain ranges (Carpathians, Alps, Apennines, Pyrenees, Cantabrian Range, Massif Central, Balkan, Karelia, Baltic area and Scandinavia) as core areas.

- Corridors of width at least 500 meters to 1 km should connect these core areas
- Stepping stones, which hold higher amount of shrubs and forest should be proposed in areas with higher level of landscape fragmentation (mainly Western Europe) to ease species migration.

2.8.3. Using habitat suitability models

- The use of habitat suitability models (HSM) for predicting areas with potentially usable environment for permanent (core areas) and temporal occurrence (stepping stones) of focal species is highly recommended. This objective method, when properly used, gives high quality, geographically accurate outputs. Moreover, when data has been harmonized, the outputs are unified for the whole analyzed territory, e.g. Europe.
- Habitat suitability models should always be based on original species occurrence data e.g. GPS telemetry data or mark – capture – recapture data from long term monitoring. The importance of recording absence data should be highlighted. All data should be provided in the ESRI shapefile form and georeferenced into common projected coordinate system.
- Environmental and landscape variables influence significantly species distribution. It is therefore necessary to include at least basic environmental and landscape factors into HSM analysis: Elevation, Slope and aspect, Vertical heterogeneity, Corine Land Cover (CLC) and variables derived from this data source, Factors of potential landscape productivity, Distance from the forest, Distance from agricultural areas and settlements, Settlements, Water bodies and Infrastructure.
- Important migration barriers such as: gas – pipelines, photovoltaic power stations, fenced areas in agriculture landscape (pastures and vineyards) and fenced sections of highways and main roads shouldn't be neglected in the analysis.

2.8.4. Network delineation

- Nationally protected areas, Natura 2000 sites and other protected areas with adequate habitats should be given the priority when identifying core areas and stepping stones.
- The effect of key migration barriers should be evaluated in detail either by field mapping or by inspection of high resolution maps (e.g. orthophoto maps)
- Mitigation measures such as overpasses and underpasses should be proposed on crossing of corridors with key barriers.
- The documentation of ecological network should be prepared in a maximum detail and should be available to all states included into network for comments. In some cases, expert recommendations can increase the quality of a proposal significantly, especially in case of data absence or lower resolution data availability.

2.9. Recommendations for effective protection of ecological networks for large mammals at the European level.

The principal recommendation proposed by the present document regarding the protection of landscape connectivity for large mammals is to delimit and protect a network of areas at European level that will provide connection within and between territories of permanent and temporal occurrence of large mammals.

In detail, we propose:

- **Delimiting core areas, stepping-stones and corridors and determining the respective protection measures:** Core areas, stepping-stones and corridors of ecological networks for large mammals should be defined as individual units with a common concept of delimitation and equal protection measures in the entire EU territory. Adopting relevant updates in EU and national legislatures regarding nature protection and land-use planning should provide this. In addition to the delimitation of these areas, limitations should be set as to the utilisation and protection of these areas. Also, all intents affecting the network functionality should be subject to assessment of impacts on the landscape connectivity and fragmentation of wild fauna populations.

- **Using already existing nationally protected areas and Natura 2000 network:** Conservation of sites of Community importance and nationally protected areas, above all areas designated to protect populations of the Eurasian Lynx, Brown Bear, Grey Wolf, Eurasian Elk, Eurasian Bison, Red Deer, forest species and/or forest habitats in general represents an instrument for the protection of the network

- **The protection of core areas** mainly involves protection of the landscape permeability as a whole with the view to providing sufficient quality of forest habitats and variability of their connections. Thus, core areas should be designed as relatively wide areas and the regulations proposed for their protection should primarily have a framework character.

- **The protection of corridors:** corridors represent the actual long-distance passages through a territory. They should not be understood as an ideal state but rather as a minimum securing permeability of the area for migration. As the fundamental requirement, any barrier that would completely inhibit migration should not interrupt them. Corridors are much smaller in size than core areas but stricter protection measures should apply to them.

2.10. Recommendations for effective protection of European landscape from fragmentation

The density of migration barriers in landscape has been reaching a level that entirely interrupts the native connection of natural and semi-natural habitats. The landscape ceases to fulfil its original function of an element connecting various populations of species. This phenomenon is known as fragmentation.

The number of migration barriers in the landscape has been constantly growing. The most significant migration barriers are the following:
1. construction of settlements in the open landscape
2. construction of transportation infrastructure and an increasing intensity of road traffic
3. establishment of fenced areas in the open landscape

Securing the connectivity of the landscape for large mammals and ungulates and thus for all ecologically similar species of wild fauna is a part of the comprehensive protection of the landscape from fragmentation. Although individual species have distinct demands on the permeability of the landscape, certain measures adopted to protect the landscape from fragmentation have a global character. These are principally the following:

- Increasing awareness of both professional and non-professional public concerning the real significance of landscape fragmentation and its subsequent impacts, in particular fragmentation of populations of wild fauna.
- Incorporating protection of the landscape from fragmentation in the EU and national legislation (e.g. Building and Spatial planning Acts)
- Incorporating landscape fragmentation as an obligatory topic in the process of environmental impact assessment by updating relevant EU directives. The process of assessment of environmental impacts of intents and concepts should consider all the effects comprehensively, i.e. in theory also including the effects on the fragmentation of fauna and flora populations, fragmentation of ecosystems, and landscape connectivity. Landscape fragmentation issues should be involved in the mentioned processes, both at the legislative level and at the level of implementation.

2.11. Recommendations based on evaluation of the effectiveness and use of overpasses and underpasses.

2.11.1. Assessing the effectiveness of ecopassages

It is assumed that globally, 83 % of the ecopassages are underpassages, specifically culverts (40 %), the others are overpassages (Van der Ree et al. 2007). Many types of ecopassages have been proposed and built, but there is little research on which to base an informed evaluation of their effectiveness. Studies of the effectiveness of ecopassages have generally focused on examining the influence of passages in reducing road- and rail-kill, facilitating movement and ameliorating other adverse effects on wildlife populations. Whether being designed to reduce road-kill and barrier effects, to facilitate movement, or to increase population viability, it is usually assumed that passages provide a safer environment for wild animals than the roads and railways they cross (Van der Ree et al. 2007, 2009, Corlatti et al. 2009, Ford et al. 2009, Lesbarréres & Fahring 2012).

The effectiveness of wildlife-crossing structures is typically assessed by documenting their rate of use by wildlife, primarily through photographic records, and the detection of footprints in a suitable medium, such as sand or snow (Clevenger & Waltho 2000, Ng et al. 2004, Van der Ree et al. 2007). Fewer studies have documented which individuals use the structure (e.g., age and sex parameters), the type of use (e.g., dispersal, migration, or daily foraging), the success of individuals following crossing (e.g., mating) or the reduction in the risk of extinction. These other parameters provide a greater insight into success and allow a more comprehensive assessment of effectiveness.

The majority of wildlife crossings have been focused on the level of individuals, rather than examining the benefits or otherwise of these structures at the population level. Studies have aimed at the use of structures by wild animals, but this does not necessarily translate to conservation gain (Ng et al. l.c., Mazza et al. 2011). Van der Ree et al. (2007) found that only five publications out of 123 examined reported on a population-level study and an additional 23 studies implied or alluded to population-level effects, such as increased population viability of prevention of a population sink. There is a need to augment Forman et al. (2003) criteria of the effectiveness of crossings and assessments that focus only on the degree of usage of structures, with assessments of the extent to which wildlife crossings enhance the viability of local populations (Crooks & Sanjayan l.c., Van der Ree et al. 2007, 2009).

Van der Ree et al. (2007) concluded that they contain little useful information for evaluating whether the overpasses and underpasses have mitigated the effects of the road(s), railroads and other man-made linear facilities on connectivity. Most studies simply record the presence of animals in or moving through ecopassages, with no information on pre-ecopassage movement rates or on movement rates at control (non ecopassage) sites. Without such comparisons, evaluation of the mitigation effectiveness of the overpasses and underpasses is not possible.

There are some reasons for the lack of evidence concerning the effectiveness of ecopassages on the restoration of landscape connectivity (Van der Ree et al. 2007, Bissonette & Adair 2008, Corlatti et al. l.c., Ford et al. l.c., Lesbarréres & Fahring l.c.):

1. Difficulty of accessing research results - In fact, many management interventions including building ecopassages remain unevaluated. Most road planning is under government ministries or departments where information, although public, is usually included in grey literature.

   There are two main reasons why most research evaluating ecopassages has not been reported in the scientific literature:

   a. The research is mostly conducted in a specific applied setting in which information is desired for a particular wildlife crossing project. The government agencies conducting the work often do not have any interest, incentive or requirement to publish the work more broadly.
   b. These studies are frequently characterized by a lack of scientific rigor. Approximately 15% of the studies involve a single ecopassage and, in these cases, the study design is unreplicated. This leads to the difficult situation where results are unique to a specific location and cannot easily be compared, in turn causing transportation agencies to expend considerable resources repeating the research or installing ecopassages that had not really been shown to be effective.

      An important reason for the low quality of research on ecopassage effectiveness is that such research projects are not initiated or even planned until after the ecopassage is in place. Typically, after the passage is built, the transportation agency that built it issues a "call for proposals" for research to evaluate its effectiveness. Road ecologists can submit proposals directly to the agency, or a consulting company might submit a proposal that includes road ecologists as expert advisors. In either case, the research is likely to produce equivocal or weak results because of a lack of benchmark or baseline data from before the ecopassage (and the road itself) was in place. In addition, monitoring of wildlife overpasses and underpasses, although is needed to assess the genetic effectiveness of wildlife ecopassages is usually of short duration: the average monitoring period (given that monitoring was occurring) was 1.7 years post-construction. The length of time needed to detect an effect of an ecopassage on animal movements depends on the expected frequency of movements: the rarer the movements, the more years will be required to develop a good estimate of movement rate. This means that more years will be needed to document movement rates for species with low population densities. In addition, for some species, there is a delay in use of a passage until the animals become aware of its presence. The number of years needed for monitoring will also depend on the measurement end-point; e.g., documentation of across-road movement rates requires shorter monitoring periods than does documentation of decreasing genetic isolation. Power analysis should be used to determine the monitoring time needed to detect a change in crossing rates or gene flow, depending on the objective. Currently, the post-construction monitoring period is usually based on funding availability, which is usually less than adequate.

2. Low priority for connectivity in road and railroad planning – Conducting research on ecopassages effectiveness requires close collaboration between ecologists and road planners, but road planners often appear unconvinced of the importance of value of such research.

2.11.2. Ecopassages design and locations

Various types and sizes of ecopassage have been evaluated in terms of their use by a range of taxa or ecological/functional groups (Clevenger et al. 2001, Iuell et al. 2003, Glista et al. l.c., Beckmann et al. 2010), including green bridges or wildlife overpasses over the road, and wildlife underpasses extended under the road, which vary from small culverts or tunnels to larger culverts and large open-span bridges. Underpasses are typically not-fauna specific structures, and have the potential to be used by a wide variety of species (Mata et al. 2008). Generally, overpasses can accommodate a wider variety of species than underpasses (Fairbank l.c.). Use rates suggest that different species preferentially use different ecopassage types, and some species require particular features in the passage. This, combined with success stories for individual species, creates the expectation that a "connectivity-friendly" road is one with an array of different types of ecopassage (Clevenger & Waltho 2005). However, that this picture has developed mainly because each study has either evaluated only a limited range of passage types, or was focused at the outset on a particular species. In fact, when all studies on ecopassages are viewed together, the conclusion that a variety of passage types is required is not supported. Rather, two simple patterns become apparent (Lesbarréres & Fahring l.c.):

i. One passage design that works for most species is the extended stream crossing, an elongated, open-span structure over a natural stream, including wide banks on both sides: the bridges or structures span the "stream banks" at high flow, plus allow room for wildlife to cross on other side. The height of the passage over the dry banks should be sufficient to allow passage of the largest terrestrial animal in the area. Although extended stream crossings might be more expensive to install than are culverts (McDonald & St. Clair 2004), in the long-term they should pay off because they provide connectivity for most animals, large and small, terrestrial and aquatic. Despite their high cost relative to other passage types, the cost of such stream crossings is still low within the context of the entire budget of a road construction project. Overall, extended stream crossings are probably the most cost-effective way of improving connectivity across roads;

ii. For effective functioning of an ecopassage, fencing is needed to keep animals off the road, to avoid road mortality between ecopassages since they act as barriers to direct access to roads and to facilitate access to crossing structures to wild animals. The use of fencing in combination with crossing structures can help to guide and funnel wildlife towards ecopassages, increasing their use and keeping animals out of the road (Glista et al. l.c., Fairbank l.c.).

In addition to the design of an ecopassage, its location has a large effect on its ability to enhance or maintain connectivity. A typical approach is to use road-kill hotspots as indicators of locations where large numbers of animals attempt to cross roads and so where overpasses and underpasses would be appropriate. Several authors have analyzed road-kill distribution data to identify local and landscape-scale factors that predict road-kill hotspots. Not surprisingly, these studies confirm that such hotspots are generally associated with locations where species habitat occurs next to the road on both sides of the road (Malo et al. 2004). However, in comparing locations with similar habitat availability, Fahrig et al. (1995)

found that amphibian road-kill hotspots occurred in sites with lower traffic, suggesting that mortality from road kills had already reduced local populations in habitats near high-traffic roads, resulting in fewer road-killed amphibians. Therefore, although road-kill hotspot analyses can be used as a general indicator of habitat–road kill associations, they should not be used as the sole indicator of the best sites for installing ecopassages. Simulation models that include animal movement behaviour and habitat distribution could be used to identify the most likely crossing sites for animals, which would indicate the best placement of ecopassages. Locations where the model indicates high crossing rates but where few road kills are actually observed could indicate locations where the population is depressed owing to past road kill and so where ecopassages might lead to population recovery, but this type of modelling has not yet been done.

The overarching imperative is that road ecologists and road ecology research should be involved throughout the road project, beginning with the earliest stages of planning. Transportation planning occurs over many years, even decades. Involving road ecologists throughout the process will facilitate incorporation of ecopassages into road projects, with the potential to improve connectivity across existing roads and mitigate connectivity loss on new roads. In addition, early involvement of road ecologists would allow them to use the road project itself as a research project, providing valuable information for connectivity mitigation on future road projects.

Most transportation projects involve improvements and expansions of existing infrastructure to accommodate more traffic, rather than the building of new roads (Forman et al. l.c., Iuell et al. l.c.). These projects represent an untapped opportunity for improvement of connectivity. For example, when a road intersects a small stream, water flow across the road is typically maintained through a drainage culvert underneath it. However, many animals will not use standard culverts. If road ecologists were included in the planning phases of road improvement projects, they might suggest replacing culverts with extended stream crossings to allow passage of animals. As a second example, many limited-access roads have concrete safety barriers (Jersey barriers) dividing the two directions of traffic and making it impossible for most non-flying animals to cross the road. During road expansion or improvement, road ecologists might suggest replacing Jersey barriers with other designs (e.g. vegetated median, centerline rumble trips) that offer traffic safety and do not completely block animal movements (Lesbarréres & Fahring l.c.). These are examples of road design specifications that can improve connectivity, even though the road expansion might result in increased traffic. Similarly, in the case of a new road, ecologists involved in the road planning stages might suggest incorporation of measures that would reduce the anticipated impact of the road on connectivity.

Advantages of overpasses are that they are less confined, quieter, and maintain ambient environmental conditions such as moisture, temperature, and light. The drawback of overpasses is that they are typically the most expensive mitigation option because of their large size and high construction costs (Glista et al. l.c., Fairbank l.c.).

The proximity of crossing structures to human population centres and human activities/use is shown to negatively affect their use by most wildlife, particularly large carnivores and other large mammals (Clevenger & Waltho l.c., Ng et al. l.c., Grilo et al. 2012). Thus restricting human use of crossing structures, especially at night, is essential in ensuring effective use by wildlife (Clevenger & Waltho l.c., Grilo et al. l.c., Fairbank l.c.).

As it may be financially impossible to place structures with the frequency needed to provide full habitat permeability, and because wildlife vehicle collisions tend to be clustered or restricted to crossing hotspots, appropriately spaced mitigation measures should be prioritized within these areas to yield the greatest increase in connectivity and decrease in wildlife-vehicle interactions (Bissonette & Adair l.c.).

2.11.3. Recommendations on preparation of effective ecopassages

Recommendations on how to improve connectivity through ecopassages may include (Iuell et al. l.c., Jaeger & Fahring l.c., McDonald & St. Clair l.c., Clevenger & Waltho l.c., Beier et al. l.c., Bond & Jones 2008, Eigenbrod et al. 2008, Forman et al. l.c., Malo et al. l.c., Benítez-López et al. 2010, Aune et al. l.c., Grilo et al. l.c., Neumann et al. 2012):

1. Multiple crossing structures should be constructed at a crossing point to provide connectivity for all species likely to use a given area. Different species prefer different types of structures. For deer or other ungulates, an open structure such as a bridge is crucial. For medium-sized mammals, e.g. carnivores, large box culverts with natural earthen substrate flooring are optimal. For small mammals, pipe culverts from 0.3m – 1m in diameter are preferable. Large underpasses provide crossing opportunities for the greatest number of species, although small animals often show preferences for small underpasses, presumably for security from predation.
2. At least one crossing structure should be located within an individual's home range. Because most reptiles, small mammals, and amphibians have small home ranges, metal or cement box culverts should be installed at intervals of 150-300 m. For ungulates and large carnivores, larger crossing structures such as bridges, viaducts, or overpasses should be located no more than 1.5 km apart. Inadequate size and insufficient number of crossings are two primary causes of poor use by wildlife.
3. Suitable habitat for species should occur on both sides of the crossing structure This applies to both local and landscape scales. On a local scale, vegetative cover should be present near entrances to give animals security, and reduce negative effects of lighting and noise. A lack of suitable habitat adjacent to culverts originally built for hydrologic function may prevent their use as potential wildlife crossing structures. On the landscape scale suitable habitat must be present throughout the linkage for animals to use a crossing structure.
4. Whenever possible, suitable habitat should occur within the crossing structure. This can best be achieved by having a bridge high enough to allow enough light for vegetation to grow under the bridge, and by making sure that the bridge spans upland habitat that is not regularly scoured by floods. Where this is not possible, rows of stumps or branches under large span bridges can provide cover for smaller animals such as reptiles, amphibians, rodents, and invertebrates; regular visits are needed to replace artificial cover removed by flood. Within culverts, mammals and reptiles prefer earthen to concrete or metal floors. As existing underpasses were often originally constructed for drainage purposes and may sometimes have standing water in them, modifying them with shelves or raised walkways has been found to be an effective way to ensure their use even when inundated with water.
5. Structures should be monitored for, and cleared of, obstructions such as detritus or silt blockages that impede movement. Small mammals and reptiles avoid crossing structures with significant detritus blockages. In the southwest, over half of box culverts less than 8 x 8 ft have large accumulations of branches, Russian thistle, sand, or garbage that impede animal movement. Bridged undercrossings rarely have similar problems.
6. Fencing should never block entrances to crossing structures, and instead should direct animals towards crossing structures. In Florida, construction of a barrier wall to guide animals into a culvert system resulted in 93.5% reduction in roadkill, and also increased the total number of species using the culvert from 28 to 42. Fences, guard rails, and embankments at least 2 m high discourage animals from crossing roads. However, when not properly maintained, fences with occasional holes or other openings can work as a trap for animals trying to cross the road. Thus endangering

migrating animals as well as vehicles using the road. The use of fences should be therefore planned only in case that financial sources for future maintenance are ensured. Also, one-way ramps on roadside fencing, enabling animals to escape, are recommended.

7. Raised sections of road discourage animals from crossing roads, and should be used when possible to encourage animals to use crossing structures. Vertebrates were 93% less susceptible to road-kills on sections of road raised on embankments, compared to road segments at the natural grade of the surrounding terrain.
8. Manage human activity near each crossing structure. Human use of crossing structures should be restricted and foot trails relocated away from structures intended for wildlife movement. However, a large crossing structure (viaduct or long, high bridge) should be able to accommodate both recreational and wildlife use. Furthermore, if recreational users are educated to maintain utility of the structure for wildlife, they can be allies in conserving corridors. At a minimum, nighttime human use of crossing structures should be restricted.
9. Design crossing structures specifically to provide for animal movement. Recent research shows that traffic noise within an undercrossing can discourage passage by wildlife, suggesting that new designs are needed to minimize vehicle noise in underpasses. Ungulates prefer undercrossings with sloped earthen sides to vertical concrete sides: visibility to the opening at the other side of the underpass is an important factor in underpass use, particularly by ungulates. High openness ratio (height x width divided by length) promote animal travel, and perhaps the best way to achieve this is to minimize the distance an animal must travel within the structure. Most culverts are designed to carry water under a road and minimize erosion hazard to the road. Culvert designs adequate for transporting water often have pour-offs at the downstream ends that prevent wildlife usage. At least one culvert every 150-300m of road should have both upstream and downstream openings flush with the surrounding terrain, and with native land cover up to both culvert openings, as noted above.

2.11.4. Recommendations on biological corridors management

Maintaining, establishing and managing biological corridors in various parts of the world have revealed some common experience (Bennett & Mulongoy l.c., Damschen et al. l.c., Dixon et al. l.c., Aune et al. l.c.):

1. Connectivity fundamentally depends on interactions of species and landscape. This dynamic interaction is primarily expressed through relationship of species, habitats and human impacts within those habitats. Different landscapes may have different connectivity values to the same species and certainly to different species. The connectivity property of a landscape may even be different for the same species at different times. Recent studies show that structural measures of landscape intactness are inconsistent predictors of connectivity for all species and in all situations.
2. A large-size interconnected landscape of natural and semi-natural habitats with embedded protected areas can provide opportunities for many species and through them, ecosystems and ecosystem processes/functions/services to respond to climate change and increasing human pressures. Moreover, connectivity is essential to conservation regardless of a changing climate.
3. The nature context, i.e. what nature needs, should be the principle driver in initiating and maintaining connectivity through biological corridors. Although it remains uncertain how much connectivity is enough it is clear that nature needs

extensive connectivity. There is little conservation risk in providing extensive connectivity while there is a great risk for providing too little.

4. Natural corridors (those existing in the landscape prior to the study) showed more wildlife movement than manipulated corridors, which had been created. This suggests that it is better to protect natural landscape features that function as corridors, rather than create new corridors. Generally, the complexity and multifunctional components of undisturbed landscapes are difficult to replicate using constructed nature and ecosystems.

2.11.5. Conclusions

As landscape fragmentation continues to increase, mitigation measures such as maintaining or establishing and managing biological corridors are becoming increasingly popular in nature conservation and landscape management to improve or maintain connectivity between habitat patches. Biological corridor function could range from providing only passage to providing habitat and passage. Whether biological corridors increase movement of plants and animals between habitat fragments has been addressed on a case-by-case basis with mixed results. Because of the growing number of well-designed experiments that have addressed this question, the recent review using meta-analysis concluded that they really facilitate and improve movement between habitat patches. Because biological corridors are species/guilds/community/landscape specific, the utility and cost-effectiveness of biological corridors must be carefully considered on a case-by-case basis. In addition, minimizing infrastructure development in relatively undisturbed areas is also of extreme importance.

Despite the fact that ecopassages are built nowadays more often than in past, particularly in the developed world, and the high cost of implementing ecopassages or other wildlife crossings, few studies have actually evaluated the efficacy of crossings, with a lack of pre and post-construction tests and monitoring, with the results of most studies therefore based on anecdotal evidence and observations. Therefore, the effectiveness of biological corridors including overpasses and underpasses should be further elaborated. Particularly, to assess the effectiveness of wildlife overpasses, long-term monitoring programmes, including fieldwork and genetic analyses, are needed.

3. Case study: ecological network for large mammals in the Czech Republic, Poland, Germany and Upper Austria

Data regarding ecological networks for large forest mammals from Central European countries namely the Czech Republic, Poland, Germany and Upper Austria were used for the following analyses performed in the case study. The data were kindly provided by respective authorities in shapefile form. All analyses were performed in GIS ArcInfo programme (ESRI).

Data description:

Czech Republic (CZ)

Data were prepared as a part of the project Assessment of landscape migration permeability for large mammals and proposal of protective and optimization measures, which was finished in 2010. Two main hierarchical levels were used during analyses: Significant Migration Areas (SMAs – polygonal layer) and corridors (linear layer). For more detailed overview see chapter 2.4.4.1. All data are provided for free as a non obligatory material for land-use planning according to the Act. no. 183/2009 Coll. (building and spatial planning) and Decree No. 500/2006 Coll. on planning analytical materials, urban planning documentation and the method of recording urban planning activity by the Nature Conservation Agency of the Czech Republic.

Poland (PL)

The ecological network for Poland was developed during the study Projekt korytarzy ekologicznych łączących Europejską Sieć Natura 2000 w Polsce (Jędrzejewski et al. 2005), which was financed by the ministry of environment / EU – project Phare PL0105.02. The newly adjusted ESRI shapefile polygonal data of polish ecological network for large forest mammals was kindly provided by Mammal research institute from Białowieża in 2012 (Mr. Marcin Górny). The polish ecological network was provided as a single polygonal layer that consists of all three interaction elements - core areas, stepping stones and broadly conceived corridors (see chapter 2.4.2.1.).

Upper Austria (UA)

Three institutions Oö. Umweltanwaltschaft, Oö. Landesregierung and Oö. Landesjagdverband cooperated on preparation of ecological network for Upper Austria. The network is composed of core areas and stepping stones consisted by suitable habitat, which are connected through corridors. We have used the ESRI shapefile data, which consisted of two layers: corridor axes (linear layer) and core areas (polygonal layer). The data in electronic form were kindly provided by Oö. Umweltanwaltschaft from Linz in 2010 (Mr. Mario Pöstinger).

Germany (D)

The shapefile data for Germany consisted of corridor axes for forest mammal species (linear layer) and core forest areas larger than 50 km^2 which is polygonal layer. All the data were kindly provided by Bundesamt für Naturschutz (Ms. Bettina Dibbern on 1. 8. 2011).

Data adjustment:

Respective national data were transformed into common projected coordinated system and merged into single polygonal layer with following parameters:

Projected Coordinate System:	**ETRS_1989_LAEA**
Projection:	**Lambert_Azimuthal_Equal_Area**
False_Easting:	**4321000,0**
False_Northing:	**3210000,0**
Central_Meridian:	**10,0**
Latitude_Of_Origin:	**52,0**
Linear Unit:	**Meter**

First of all, the national ecological network layer was intersected by linear national border layer. After that some adjustments were needed along the border. If the national ecological network layer partly overlapped the border to neighbouring country (due to national border layer inaccuracy), this newly emerged polygon wasn't incorporated to the network of respective country. It should be mentioned that all ecological network proposals were prepared prior to the Czech network proposal (prior 2010). We counted with this situation during the finalization of Czech shapefile layers with significant migration areas and corridors. The output layers were adjusted to be linked at the borders as much as possible.

Data used for analyses:

We have analyzed the layer of significant migration areas, which includes core areas, stepping stones and 500 m wide corridors in the Czech Republic. Further, merged ecological network layer consisted of 500 m wide corridors and core areas for the Germany and Upper Austria. Such data were used in four following chapters 3.1. - 3.4 (see fig. 57). The corridor layer with total width 500 m **excluding core areas** was prepared in CZ, D and UA for analyses in chapters 3.5., 3.6. and 3.7. Ecological network in Poland is planned to encompass broad areas of the landscape. Polish proposal cover also (landscape) corridors, core and stepping stone areas, but it was delivered within single layer, therefore the respective national layer remained unchanged for all analyses.

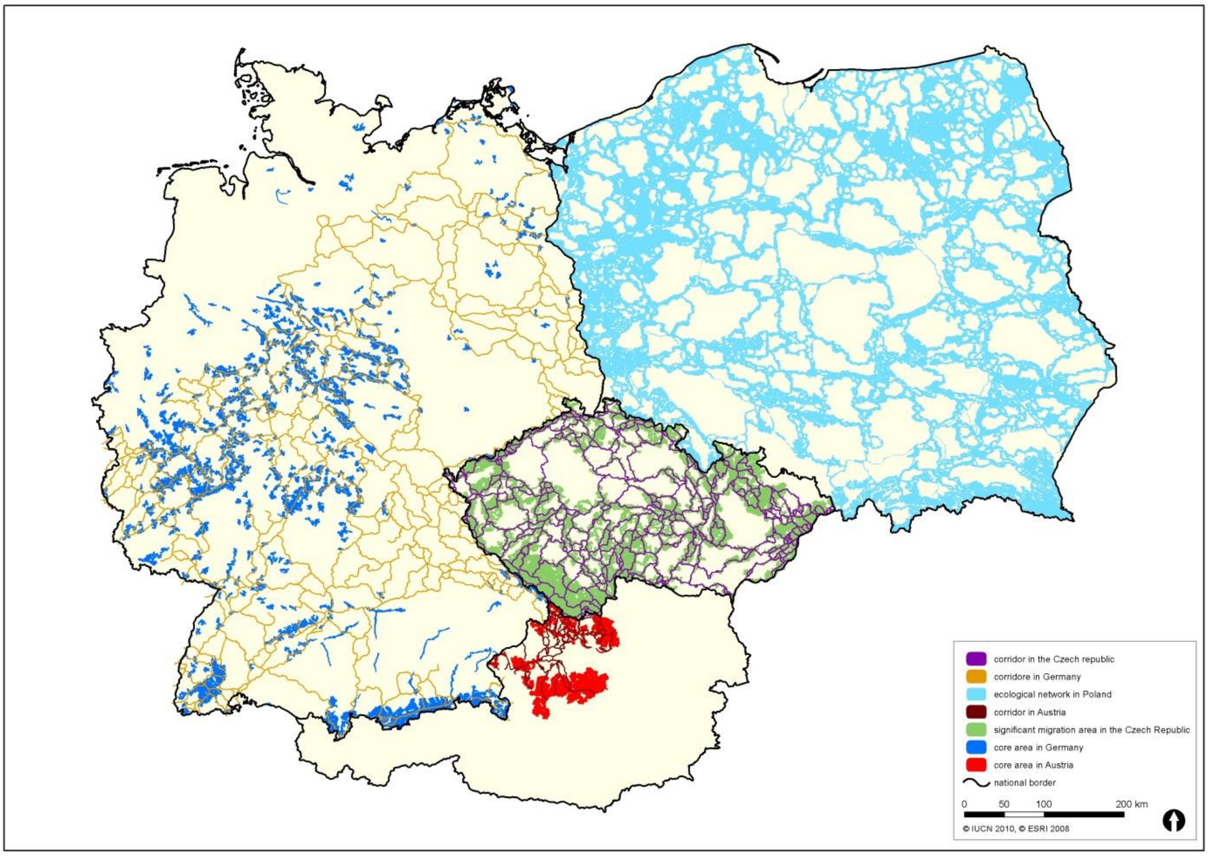


Figure 57. Ecological network used for analyses done in chapters 3.1.-3.4. in the Czech Republic, Germany and Upper Austria, which encompass corridors, core and stepping stone areas. The ecological network in the Poland encompasses broad areas of the landscape. The polish layer remained unchanged in all analyses.

3.1. Evaluation of ecological network for large mammals with respect to NATURA 2000 sites proposed for large carnivores

Natura 2000 Special Areas of Conservation (SACs) proposed under the EC Habitats Directive (Council Directive 92/43/EEC) were analyzed with respect to merged polygonal layer of ecological network in the central Europe (CZ, D, PL and UA).

We have used the GIS layer of Natura 2000 downloaded from EEA webpage datasets section as basic source for this analysis. The second main data source was the full version of the latest Natura 2000 access database (Natura2000_EC_End2011.mdb) provided by Brian Mac Sharry from EEA on 3.9.2012. We selected only those sites in respective four countries, where the *Lynx lynx* (and synonymous *Felis lynx* in Germany), *Canis lupus* and *Ursus arctos* were reported as a species of the European interest. These sites were further sorted by excluding those classified “D” in the column “POPULATION (99 sites) or there was a missing value (one site in Germany with sitecode DE4129302). Altogether 122 sites (some of them are designated for two or three carnivore species) were included for the analysis. Thirteen sites of them are located in Austria, four sites in the Czech Republic, 41 sites in Germany and 64 sites in Poland (see ANNEX 1).

Nonetheless, some complications have arisen especially along the Czech border during analysis of network overlap with Natura 2000 sites designated for large carnivores. It was caused due to N2k site and or national border layers inaccuracy. As a result some sites from one country partially overlapped the national border and were assigned to neighbouring country. We have to mention that we did not adjust resultant layers to fit perfectly. All discrepancies are also mentioned in respective tables.

Table 5. List of selected Natura 2000 sites designated for large mammals in the Czech Republic, which are in the overlap with ecological network.

FID_NATURA	SITECODE	SITENAME	SITE AREA (ha)	SITE AREA OVERLAP WITH ECOL. NETWORK (ha)	SITE OVERLAP WITH ECOL. NETWORK (%)	TARGET SPECIES
1342	CZ0314024	Šumava	171866,11	164774,07	95,87	lynx
1345	CZ0314123	Boletice	20348,73	20326,38	99,89	lynx
1346	CZ0314124	Blanský les	22211,94	19130,45	86,13	lynx
2132	CZ0724089	Beskydy	120357,67	105607,54	87,74	bear, wolf, lynx
			334784,46	**309838,45**		

Table 6. List of selected Natura 2000 sites designated for large mammals from countries bordering Czech Republic that partially overlapped the Czech national border due to data inaccuracy (both site and national border inaccuracy).

FID_NATURA	SITECODE	SITENAME	SITE AREA (ha)	SITE AREA OVERLAP TO CZECH REPUBLIC (ha)	TARGET SPECIES
15	AT1201A00	Waldviertler Teich-, Heide- und Moorlandschaft	13722,12	27,36	lynx
143	AT3115000	Maltsch	353,00	92,46	lynx
149	AT3121000	Böhmerwald and Mühltäler	9351,00	8,27	lynx
21159	DE5048302	Müglitztal	1657,00	4,86	wolf lynx
21166	DE5050301	Nationalpark Sächsische Schweiz	9359,00	31,96	lynx
21167	DE5050302	Lachsbach- und Sebnitztal	628,00	9,04	lynx

21169	DE5050304	Bielatal	549,00	2,61	lynx
21172	DE5051301	Sebnitzer Wald und Kaiserberg	239,00	4,01	lynx
21268	DE5149301	Mittelgebirgslandschaft um Oelsen	680,00	6,77	lynx
21270	DE5153301	Hochlagen des Zittauer Gebirges	727,00	33,55	lynx
21389	DE5248306	Fürstenauer Heide und Grenzwiesen Fürstenau	522,00	12,37	lynx
22470	DE6441301	Fahrbachtal	444,00	0,31	lynx
22757	DE6946301	Nationalpark Bayerischer Wald	24206,00	132,04	lynx
22842	DE7148301	Bischofsreuter Waldhufen	967,00	42,31	lynx
22887	DE7248302	Hochwald und Urwald am Dreisessel	273,00	4,28	lynx
12648	PLH240005	Beskid Slaski	26405,40	2,67	lynx
			90082,52	**414,86**	

Table 7. List of selected Natura 2000 sites designated for large mammals in Germany, which are in the overlap with ecological network.

FID_NATURA	SITECODE	SITENAME	SITE AREA (ha)	SITE AREA OVERLAP WITH ECOL. NETWORK (ha)	SITE OVERLAP WITH ECOL. NETWORK (%)	TARGET SPECIES
19671	DE3742302	Hackenheide	1208,85	2,42	0,20	wolf
19863	DE3944301	Forst Zinna/Keilberg	7093,00	603,49	8,51	wolf
19957	DE4051301	Lieberoser Endmoräne und Staakower Läuche	8255,00	657,40	7,96	wolf
20557	DE4552301	Truppenübungsplatz Oberlausitz	13597,00	860,54	6,33	wolf
20558	DE4552302	Oberlausitzer Heide- und Teichlandschaft	13732,00	1473,06	10,73	wolf
21054	DE4951301	Hohwald und Valtenberg	513,00	54,84	10,69	lynx
21159	DE5048302	Müglitztal	1657,00	35,37	2,13	lynx
21166	DE5050301	Nationalpark Sächsische Schweiz	9359,00	1746,64	18,66	lynx
21167	DE5050302	Lachsbach- und Sebnitztal	628,00	102,03	16,25	lynx
21168	DE5050303	Tafelberge und Felsreviere der linkselbischen Sächsischen Schweiz	471,00	33,00	7,01	lynx
21169	DE5050304	Bielatal	549,00	88,31	16,09	lynx
21268	DE5149301	Mittelgebirgslandschaft um Oelsen	680,00	126,33	18,58	lynx
21270	DE5153301	Hochlagen des Zittauer Gebirges	727,00	136,42	18,76	lynx
21389	DE5248306	Fürstenauer Heide und Grenzwiesen Fürstenau	522,00	67,91	13,01	lynx
22105	DE5937301	Zeitelmoos bei Wunsiedel	398,00	110,55	27,78	lynx
22107	DE5937371	Schneebergmassiv mit Fichtelseemoor	3047,79	607,59	19,94	lynx
22375	DE6336301	US-Truppenübungsplatz Grafenwöhr	19279,00	1471,74	7,63	lynx
22470	DE6441301	Fahrbachtal	444,00	163,69	36,87	lynx
22659	DE6739301	Regentalhänge bei Hirschling	352,00	50,67	14,39	lynx
22678	DE6812301	Biosphärenreservat Pfälzerwald	35997,00	8158,43	22,66	lynx
22722	DE6844373	Großer und Kleiner Arber mit Arberseen	2295,20	2112,13	92,02	lynx
22757	DE6946301	Nationalpark Bayerischer Wald	24206,00	10893,11	45,00	lynx
22794	DE7043371	Deggendorfer Vorwald	1497,25	1129,07	75,41	lynx
22796	DE7045371	Oberlauf des Regens und Nebenbäche	1921,91	229,37	11,93	lynx

22841	DE7145371	Wiesengebiete u. Wälder um den Brotjackelriegel und um Schöllnach	417,55	20,88	5,00	lynx
22842	DE7148301	Bischofsreuter Waldhufen	967,00	73,53	7,60	lynx
22884	DE7246371	Ilz-Talsystem	2846,58	70,41	2,47	lynx
22887	DE7248302	Hochwald und Urwald am Dreisessel	273,00	268,44	98,33	lynx
23349	DE8342301	Nationalpark Berchtesgaden	21364,00	10562,98	49,44	lynx
			174298,13	**41910,33**		

Table 8. List of selected Natura 2000 sites designated for large mammals in countries bordering Germany. Respective sites partially overlapped German national border due to data inaccuracy (both site and national border inaccuracy).

FID_NATURA	SITECODE	SITENAME	SITE AREA (ha)	SITE AREA OVERLAP TO GERMANY (ha)	TARGET SPECIES
149	AT3121000	Böhmerwald and Mühltäler	9351,00	387,455798	lynx
1342	CZ0314024	SUMAVA	171866,114	2999,383676	lynx
12264	PLH080011	DOLINA PLISZKI	5033,9	57,45339848	wolf
12285	PLH080044	WILKI NAD NYSA	12226,8	29,71780437	wolf
			198477,81	**3474,010677**	

Table 9. List of selected Natura 2000 sites designated for large mammals in Poland, which are in the overlap with ecological network.

FID_NATURA	SITECODE	SITENAME	SITE AREA (ha)	SITE AREA OVERLAP WITH ECOL. NETWORK (ha)	SITE OVERLAP WITH ECOL. NETWORK (%)	TARGET SPECIES
11913	PLB040003	DOLINA DOLNEJ WISLY	33559,00	33382,89	99,48	wolf
12040	PLC120001	TATRY	21018,10	21011,96	99,97	bear wolf lynx
12041	PLC140001	PUSZCZA KAMPINOSKA	37640,50	37681,41	100,11	lynx
12042	PLC180001	BIESZCZADY	111519,50	110696,40	99,26	bear wolf lynx
12043	PLC200004	PUSZCZA BIALOWIESKA	63147,60	62694,32	99,28	wolf lynx
12059	PLH020015	WRZOSOWISKO PRZEMKOWSKIE	6663,70	6664,30	100,01	wolf
12081	PLH020050	DOLINA DOLNEJ KWISY	5972,20	5244,74	87,82	wolf
12091	PLH020063	WRZOSOWISKA SWIETOSZOWSKO-LAWSZOWSKIE	10141,60	10140,22	99,99	wolf
12098	PLH020072	UROCZYSKA BOR W DOLNOSLASKICH	8067,80	8057,89	99,88	wolf
12114	PLH020090	DABROWY KLICZKOWSKIE	552,90	552,87	100,00	wolf
12170	PLH060013	OSTOJA POLESKA	10159,10	10131,46	99,73	wolf
12174	PLH060017	ROZTOCZE SRODKOWE	8472,80	8466,56	99,93	wolf lynx
12188	PLH060031	UROCZYSKA LAS W JANOWSKICH	34544,20	34344,97	99,42	wolf
12191	PLH060034	UROCZYSKA PUSZCZY SOLSKIEJ	34671,50	34576,61	99,73	wolf lynx
12196	PLH060043	LASY SOBIBORSKIE	9709,30	9630,41	99,19	wolf
12239	PLH060092	NIEDZIELISKI LAS	267,20	59,79	22,38	wolf lynx
12240	PLH060093	UROCZYSKA ROZTOCZA WSCHODNIEGO	5810,00	5710,93	98,29	wolf lynx
12254	PLH060107	OSTOJA PARCZEWSKA	3591,50	3588,19	99,91	wolf
12261	PLH080007	BUCZYNA SZPROTAWSKO-PIOTROWICKA	1423,30	1423,43	100,01	wolf
12264	PLH080011	DOLINA PLISZKI	5033,90	5031,51	99,95	wolf
12273	PLH080032	BORY CHROBOTKOWE PUSZCZY NOTECKIEJ	2309,00	2309,31	100,01	wolf
12277	PLH080036	JEZIORA GOSCIMSKIE	2995,80	2996,39	100,02	wolf
12278	PLH080037	LASY DOBROSULOWSKIE	11192,90	11184,96	99,93	wolf

12283	PLH080042	STARA DABROWA W KORYTACH	1630,40	1629,95	99,97	wolf
12285	PLH080044	WILKI NAD NYSA	12226,80	12213,03	99,89	wolf
12339	PLH120001	BABIA GÓRA	3350,40	3354,98	100,14	lynx
12350	PLH120013	PIENINY	2334,60	2336,88	100,10	lynx
12355	PLH120018	OSTOJA GORCZANSKA	17997,90	17984,48	99,93	bear wolf lynx
12356	PLH120019	OSTOJA POPRADZKA	57931,00	51957,98	89,69	bear wolf lynx
12488	PLH180001	OSTOJA MAGURSKA	20084,50	19958,42	99,37	bear wolf lynx
12493	PLH180012	OSTOJA PRZEMYSKA	39656,80	36191,62	91,26	wolf lynx
12494	PLH180013	GÓRY SLONNE	46071,50	45407,38	98,56	wolf lynx
12495	PLH180014	OSTOJA JASLISKA	29286,80	29214,14	99,75	bear wolf lynx
12498	PLH180017	HORYNIEC	11633,00	9955,97	85,58	wolf
12534	PLH180054	LASY SIENIAWSKIE	18015,40	18006,17	99,95	wolf
12538	PLH200004	OSTOJA WIGIERSKA	16072,10	15749,74	97,99	wolf
12539	PLH200005	OSTOJA AUGUSTOWSKA	107068,70	106467,43	99,44	wolf lynx
12540	PLH200006	OSTOJA KNYSZYNSKA	136084,40	133264,46	97,93	wolf lynx
12541	PLH200007	POJEZIERZE SEJNENSKIE	13630,90	6650,24	48,79	wolf
12542	PLH200008	DOLINA BIEBRZY	121206,20	112019,14	92,42	wolf
12621	PLH220078	NOWA BRDA	10020,90	10031,01	100,10	wolf
12648	PLH240005	BESKID SLASKI	26405,40	25718,84	97,40	wolf lynx
12649	PLH240006	BESKID ZYWIECKI	35276,10	33759,71	95,70	bear wolf lynx
12659	PLH240023	BESKID MALY	7186,20	7162,02	99,66	wolf lynx
12681	PLH260010	LASY SUCHEDNIOWSKIE	19120,90	17114,34	89,51	wolf
12717	PLH280005	PUSZCZA ROMINCKA	14754,30	14755,60	100,01	wolf lynx
12726	PLH280016	OSTOJA BORECKA	25340,10	24195,73	95,48	wolf
12746	PLH280048	OSTOJA PISKA	57826,60	55832,32	96,55	wolf
12747	PLH280049	NIECKA SKALISKA	11385,70	8255,81	72,51	wolf
12750	PLH280052	OSTOJA NAPIWODZKO-RAMUCKA	32612,80	32100,40	98,43	wolf
12759	PLH300006	JEZIORO KUBEK	1048,80	1049,24	100,04	wolf
12772	PLH300021	POLIGON W OKONKU	2180,20	2182,08	100,09	wolf
12840	PLH320046	UROCZYSKA PUSZCZY DRAWSKIEJ	74416,30	74006,91	99,45	wolf
			1400319,10	**1354107,51**		

There were no Natura 2000 sites designated for large mammals from countries bordering Poland that at least partially overlapped to polish territory.

Table 10. List of selected Natura 2000 sites designated for large mammals in Upper Austria, which are in the overlap with ecological network.

SITECODE	SITENAME	SITE AREA (ha)	SITE AREA OVERLAP WITH ECOL. NETWORK (ha)	SITE OVERLAP WITH ECOL. NETWORK (%)	TARGET SPECIES
AT1201A00	WALDVIERTLER TEICH-, HEIDE- UND MOORLANDSCHAFT	13722,12	100,38	0,73	lynx
AT2204000	STEIRISCHES DACHSTEINPLATEAU	7451,17	63,33	0,85	bear
AT2243000	TOTES GEBIRGE MIT ALTAUSSEER SEE	24201,69	17,79	0,07	bear
AT3111000	NATIONALPARK KALKALPEN, 1. VERORDNUNGSABSCHNITT	21454,00	21395,96	99,73	bear, lynx
AT3115000	MALTSCH	353,00	209,71	59,41	lynx
AT3121000	BÖHMERWALD UND MÜHLTÄLER	9351,00	8421,82	90,06	lynx
		76532,98	**30208,99**		

Table 11. List of selected Natura 2000 sites designated for large mammals in countries bordering Upper Austria. Two respective sites partially overlapped Austrian national border due to data inaccuracy (both site and national border inaccuracy).

FID_NATURA	SITECODE	SITENAME	SITE AREA (ha)	SITE AREA OVERLAP TO UPPER AUSTRIA (ha)	TARGET SPECIES
1342	CZ0314024	ŠUMAVA	171866,114	383,21	lynx
22887	DE7248302	Hochwald und Urwald am Dreisessel	273	0,19	lynx
			172139,11	**383,40**	

Table 12. Total area and proportion of Natura 2000 sites designated for large mammals within ecological network in respective countries.

country	total area of sites designated for large carnivores (ha)	N2k sites within ecological network (ha)	% N2k sites within ecological network
Germany	181994,63	41910,33	23,03
whole Austria	212380,55	30208,99 (upper Austrian part)	14,22
Czech Republic	334166,64	309838,45	92,72
Poland	1386864,66	1354107,51	97,64

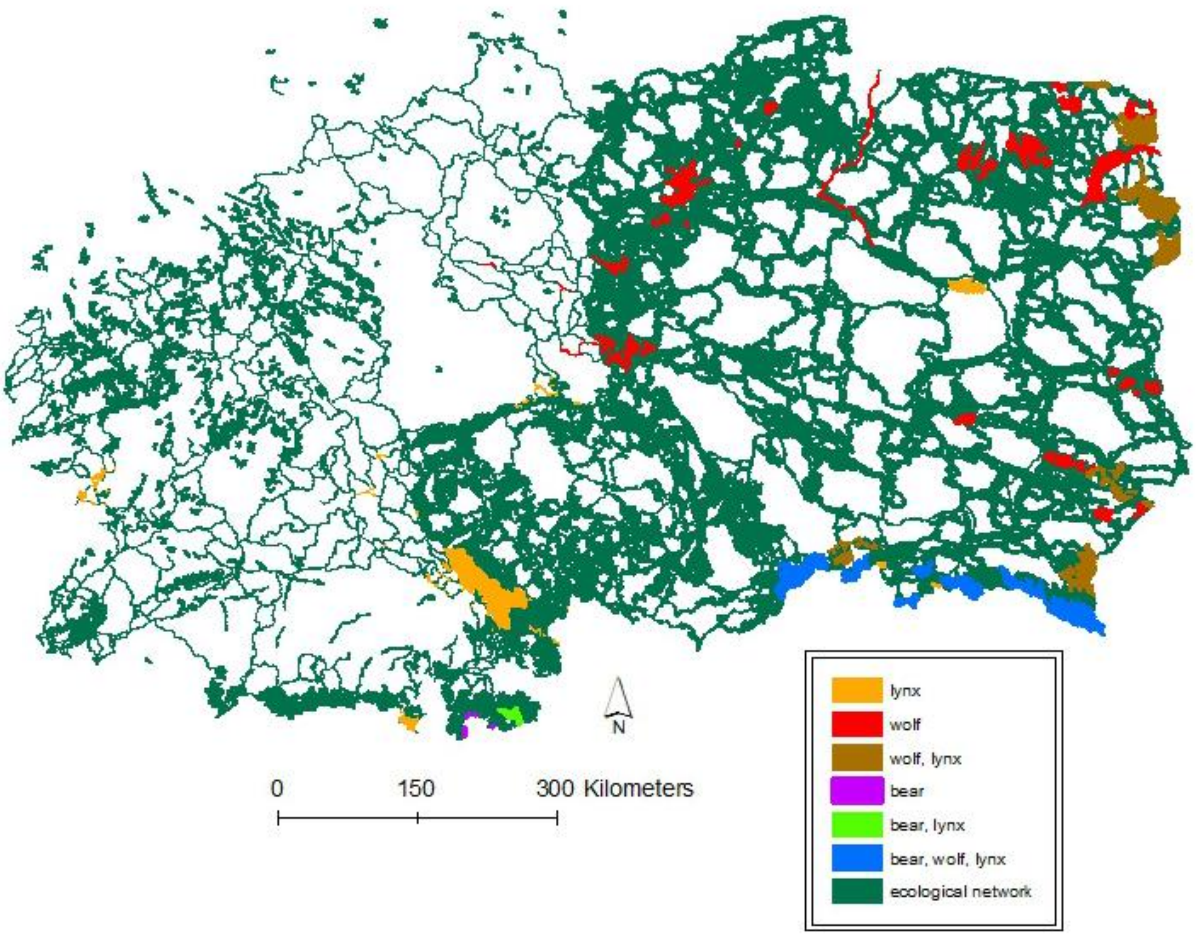


Figure 58. Selected sites of community importance designated for large carnivores, which are in the overlap with ecological network proposed in the Central Europe.

Discussion:

The NATURA 2000 sites designated for large carnivores are one of the basic legislative tools to ensure proper protection and enhance management practices for large carnivores' population sustainability. Presented results are based on analysis of sites that can be defined as core areas for large carnivores as they were reported to be hosting permanent population of at least one carnivore species (they have A-C category in column "population").

From the above map (fig. 58) is obvious that populations of all three large carnivore species (the bear, the wolf and the lynx) are together currently present only in the Carpathian mountain range encompassing border area between Slovakia and Poland. These are namely Polish sites mentioned from the most eastern to western site: Bieszczady, Ostoja Jasliska, Ostoja Magurska, Ostoja Popradzka, Ostoja Gorczanska, Tatry and Beskid Zywiecki. The only site designated for all three large carnivores in the Carpathian part of the Czech Republic is SCI Beskydy, situated close to Polish and Slovakian border (site is also Protected Landscape Area according to national legislation). Moreover, two sites that has been designated for the lynx only (Pieniny and Babia Góra), are also overlapped with ecological network. Other two closely connected sites in eastern Poland north from Bieszczady – Góry Slonne and Ostoja Przemyska are designated for the lynx and the wolf. The gap between Czech site Beskydy and Polish site Beskid Zywiecki is partially covered by two sites Beskid Slaski and Beskid Maly, which are designated also for the lynx and the wolf. This system of sites seems to be well covered in ecological network and also connectivity of selected sites appears to be sufficient in this region.

Most sites in the Poland are designated for the wolf only. Their spatial arrangement reflects the current permanent breeding occurrence of wolves in the country, which is confined to two distinct areas: the north-eastern and western part of the Poland. Three well known sites in the North-East of the Poland: Puszcza Bialowieska, Ostoja Knyszynska and Ostoja Augustowska are designated together for wolf and lynx. The only other site for the lynx that is also overlapping with ecological network is Puszcza Kampinoska in the central part of the country. The sites designated for wolf in the western Poland, close to the German border, are becoming very important because the populations here started to breed recently. These populations have originated via migration from Eastern Poland. Three of the sites are closely linked together: Stara Dabrowa w Korytach, Dolina Pliski and Lasy Dobrosulowskie. The corresponding site on German side lying about 50 km far is Lieberoser Endmoräne und Staakower Läuche. Other sites in the south-western part of the Poland forming larger spatially protected area, but not closely connected are: Wrzosowisko Przemkowskie, Buczyna Szprotawsko-Piotrowicka, Wrzosowiska Swietoszowsko-Lawszowskie, Dabrowy Kliczkowskie, Dolina Dolnej Kwisy, Uroczyska Borow Dolnoslaskich and Wilki nad Nysa. The last mentioned site has also own counterpart sites in Germany. These German sites Truppenübungsplatz Oberlausitz and Oberlausitzer Heide- und Teichlandschaft are known to be hosting stable wolf population in Lusatia. To sum up, Polish sites designated for large carnivores shows the highest spatial overlap with ecological network. Nevertheless, this situation is especially caused due to the fact that Polish ecological network is planned a priory to encompass broad areas that cover also stepping stones and core areas.

As regards the Czech Republic, all four SCI´s – Beskydy, Boletice, Blanský les and Šumava designated for large carnivores are well covered by ecological network proposal. The later three sites form second large compact area in south-eastern part of Bohemia (first site

Beskydy lies in the Carpathians), which serve as a refugium for permanent lynx breeding population. However, these two areas seems to be rather isolated in spite of that some stepping stones such as protected landscape areas lying between two regions has been reported to be at least temporarily occupied by lynx (Českomoravská vysočina). The role of biological corridors and area significant for migration thus should play bigger role in Czech legislation.

Only small parts of SCI´s for the lynx are overlapping with ecological network in the north-east of Upper Austria close to Czech border. These sites are Waldviertler Teich- und Moorlandschaft and Maltch. The site Böhmerwald und Mühltäler form the bigger compact area in the North of Upper Austria, which is adjoining to Czech SCI Šumava. In the southern part of Upper Austria close to border with Steiermark lies the largest site, which is designated solely for the bear – the Nationalpark Kalkalpen. Other two sites for the bear in this region – Totes Gebirge mit Altausseer See and Steirisches Dachsteinplateau lies from their biggest part in the neighboring Steiermark and the observed minor overlap is caused rather by data inaccuracy. The results clearly imply that both the Northern and the Southern Alpine part in the Upper Austria had rather lower spatial connectivity (due to dense transport and settlement infrastructure). The protection of ecological corridors is thus at utmost importance.

Two German sites close to the Czech-Austrian border (Hochwald und Urwald am Dreisessel, Bischofsreuter Waldhufen and Ilz-Talsystem) form only minor portion of the overlap with ecological network. On the opposite the SCI Nationalpark Bayerischer Wald designated for lynx, which forms compact trans-boundary area with Czech site Šumava, is the biggest site with the highest share of overlap with ecological network in the whole Germany. The other sites such as Fahrbachtal, Zeitelmoos bei Wunsiedel, Schneebergmassiv mit Fichtelseemoor in the Bavaria or the Fürstenauer Heide und Grenzwiesen Fürstenau, Mittelgebirgslandschaft um Oelsen, Bielatal, Tafelberge und Felsreviere der linkselbischen Sächsischen Schweiz and Nationalpark Sächsische Schweiz in the Saxony, that lies close to the Czech border, overlap with ecological network only through corridors and thus form only minor portion from the whole German network. Moreover they do not have their counterpart SCI´s in the Czech Republic, which is to the large extent due to inexistence of permanent large carnivore populations on the Czech side. The only site in the east central Germany - Biosphärenreservat Pfälzerwald, tends to be rather separated as the another SCI for large carnivores hadn't been proposed nearby.
Further analyses should be targeted to evaluation of sites, which has been reported to host temporal large carnivore populations (a priory excluded from this analysis) as they may well serve as stepping stones between core SCI´s.

3.2. Evaluation of ecological network for large mammals with respect to Nationally designated areas (CDDA)

The Common Database on Designated Areas (CDDA) contain areas that are protected according to national legislation of respective reporting state. This data set is published on EEA website under the dataset section. Whole dataset is updated annually. Merged dataset of CDDA boundary delivery from 2003 – 2008 has been used for this analysis. Dataset is based on merged dataset of 2007 (SitesEUR) and CDDA 2008. The whole shapefile dataset (siteseur_08.zip) was downloaded from respective EEA database (http://www.eea.europa.eu/data-and-maps/data/nationally-designated-areas-national-cdda-3). Only relevant designated areas for three countries (D, CZ, A) were further analyzed.
Two polygone shapefile layers for Poland were downloaded from http://cdr.eionet.europa.eu/pl/eea/cdda1/envtus8ag separately: rezerwaty_15_03_2012.shp and parki_krajobrazowe_30.08.2011.shp. Single polygone CDDA layer for all the countries has been prepared.

Table 13. Total area size and proportion of CDDA within ecological network in respective country.

country	CDDA area in the country (ha)	CDDA area in ecological network (ha)	% CDDA within ecological network
Czech Republic	1313498,14	931516,14	70,92
Germany	20771919,23	2396753,04	11,54
Poland	2791015,94	2083697,33	74,66
Austria	2198715,66	Upper Austrian part - 33331,98	Upper Austrian part - 1,52

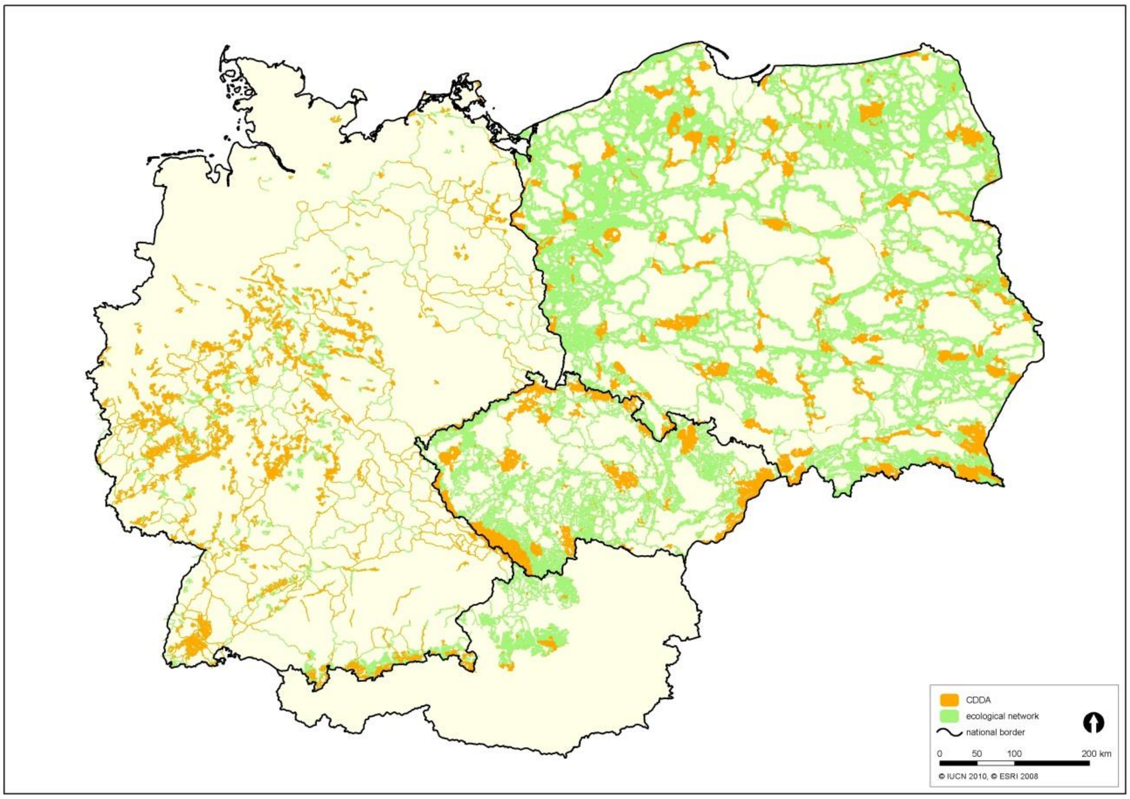


Figure 59. Map showing CDDA overlap with ecological network in the Central Europe (Poland, Germany, Czech Republic and Upper Austria).

Discussion:

Establishing of nationally designated areas depends largely on national nature protection strategies and legislation rules, which were set independently in the past. In the recent time some unification has been started with the aim to classify member states' designated areas into IUCN categories of protected areas. Usually, designated areas can be divided into small scale and large scale protected areas. However, conservation approaches varies significantly even within this categories.

In spite of that, our results are giving the general overview of those CDDA sites that are in the overlap with forest habitats. This is simply given by the fact that all ecological network proposals in the central European countries were planned according to the main large carnivore's ecological preferences for forested areas.

The largest CDDA overlap with ecological network proposal has been found in the Poland and the Czech Republic. Approximately 75% of Polish and 70% of Czech nationally protected areas are included into the national ecological network proposal for the large mammals. The German and Upper Austrian shares of the CDDA and ecological network overlap are much smaller, constituting only up to 11,5% and 1,5% respectively. These apparent differences between two pairs of states are given mainly due to different methodologies and concepts of ecological network delineation. Nevertheless the CDDA sites are contributing especially such as stepping stones that are supporting and enhancing the opportunity to large mammals migration.

It has to be mentioned that existing overlap between CDDA and NATURA 2000 sites hadn't been taken into account in this analysis. Due to this fact our results may overestimate to some degree the final coverage of legally protected sites within the ecological network. On the other hand the CDDA sites constituted by forest habitats are contributing very much to the ecological network protection. The gaps has to be filled in especially non forest areas, where mitigation measures should be targeted on riparian vegetation preservation and hedgerows planting in the intensively managed and agricultural areas.

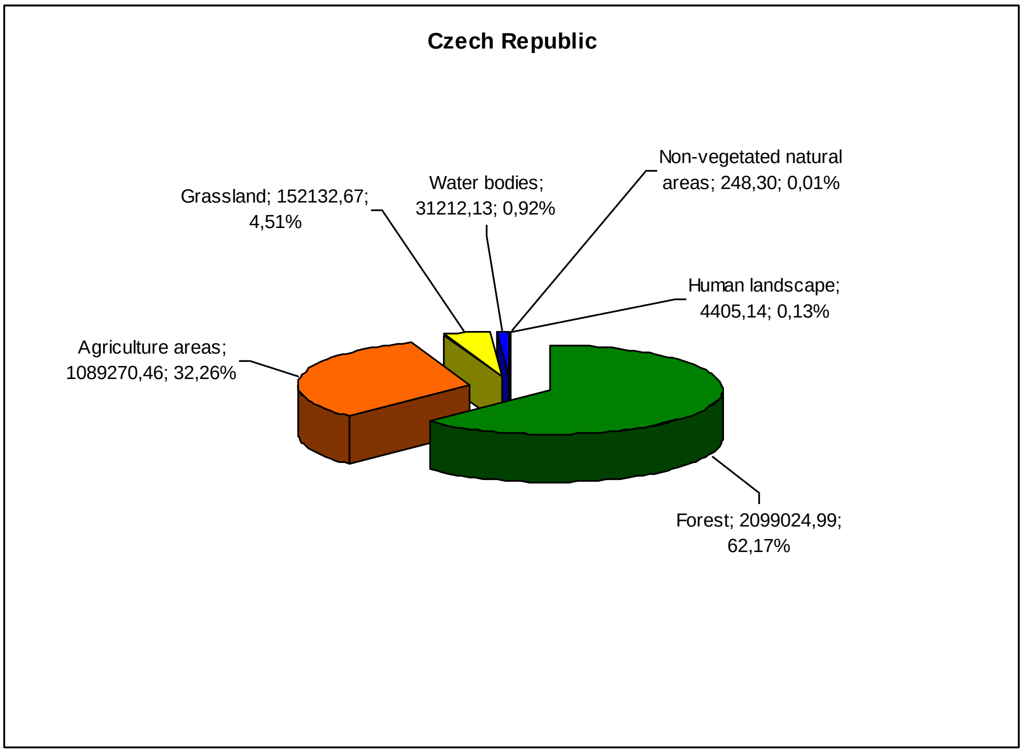
3.3. Evaluation of ecological network for large mammals with respect to Corine Land Cover (CLC)

CLC is a part of the European Commission programme COoRdinate INformation on the Environment. The CLC database is a key database for integrated environmental assessment. It provides a pan-European inventory of land cover, divided into main 44 categories, available as vector data. For further analyses we have merged habitat types into following six categories: forest, grassland, non-vegetated natural areas, human landscape, agricultural land and water bodies (see tab. 15). Corine Land Cover 2006 seamless vector data - version 13 (02/2010) were downloaded from EEA database accessible at www.eea.europa.eu.

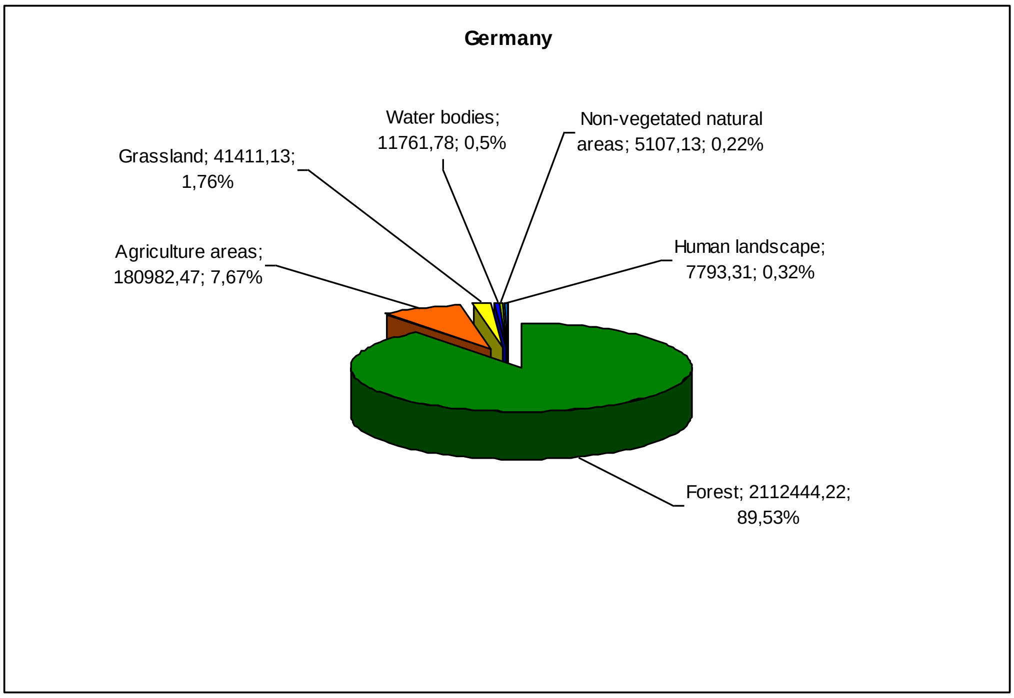
Table 14. Six main habitat categories divided to sub-categories of Corine Land Cover classes that were used in analysis.

Forest	**Grassland**	**Non-vegetated natural areas**	**Human Landscape**	**Agricultural areas**	**Water bodies**
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-Vineyeards	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	

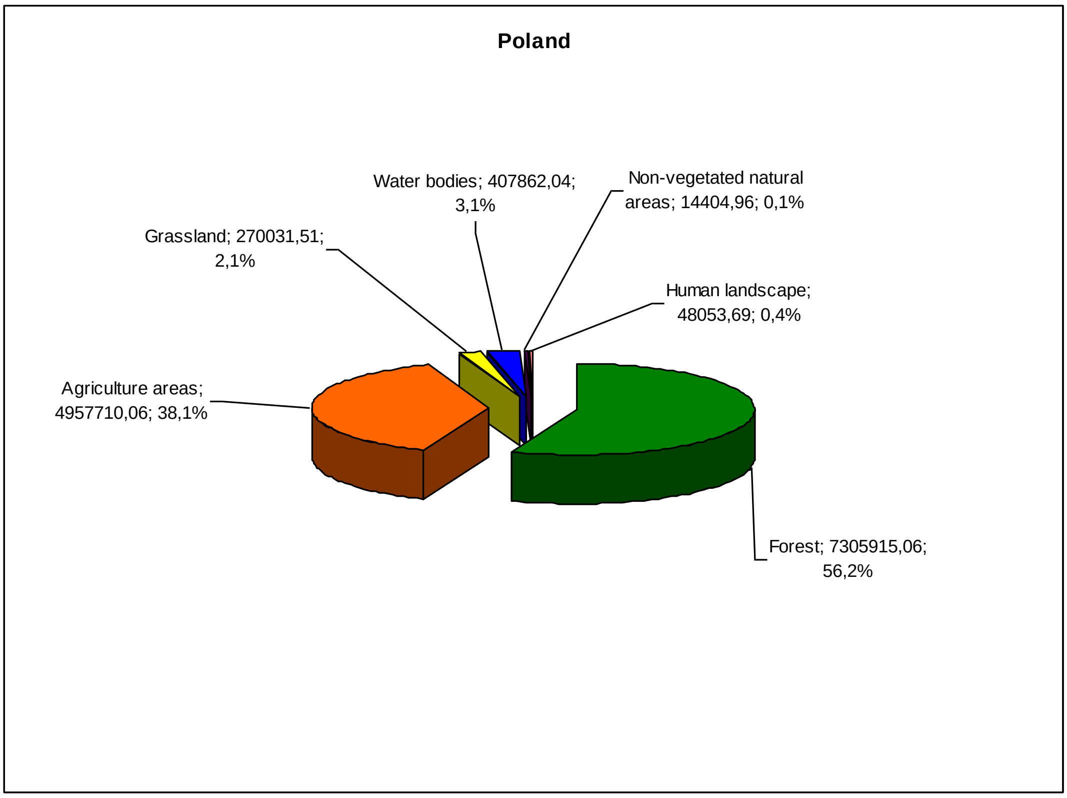
Graph 1: CLC categories in the Czech ecological network. The number for each category indicates the total area (ha) and share within the national network.



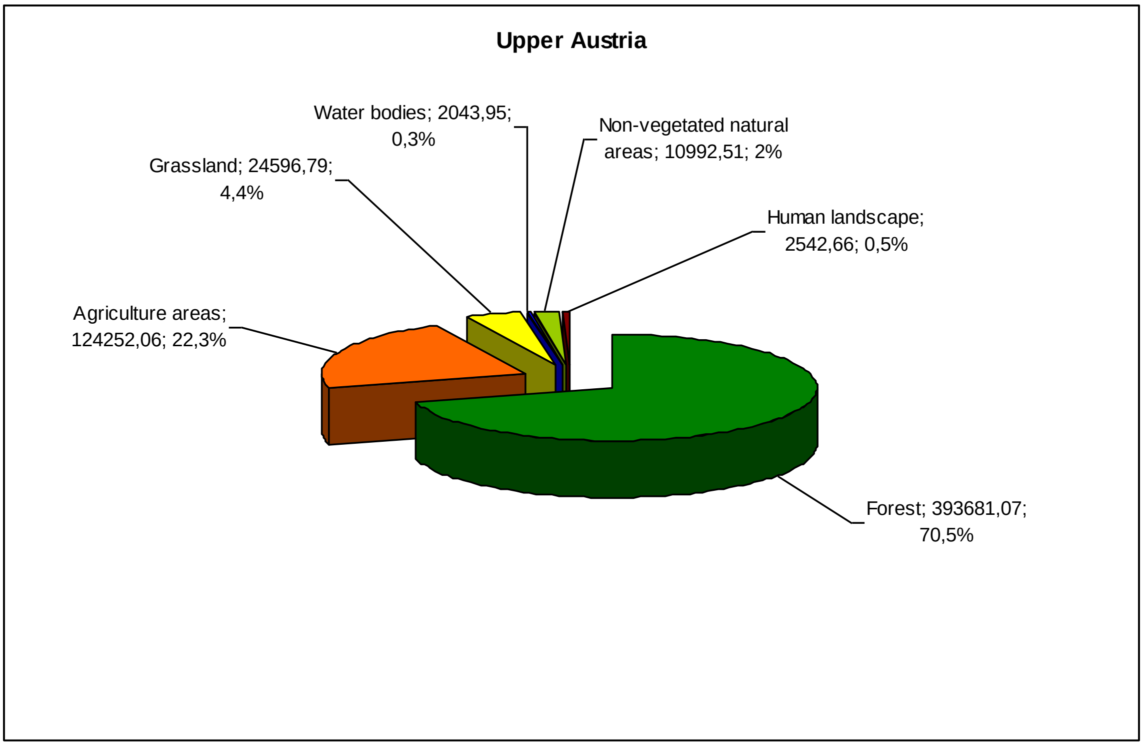
Graph 2: CLC categories in German ecological network. The number for each category indicates the total area (ha) and share within the national network.



Graph 3: CLC categories in Polish network. The number for each category indicates the total area (ha) and share within the national network.



Graph 4: CLC categories in Upper Austrian network. The number for each category indicates the total area (ha) and share within the national network.



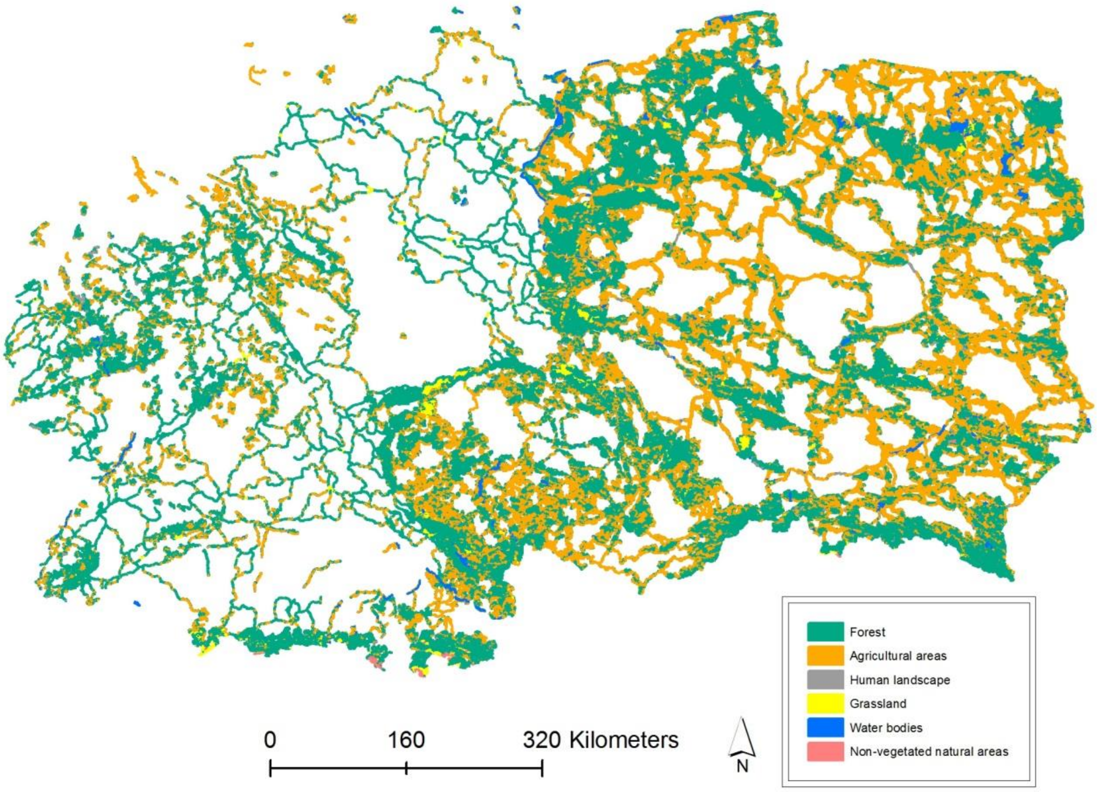


Figure 60. The distribution of six main Corine Land Cover categories (agricultural areas, forest, grassland, non-vegetated natural areas, water bodies, human landscape) within the central European ecological network.

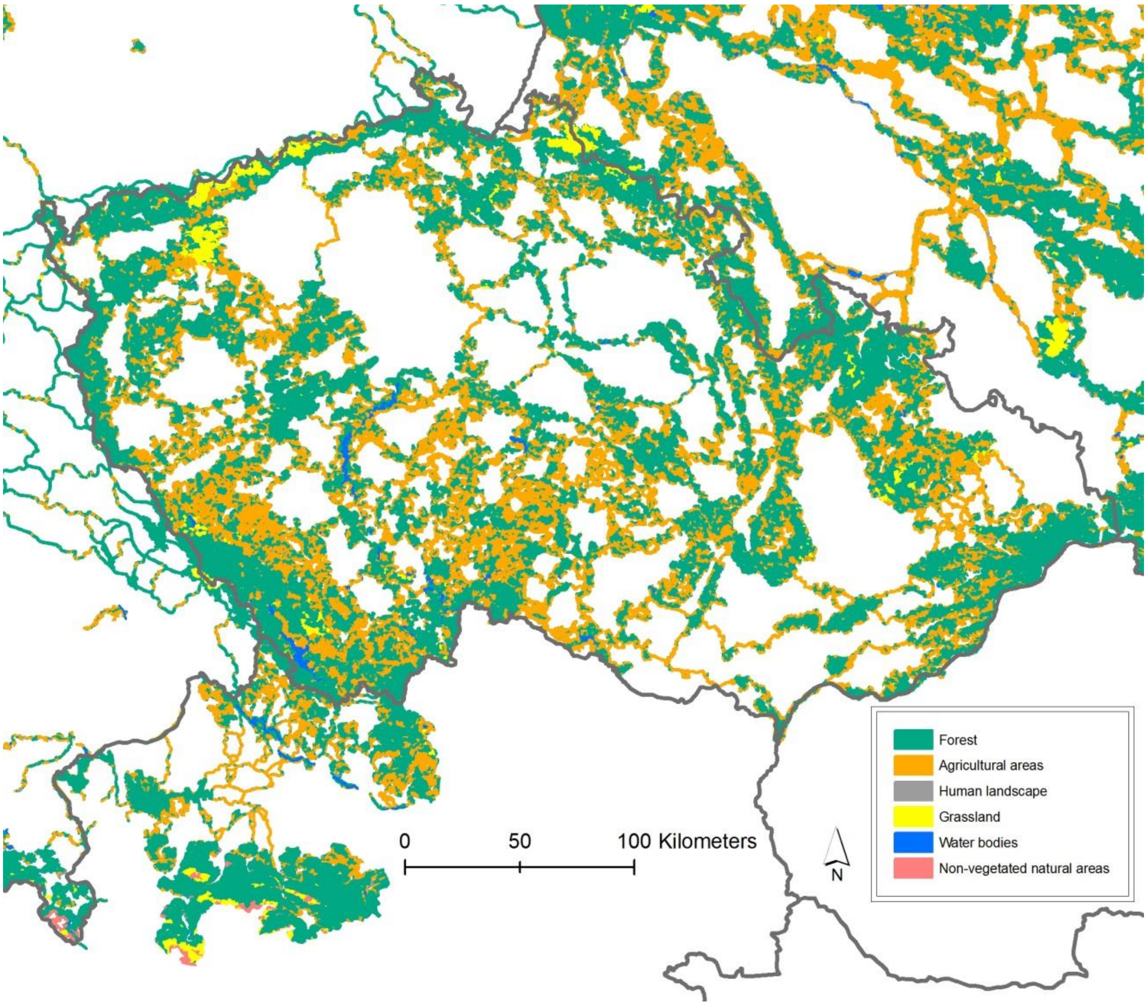


Figure 61. The distribution of six main Corine Land Cover categories (agricultural areas, forest, grassland, non-vegetated natural areas, water bodies, human landscape) in the Czech ecological network.

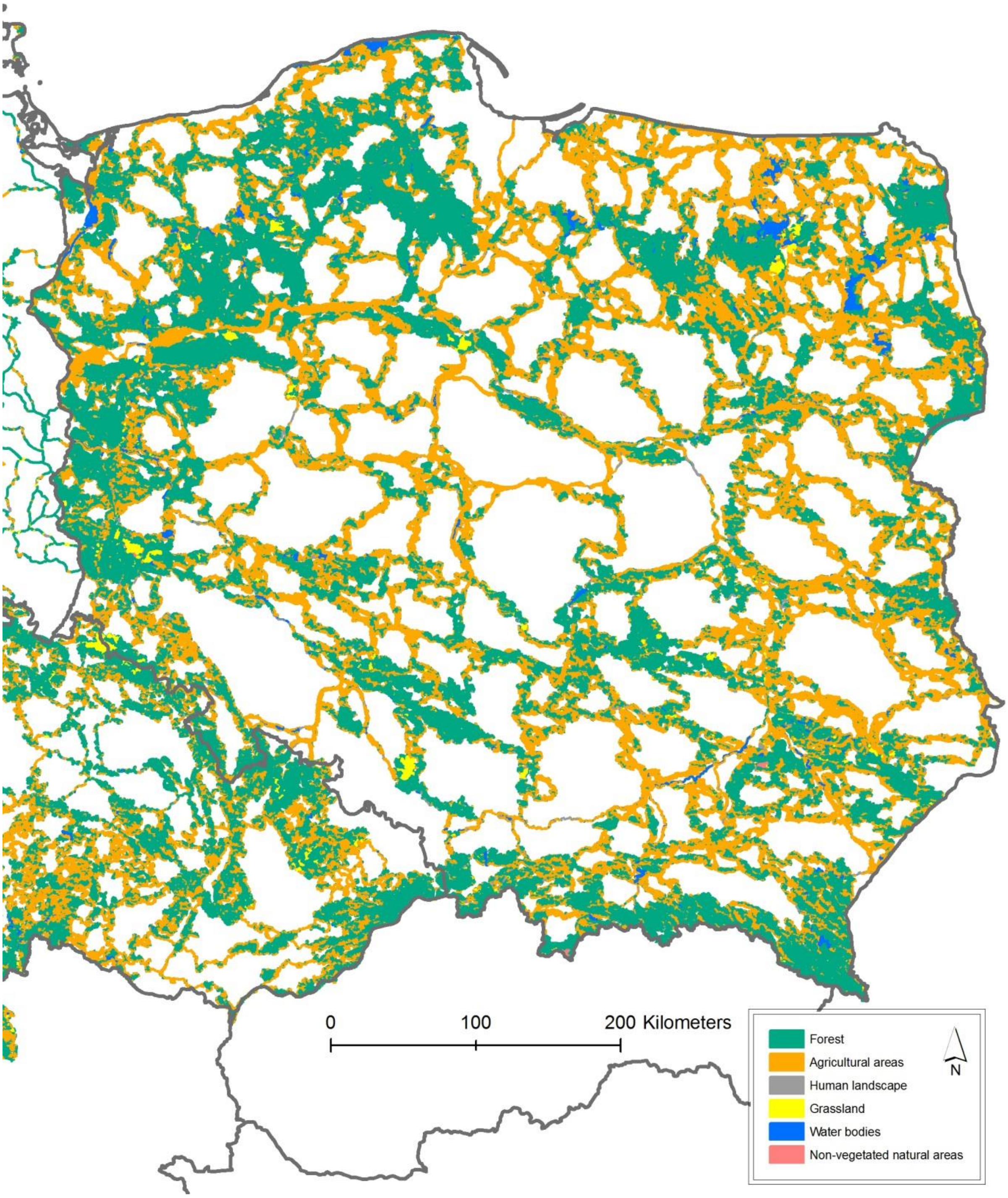


Figure 62. The distribution of six main Corine Land Cover categories (agricultural areas, forest, grassland, non-vegetated natural areas, water bodies, human landscape) in the Polish ecological network.

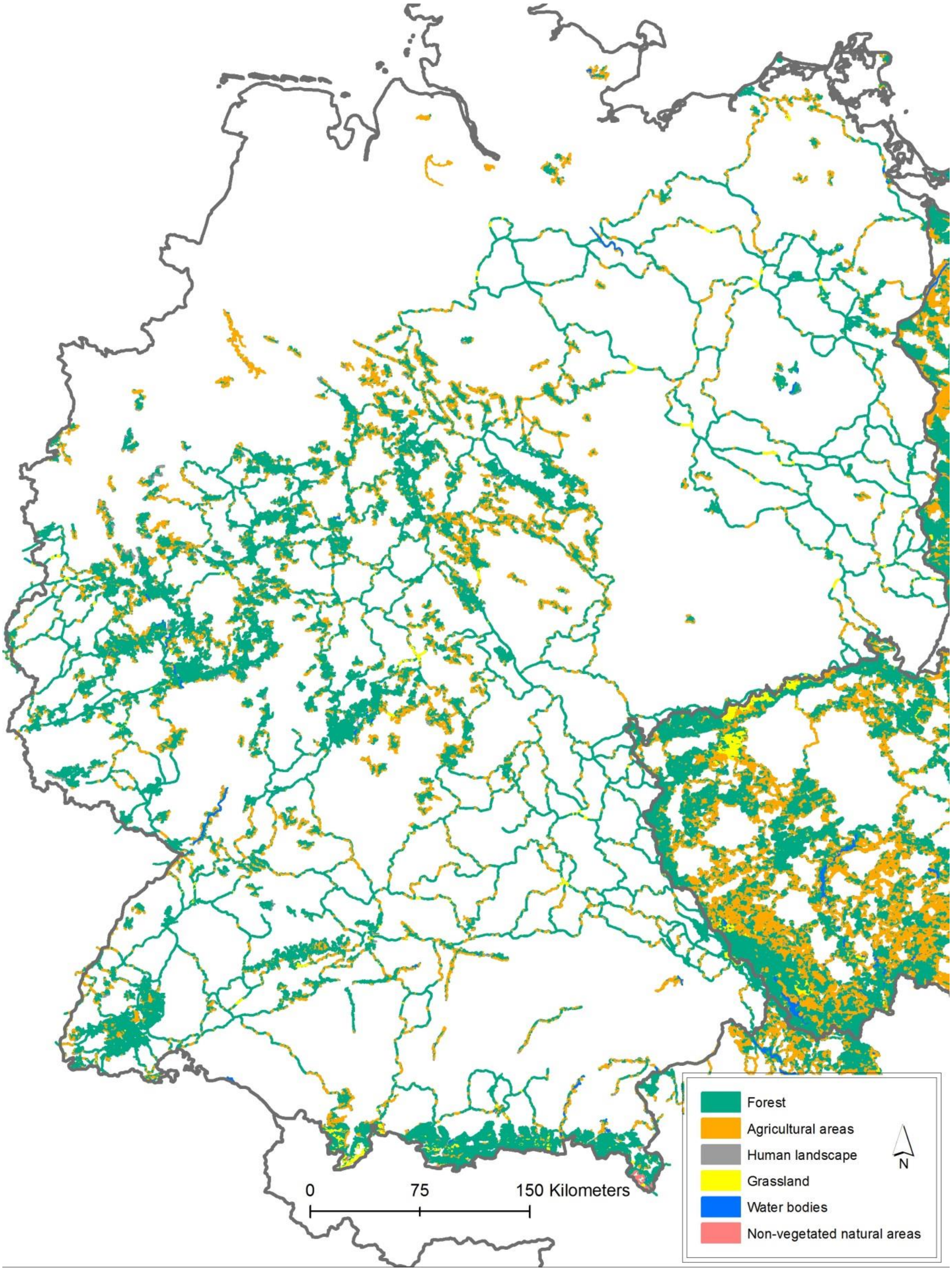


Figure 63. The distribution of six main Corine Land Cover categories (agricultural areas, forest, grassland, non-vegetated natural areas, water bodies, human landscape) in the German ecological network.

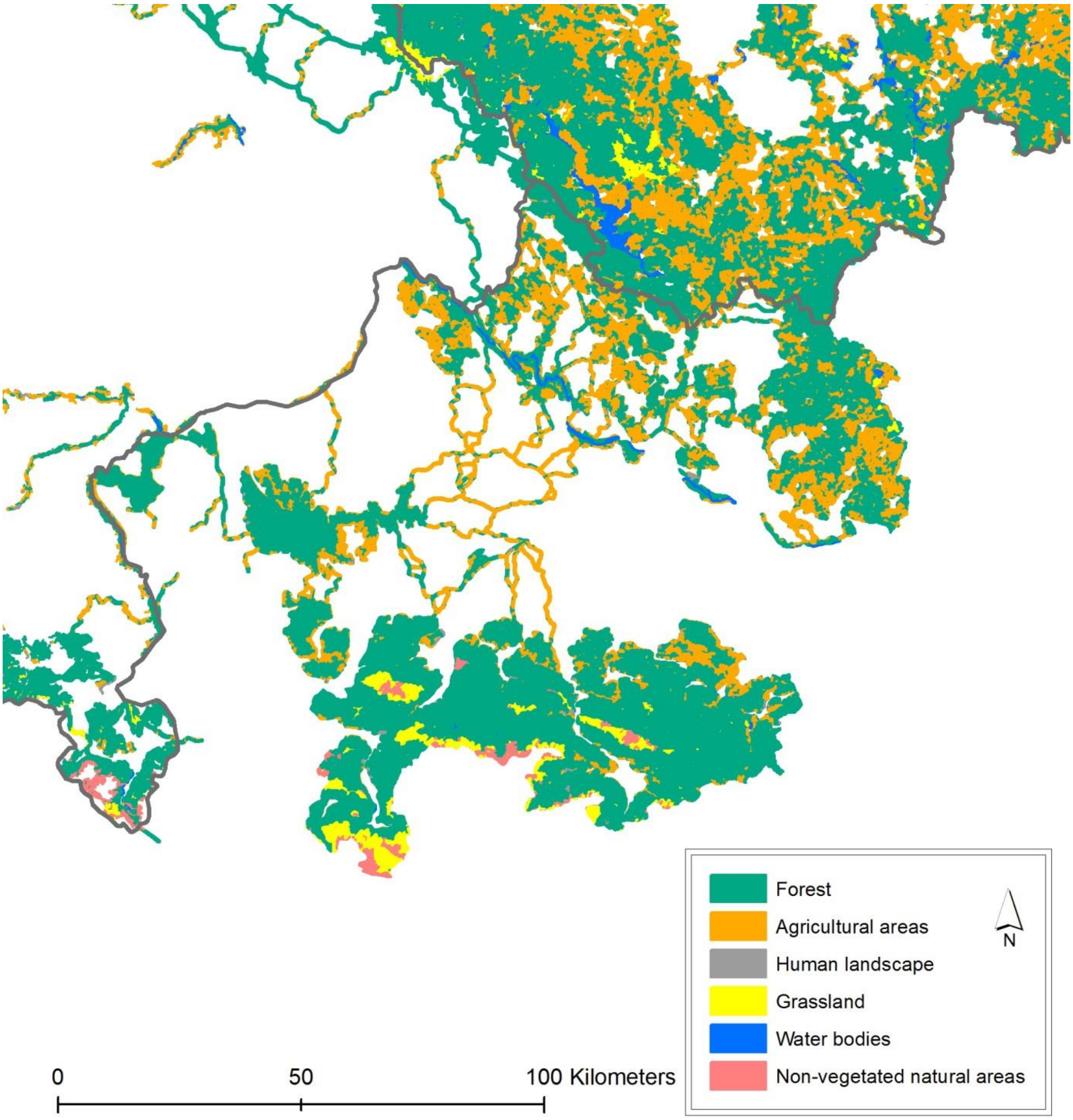


Figure 64. The distribution of six main Corine Land Cover categories (agricultural areas, forest, grassland, non-vegetated natural areas, water bodies, human landscape) in the Upper Austrian ecological network.

Discussion:

The most frequent Corine land cover category within the proposed ecological network for large mammals is undoubtedly the category forest. This result is consistent through all countries. The biggest share of the forest category within the whole ecological network can be found in Germany (89,53%) following by Upper Austria (70,5%), Czech Republic (62,17%) and Poland (56,2%). The agricultural areas category has been identified to be the second most represented within the ecological network also in all respective counties. This category accounts for the highest share in Poland (38,1%), followed by the Czech Republic (32,26%), Upper Austria (22,3%) and Germany (7,67%). The third category, which is also represented identically in all four countries, is grassland category. The biggest shares of the grassland can be found in the Czech republic (4,51%) and Upper Austria (4,4%), while this category is represented in much lower shares in Poland and Germany (2,1% and 1,76%) respectively. The other three remaining categories (water bodies, non-vegetated natural areas and human landscape) made up really minor portion of the whole network in the respective country - Poland 3,6%, Upper Austria 2,8%, Czech Republic 1,06% and Germany 1,04%. The water bodies category is prevailing in three countries (Poland 3,1%, Czech Republic 0,92% and Germany 0,5%), while in Upper Austria non-vegetated natural areas predominates (2%). Very pleasing finding is that the human landscape category is almost absent within the ecological network – Upper Austria 0,5%, Poland 0,4%, Germany 0,32% and Czech Republic (0,13%).

From above mentioned results (figs. 60-64) is obvious that the ecological network proposals are very consistent in country comparisons. As the large mammals are primarily forest dependent species, it is not surprising that the CLC forest category is the most frequent within the network in all the countries. On the other hand, the agricultural areas and grassland categories were identified to be next most frequent, although these habitats rather hinders than facilitates large mammals migration. The attention has to be paid especially to non-forested areas that host the majority of migration barriers or can be a barrier just by themselves. In these areas mitigation measures should be prepared. One of the positive results is the fact that the ecological network in the countries consists of negligible share of human landscape category. However, this category could be rather underestimated because of the resolution of CLC layer. Especially small scale and loose towns and villages can be associated with agricultural and grassland categories. The last mentioned categories occurring in synergy are often regarded as barriers in the bottlenecks of corridors.

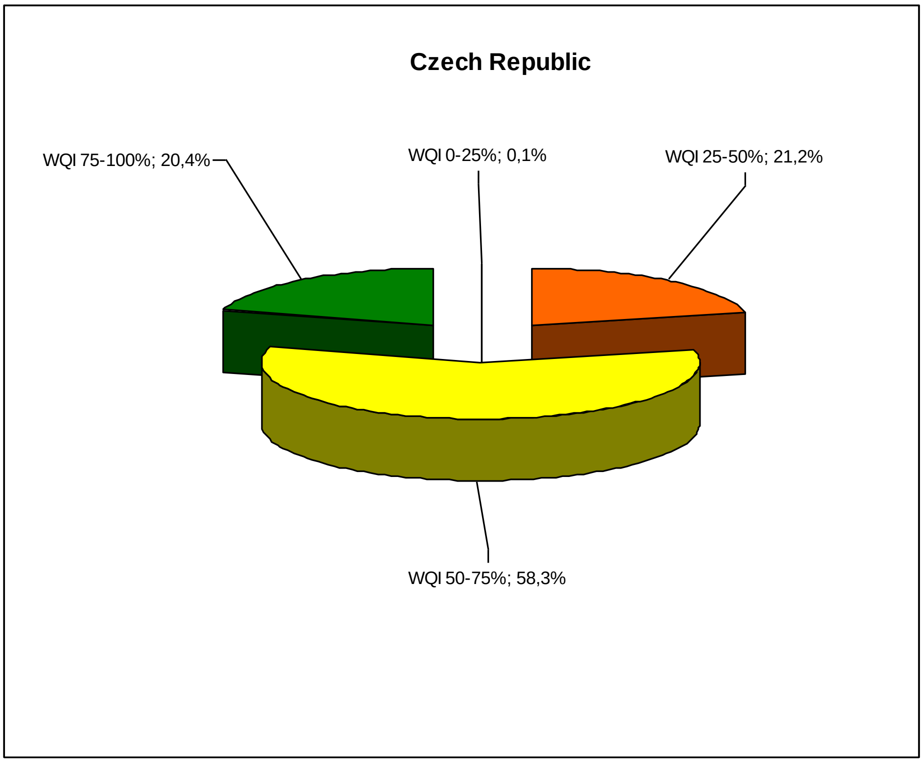
3.4. Evaluation of ecological network for large mammals with respect to Wilderness Quality Index (WQI)

Wilderness quality index is based on the factors such as distance from nearest road or railway, population density, land use and terrain ruggedness. For this analysis we have used raster data Map_4_3_wilderness.tif for Wilderness Quality Index (WQI) including terrain ruggedness for Europe provided by Mette Lund from the EEA and Marcus Zisenis (Downloaded 25.7.2012 from http://www.eea.europa.eu/data-and-maps/figures/wilderness-quality-index, https://dsifilex.mnhn.fr/get?k=kl5p3SIyA4az106VJEp).

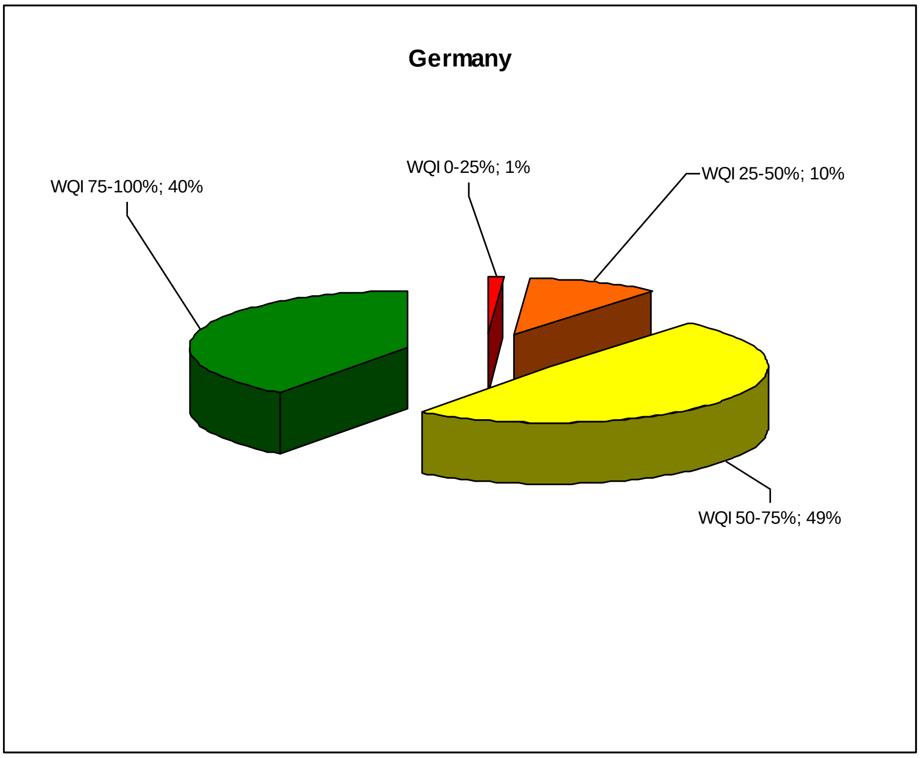
Provided raster data were converted into a single shapefile layer, georeferenced and the same projected coordinate system as layer of ecological network in Central European countries was assigned. For further analysis we have divided the whole WQI scale range into four major categories. The data layer contained wilderness quality index in the scale from 69 – 163. We have sorted categories of wilderness quality index as follows:

1) the lowest WQI category 69 – 92 (0-25%)
2) lower WQI category 93 – 115 (25-50%)
3) higher WQI category 116 – 138 (50-75%)
4) the highest WQI category 139 – 163 (75-100%)

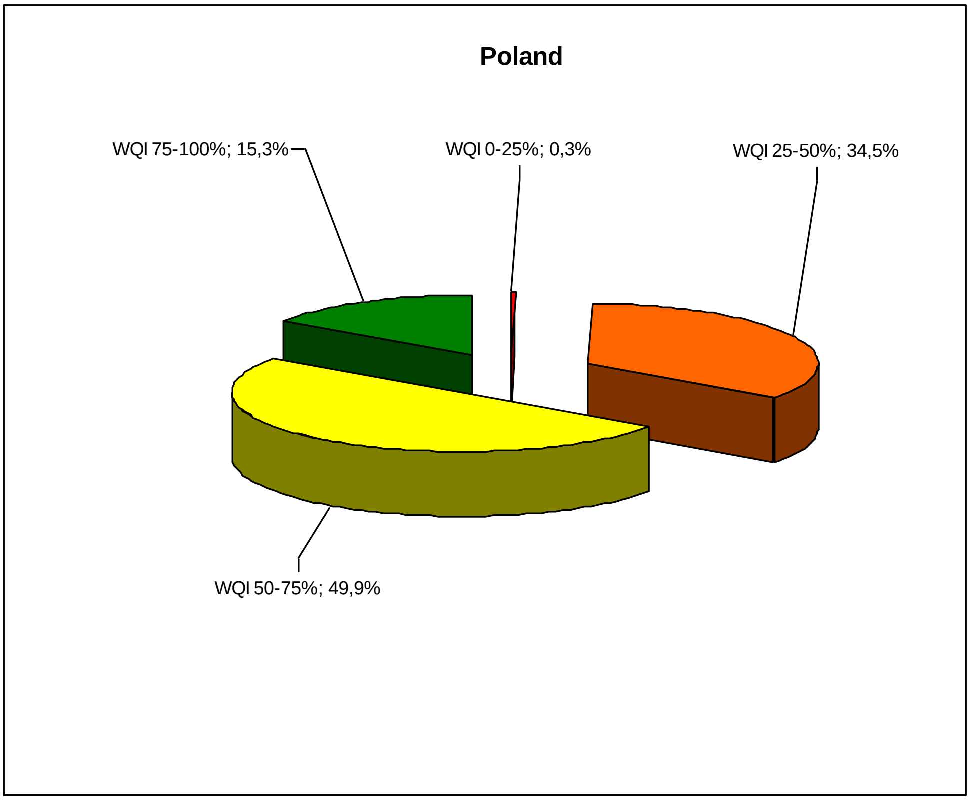
Graph 5. Wilderness Quality Index categories within the Czech ecological network.



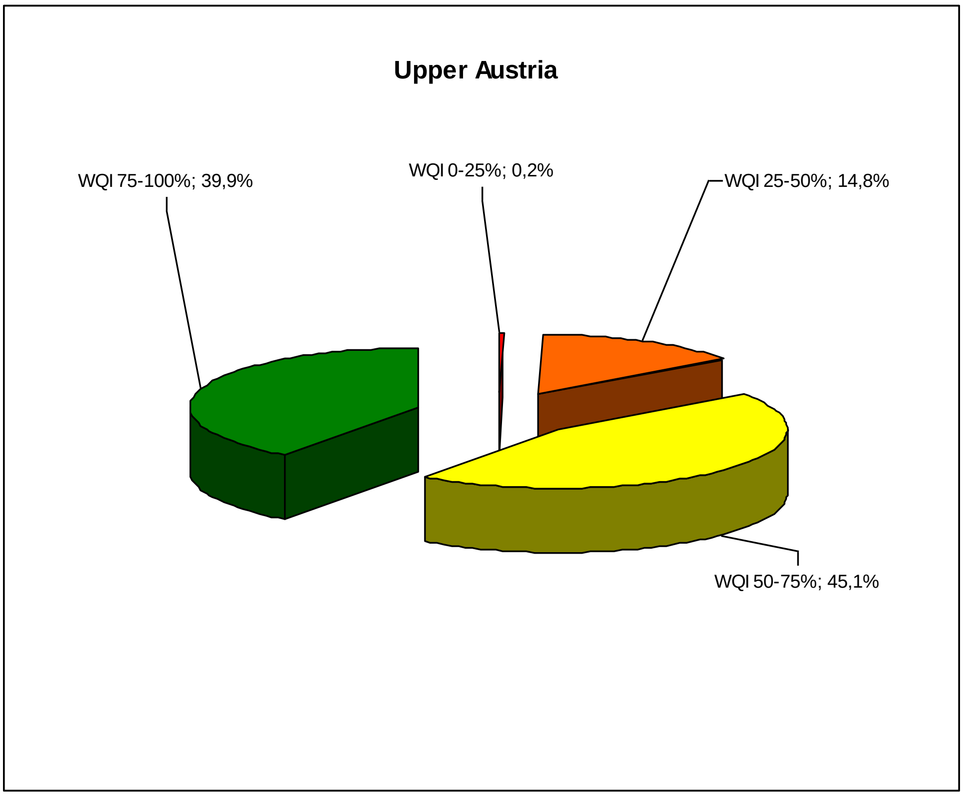
Graph 6. Wilderness Quality Index categories within German ecological network.



Graph 7. Wilderness Quality Index categories within Polish ecological network.



Graph 8. Wilderness Quality Index categories within Upper Austrian ecological network.



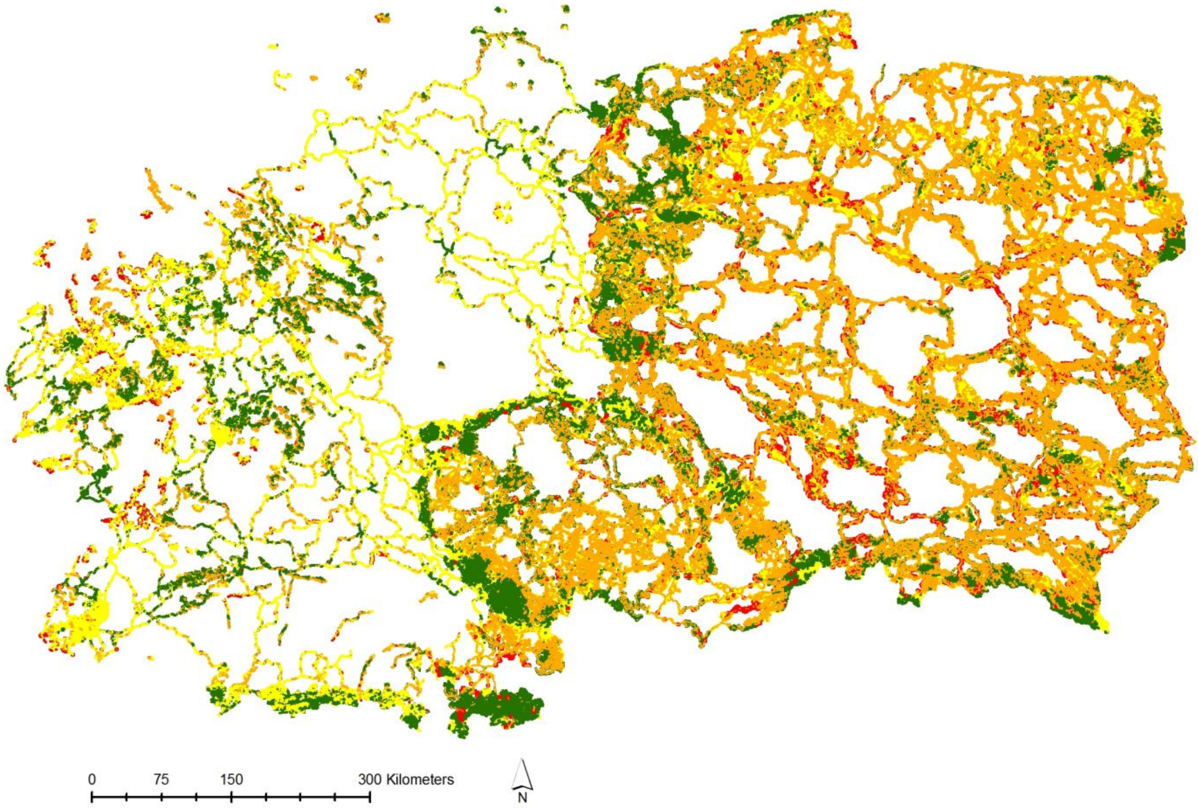


Figure 65. Wilderness Quality Index categories within ecological network in the Central Europe. Category 0-25% WQI depicted in red, category 25-50% WQI in orange, category 50-75% in yellow and category 75-100% WQI in green.

Discussion:

The majority (78,7%) of ecological network in the Czech Republic is covered by areas with high WQI (50-100% WQI). Low WQI areas (0-50% WQI) occupy only 21,3% of the network. Most of the low WQI areas appeared to be in lowlands of southern Moravia and central Bohemia north and east from capital city of Prague, which is depicted in red colour on fig. 65.

The ecological network in Germany is constituted almost solely by high quality areas with best WQI. Two highest WQI categories (50-100% WQI) cover 89% of the whole network. The two lowest WQI categories (0-50% WQI) are often found within core areas and corridors in the western, the most urbanized, part of the country, which occupy remaining 11% of the country's ecological network.

65,2% of the Polish ecological network is covered by two best WQI categories (50-100%). This is significantly lower share than in Czech Republic (13,5% higher share) and Germany (23,8% higher share). The biggest part of the country's ecological network consists of areas with category 50-75%, which is almost 50% (49,9%). This is presumably caused by the geographic attributes as the Poland lies in lower altitudes and the percentage of forest cover is also lower.

The ecological network in Upper Austria is composed by incredible WQI amount in two highest categories (50-100% WQI), which in total reach to 85%. Two other WQI categories make up only 15% of the network. This is also probably caused by the inclusion of vast forested core areas located in the Alpine mountains.

According to above mentioned findings, it is largely evident, that the ecological network in Central Europe is made up of better WQI categories. This is largely due to the fact that ecological network is primarily planned in mountain and foothill areas with higher altitude. Another factor that reflects quality of WQI is also the prevailing forest cover. Because the presented ecological network is planned for large mammals, living in large forested areas, both outputs such as WQI and ecological network will be probably to large extent positively correlated.

3.5. Evaluation of biological corridors for large mammals with respect to main cities

Analyses in this chapter and following chapter 3.6. are based on merged shapefile of biological corridor network from the Czech Republic, Germany and Upper Austria. **This network consists solely of 500 m wide corridors, excluding core areas and stepping stones.** Corridor network in Poland is a different case: it is planned to encompass broad areas of the landscape covering also core areas and stepping stones, therefore the respective national layer remained unchanged during further network evaluation (see fig. 66).

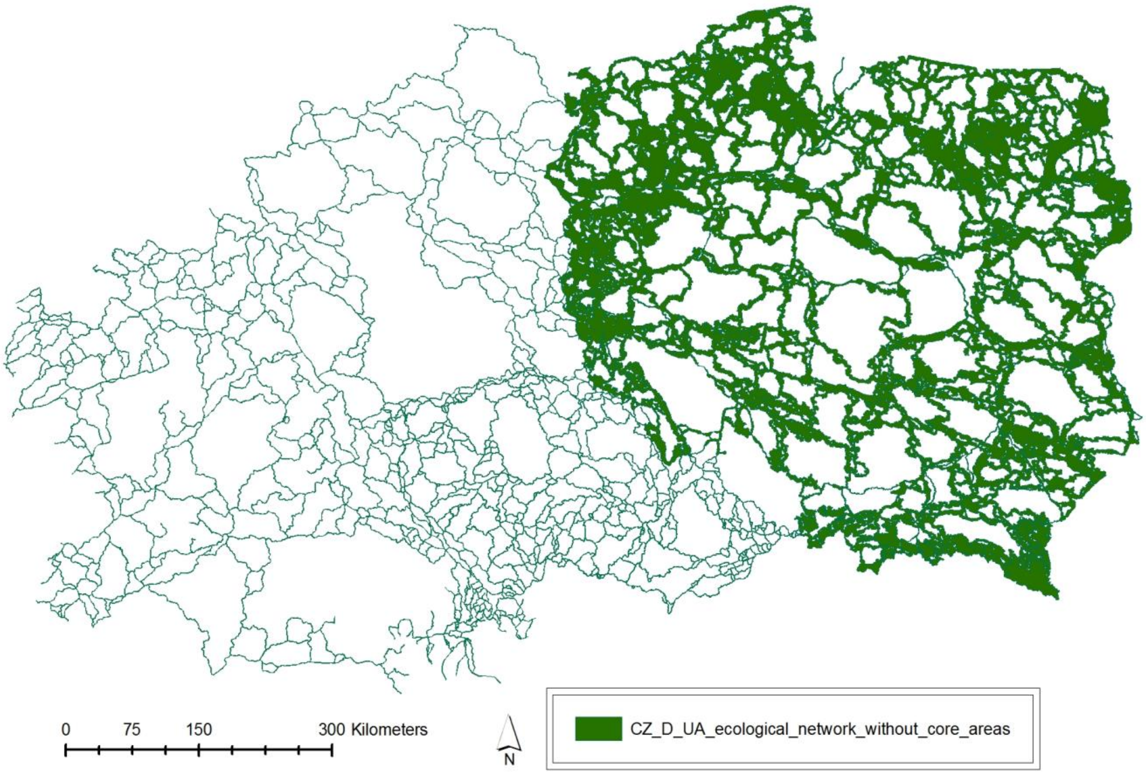


Figure 66. Biological corridors with 500 m wide buffer zone in the Czech Republic, Germany and Upper Austria. Polish corridor network remained the same without any changes.

The main aim of analysis in this chapter was to identify such places within the ecological network, which are to some extent negatively influenced by the presence of existing urbanized area. We have done two comparisons. In the first case, the biological corridors in the Czech Republic, Germany and Upper Austria were prepared with the **500 m wide buffer zone**. The Polish proposal encompassing wide areas remained the same in all analyses. The second variant of the analysis predicts conflict areas, interfering with the ecological functions of the network in the future. These are mainly new zones around human settlements and/or transportation infrastructure. Any further expansion of these areas should be therefore assessed as to their possible impact on the landscape permeability for migrating animals. In the second case **the 1 km wide buffer zone** around the corridor axis has been used in the three countries (CZ, D and UA). This analysis has been done by using the ESRI (ESRI 2008) polygon layer containing main European cities.

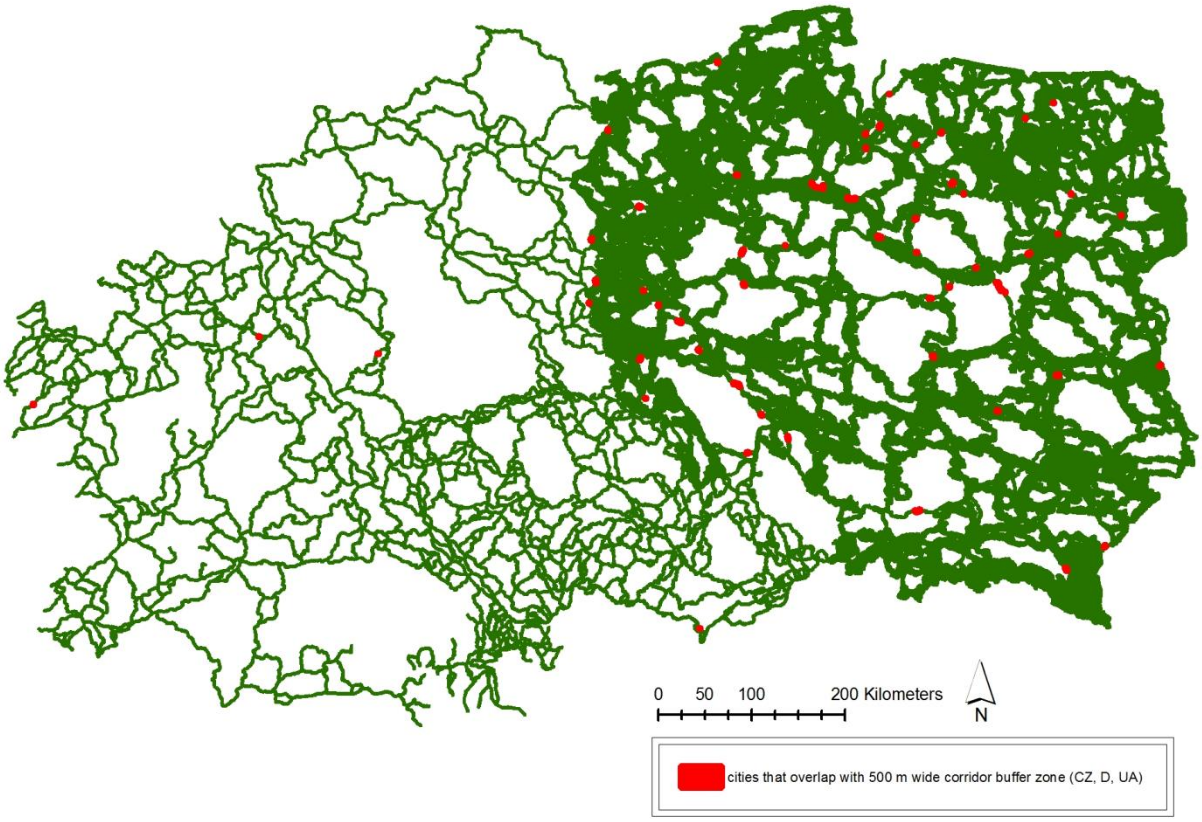


Figure 67. Cities that partially overlapped with corridor network. Corridors in the Czech Republic, Germany and Upper Austria were prepared with **500 m wide buffer zone**. The Polish corridor network remained unchanged.

Table 15. City that partially overlapped with biological corridor in the Czech Republic.

Country	**City**	**City overlap area (ha)**
Czech Republic	BŘECLAV	1,57

Table 16. Cities that partially overlapped with biological corridors in Germany.

Country	**City**	**City overlap area (ha)**
Germany	TRIER	20,69
	BAD HERSFELD	15,23
	JENA	12,91

Table 17. Cities that partially overlapped with biological corridors in Poland.

Country	**City**	**City overlap area (ha)**
Poland	TORUN	355,78
	WARSZAWA (WARSAW)	258,62
	WLOCLAWEK	228,44
	WROCLAW BRESLAU	184,77
	DZIALDOWO	166,63
	GLOGOW	163,61
	KRAKOW	141,09
	PULAWY	111,39
	POZNAN	106,57
	WYSZKOW	86,29
	OPOLE	74,72

TOMASZOW MAZOWIECKI	74,14
WLODAWA	69,66
BOLESLAWIEC	61,55
BYDGOSZCZ	59,22
SANOK	57,23
NOWE	44,74
GORZOW WIELKOPOLSKI	42,23
STARACHOWICE	39,69
BRZEG	38,00
SCINAWA	34,94
SIERPC	34,00
FRANKFURT AN DER ODER	30,63
NOWA SOL	29,51
GUBIN	29,02
NYSA	27,17
KWIDZYN	26,95
SREM	25,28
LOWICZ	25,18
PRZEMYSL	20,07
OSTRODA	19,83
SOCHACZEW	19,08
ZIELONA GORA	17,72
MRAGOWO	12,66
GRUDZIADZ	10,98
PILA	10,07
SZCZECIN	7,89
NOWY DWOR MAZOWIECKI	7,42
LAPY	6,66
LOMZA	5,15
KOSZALIN	5,04
MALBORK	4,25
OSTROW MAZOWIECKA	3,20
PLOCK	2,92
FORST	1,45
ILAWA	1,13
MLAWA	0,91
GNIEZNO	0,52
JELENIA GORA	0,51
GIZYCKO	0,20

Table 18. Total area of city overlap with 500 m wide corridor in CZ, D and Polish corridor network.

Country	**Total area of city overlap with 500 m wide corridor (ha)**
Poland	2784,71
Germany	48,83
Czech Republic	1,57

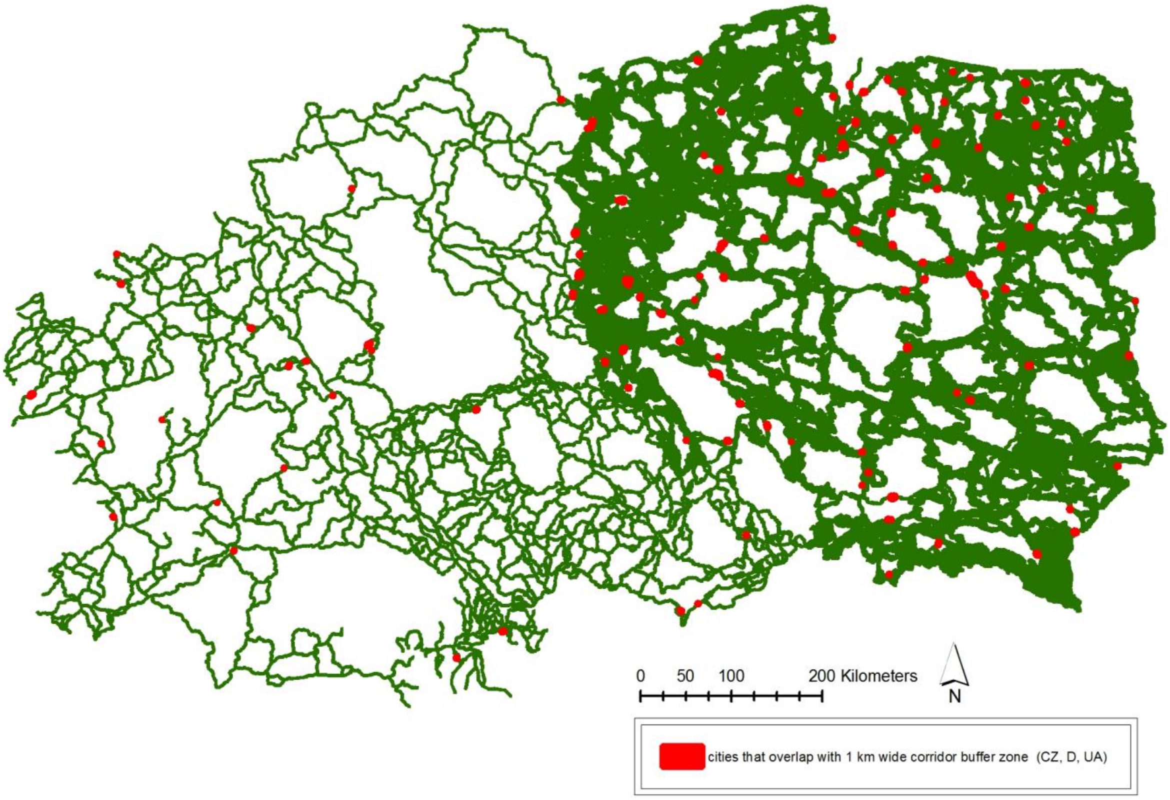


Figure 68. Cities that partially overlapped with corridor network. Corridors in the Czech Republic, Germany and Upper Austria have **1 km wide buffer zone**. Polish ecological network remained the same as in all previous figures.

Table 19. Cities that partially overlapped with 1 km wide buffer zone around biological corridor in the Czech Republic.

Country	City	City overlap area (ha)
Czech Republic	BRECLAV	159,11
	HRANICE	107,61
	CHOMUTOV	46,78
	HODONIN	38,96

Table 20. Cities that partially overlapped with 1 km wide buffer zone around biological corridor in Upper Austria.

Country	City	City overlap area (ha)
Upper Austria	LINZ	117,58
	VOCKLABRUCK	29,71

Table 21. Cities that partially overlapped with 1 km wide buffer zone around biological corridor in Germany.

Country	City	City overlap area (ha)
Germany	JENA	251,03
	TRIER	220,43
	GUMMERSBACH	121,38
	MEININGEN	106,35
	BAD HERSFELD	75,165
	BADEN-BADEN	66,81
	SUHL	45,20
	KAISERSLAUTERN	34,54
	TORGELOW	28,69
	SONNEBERG	25,59

HEIDENHEIM AN DER BRENZ	14,55
WOLFSBURG	12,67
NEUSTADT AN DER AISCH	2,02
DARMSTADT	1,58
SCHWABISCH HALL	0,51
HAGEN	0,08

Table 22. Total area of city overlap with 1 km wide corridor buffer zone in the three countries (D, CZ, UA).

Country	Total area of city overlap with 1 km wide corridor buffer zone (ha)
Germany	1006,58
Czech Republic	352,46
Upper Austria	147,29

Discussion:

The highest number of cities, that lies with at least some part of their area in the proposed ecological network, can be found in Poland. Altogether fifty cities somehow overlaps with the proposed network. To some extent this can be a by-product of our analysis: on the edges of polygons small overlap between two layers (ecological network layer and city layer) may occur because of layers' imperfections. However, nine cities overlaps with ecological network more than by 100 ha (Torun, Warszawa, Wloclawek, Wroclav Breslau, Dzialdowo, Glogow, Krakow, Pulawy and Poznan). These cities are located rather in the north and south-central part of the country. Other seven cities: Wyszkow, Opole, Tomaszow Mazowiecki, Wlodawa, Boleslawiec, Bydgoszcz and Sanok overlaps with the ecological network by more than 50 ha. This partial inclusion of cities into the polish ecological network is probably caused by the methodology of the network delineation: polish network is proposed on the national scale, it covers broad areas (wide landscape corridors) without taking into account the local situation. Thus, areas with unfavourable habitats or even migration barriers like roads and cities are into small extent incorporated into the network.
The intact polish areas are located especially in the Carpathians, along polish eastern border and in the north western part of the country.

When we compare the situation in the three remaining countries (CZ, D, UA), where the 500 m and 1000 m wide buffer zones around the corridor axis has been prepared, we can see much lower degree of corridor overlap with city area. In the first case, when we used 500 m buffer zone around corridors, only three cities that are in conflict with corridor area were identified in Germany. These are the cities of Trier, Bad Hersfeld and Jena, which are located in western or central, very urbanized part of Germany. Their area overlaps with corridors only up to 20 ha, which is negligible share. The only city that has been included to corridor area in the Czech Republic is the city of Břeclav, which is located in south-eastern part of the country in the lowlands, where is the lack of forested area. Neither city turned out to be included in the corridor network that had 500 m wide buffer zone in the Upper Austria.

In order to model future situation, when the city suburbs will spread into the surroundings, we tried to evaluate the possible city conflicts with 1 000 m wide buffer zone around the corridor axis. This was done again only in the Czech Republic, Germany and Upper Austria. In total, sixteen cities had overlapped with corridor in Germany, especially in the central and western part of the country (see tab. 21).

Four cities, namely Břeclav, Hranice, Chomutov and Hodonín, are expected overlap with ecological network in the Czech Republic in the future. Especially the surroundings of the Hranice city is nowadays regarded as the most critical section for migration of large mammals between eastern Carpathians and northwestern parts of our country. This is largely due to the fact that the lowland between the two forested areas is already divided by (for migrating animals) hardly permeable highway.

The surroundings of the biggest cities such as Linz and Vocklabruck is expected to be the most affected by the urban sprawl in the Upper Austria.

We recommend that the future development of all the above mentioned cities should be monitored and their possible negative impacts on the landscape permeability for migrating animals should be assessed and prevented in spatial planning processes.

3.6. Evaluation of biological corridors for large mammals with respect to road network

As a basic source for road network in the Europe served the layer, which was downloaded from following web page for free - http://www.mapcruzin.com/free-europe-arcgis-maps-shapefiles.htm. We used this layer for three following states only: Poland, Germany and Upper Austria. We further selected only attribute motorway from this source layer. The basic road network data in the Czech Republic was derived from Database of Geographic Datasets of the Czech Republic (® ZABAGED), which is produced and updated by organizations of the Czech Office for Surveying, Mapping and Cadastre (ČÚZK). The categories highway and speedway were used in the Czech Republic. Both data sources were merged into single road network layer in the central Europe and than intersected with the layer of ecological network (corridors only in CZ, D and UA) – see fig. 69.

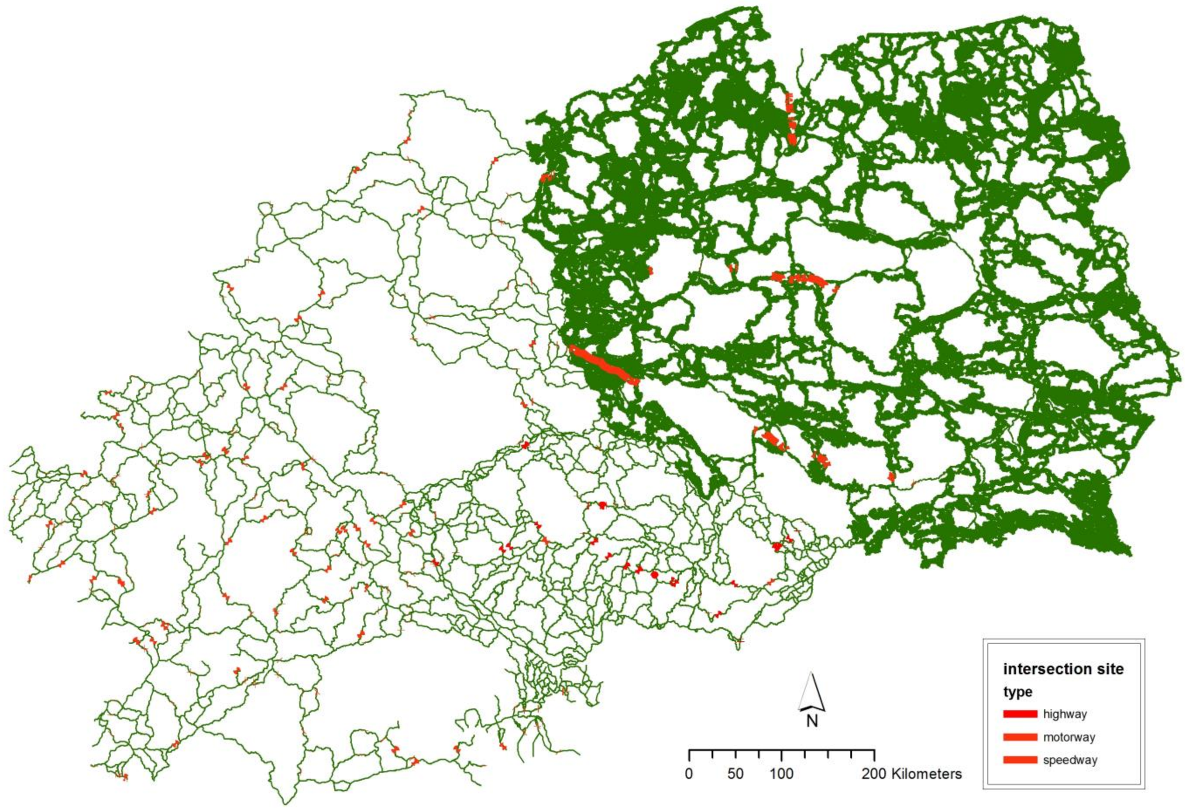


Figure 69. Map showing main intersection sites of biological corridors with highways and speedways in the Czech Republic and motorways in the Poland, Germany and Upper Austria.

Discussion:

Traffic infrastructure has been identified to be one of the most critical barriers hindering free animal migration through the landscape. For the analysis we have chosen presumably the most problematic structures: highways, motorways and speedways, which carry also the highest traffic volumes.

In the Poland, critical sites for migration have been identified on five main highways. Highway A1 in central part of the country leading from north to south. Highway A2 in the central part leading in east-west orientation. Highway A4 is being built in southern part of the country also in east-west orientation. The beginning of this road in the southwestern part of the country is labelled A18, this also crosses the ecological network. Highway A6 interferes with ecological network in the north-western part of the country close to Szczecin city near German border. The ecological network in the whole eastern part of the Poland seems to have been intact by transportation infrastructure until now. However, new highways are currently being planned and built, and therefore great emphasis should be taken on the mitigation measures proposal.

The critical highway crossings have been identified on five highways, D1, D2, D5, D8 and D11, in the Czech Republic. Most critical is the situation on the oldest highway D1, which is intersecting the ecological corridors in the highlands in length at about 200 km. This highway is hardly permeable for large mammals, because there is no suitable overpass and only several underpasses with inproper dimensions and/or unsuitable surroundings. Barrier section has been identified also on the highway D2, which continuously adjoins D1 in the north-east direction towards the Poland. The bottleneck section of the highway is located near the city of Hranice, in the lowland, where the combination of barriers hinder considerably migration between two large forest complexes (see Chapter 3.5.). Highway D11, where some barrier sections were also located, is newly built one with probably the highest concentration of mitigation measures (underpasses and/or overpasses). Unfortunately, this doesn't apply for the highway D5, which cross the western part of the country in east-west direction. On this highway four barrier sections have been identified. Moreover, other six speedways 4, 6, 10, 35, 52, 55 were identified to cross the corridors in several barrier sections. The high number of barrier sections is distributed also on speedway leading from Prague north to the city of Turnov (R10).

The transportation network in Germany is much denser than in other three studied countries. With this respect, it is not so much surprising that the list of motorways that interfered with the ecological network includes 41 items (motorway number: A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11-A15, A17, A19, A20, A24, A35, A38, A44, A45, A46, A48, A60-A66, A70-A73, A81, A93, A95, A96, A98, D5, E42). The identified barrier sites are more or less scattered throughout the whole country. One of the most obvious motorway cumulation is located up to 100 km from the most western part of the Czech Republic. On the opposite, the corridor areas that are weakly influenced by the presence of the motorways are located in the Alpine region, the border area along Czech Republic in Bavaria and Saxony and the area along the Polish border.

In total, four motorways A1, A7, A8 and A9 have been identified to cross the corridor network in the Upper Austria. The motorway A1 is cutting the corridors in southern part of the country in east-west direction. Two sections, where the motorway A7 cross the corridors, lie in the north-east part of the country. At least three sections of the motorway A8 cross the corridor network. This road is located about 15 km north from highway A1 in the central, lowland part of the country, where the cumulation of barriers causes critical obstacle for animal migration between core areas in the northern and southern (Alpine) part of the country.

3.7. Biological corridors in the Czech Republic and overlap with biotopes mapped according to NATURA 2000

This GIS analysis was based on intersection of the layer of biological corridors with 500 m wide buffer zone and the NATURA 2000 habitat mapping layer in the Czech Republic, which is managed by Nature Conservation Agency. The layer was originally prepared for SCI´s designation. However, this layer of biotopes is continuously updated according to new findings. These up-to date data are regularly acquired from field monitoring, done by many botanists from the whole country. We have used the last update of the biotope layer that was done in May 2012.

Table 23. List of biotopes, their area and percentage proportion within biological corridor network in the Czech Republic.

biotope code	biotope name	biotope area within biological corridor (ha)	biotope area within biological corridor (%)
-1	**non natural biotope**	**271424,75**	**56,0133**
A1	Alpine grasslands	122,49	0,0253
A2	Alpine and subalpine dwarf-shrub vegetation	90,34	0,0186
A3	Snow beds	0,00	0,0000
A4	Subalpine tall-herb vegetation	185,73	0,0383
A5	Cliff vegetation in the Sudeten cirques	0,47	0,0001
A6	Acidophilous vegetation of alpine cliffs and boulder screes	36,38	0,0075
A7	Pinus mugo scrub	247,69	0,0511
A8	Subalpine deciduous scrub	8,97	0,0019
K1	Willow carrs	329,29	0,0680
K2	Riverine willow scrub	187,89	0,0388
K3	Tall mesic and xeric scrub	1358,48	0,2803
K4	Low xeric scrub	3,29	0,0007
L1	Alder carrs	330,81	0,0683
L2	**Alluvial forests**	**10752,34**	**2,2189**
L3	**Oak-hornbeam forests**	**17926,97**	**3,6995**
L4	Ravine forests	2780,65	0,5738
L5	**Beech forests**	**43159,11**	**8,9066**
L6	Thermophilous oak forests	1243,69	0,2567
L7	**Acidophilous oak forests**	**9678,19**	**1,9973**
L8	Dry pine forests	2151,72	0,4440
L9	**Spruce forests**	**12954,43**	**2,6734**
M1	Reed and tall-sedge beds	1134,08	0,2340
M2	Vegetation of annual hygrophilous herbs	23,73	0,0049
M3	Vegetation of perennial amphibious herbs	1,79	0,0004
M4	River gravel banks	21,90	0,0045
M5	Petasites fringes of montane brooks	43,02	0,0089
M6	Muddy river banks	6,09	0,0013
M7	Herbaceous fringes of lowland rivers	24,13	0,0050
R1	Springs	138,10	0,0285
R2	Fens and transitional mires	395,70	0,0817
R3	Raised bogs	465,04	0,0960
S1	Cliffs and boulder screes	725,60	0,1497
S2	Mobile screes	17,31	0,0036
S3	Caves	0,40	0,0001
T1	**Meadows and pastures**	**12809,10**	**2,6434**
T2	Nardus grasslands	386,30	0,0797
T3	Dry grasslands	582,99	0,1203
T4	Forest fringe vegetation	95,44	0,0197

T5	Sand and shallow soil grasslands	100,50	0,0207
T6	Vegetation of spring therophytes and succulents	3,90	0,0008
T7	Inland salt marshes	0,01	0,0000
T8	Lowland to montane heaths	151,73	0,0313
V1	Macrophyte vegetation of naturally eutrophic and mesotrophic still waters	817,47	0,1687
V2	Macrophyte vegetation of shallow still waters	23,15	0,0048
V3	Macrophyte vegetation of oligotrophic lakes and pools	1,80	0,0004
V4	Macrophyte vegetation of water streams	538,60	0,1111
V5	Charophycae vegetation	2,67	0,0006
V6	Isoëtes vegetation	0,25	0,0001
X1	Urbanized areas	773,40	0,1596
X2	Intensively managed fields	2423,41	0,5001
X3	Extensively managed fields	352,76	0,0728
X4	Permanent agricultural crops	36,53	0,0075
X5	Intensively managed meadows	3597,72	0,7425
X6	Anthropogenic areas with sporadic vegetation outside human settlements	247,05	0,0510
X7	Herbaceous ruderal vegetation outside human settlements	1590,09	0,3281
X8	Scrub with ruderal or alien species	108,77	0,0224
X9A	**Forest plantations of allochtonous coniferous trees**	**67640,80**	**13,9589**
X9B	Forest plantations of allochtonous deciduous trees	2273,34	0,4691
X10	Clearings with an undergrowth of the original forest	4087,44	0,8435
X11	Clearings with nitrophilous vegetation	4612,64	0,9519
X12	Stands of early successional woody species	2415,97	0,4986
X13	Woody vegetation outside forest and human settlements	365,20	0,0754
X14	Streams and water-bodies without vegetation of conservational importance	562,54	0,1161
		484572,16	**100,0000**

The greatest proportion, the area over half (56,01%) of the whole biological corridor network in the Czech Republic is consisted by non natural ("non nature valuable") biotopes. These biotopes are often agricultural fields, intensively managed meadows outside or near the settlements and other human intensively used landscape. Also, autochthonous coniferous or deciduous forests, intensively managed for regular production purposes can be included within this category. The second most frequent category, which occurs in the corridor area, is the category of forests plantations of allochtonous coniferous trees (13,96%). As expected, other well represented biotopes within corridors' area were also forest biotope categories. The beech forests category with almost nine percent (8,91%) is third most represented. Corridors consists also of Oak-hornbeam forests and spruce forests with the share of 3,7% and 2,67% from all biotopes respectively. One of the non-forests biotopes within corridors are meadows and pastures, which cover almost the same share as spruce forests (2,64 %). The category of alluvial forests covers corridors from 2,22%. The category of Acidophilous oak forests (1,99%) is one of the last biotopes that have representation above 1% of the total corridor area. All other biotope categories cover less than 1% of the total corridors' surface, which is the share of 7,89% of whole corridors area (tab. 23).

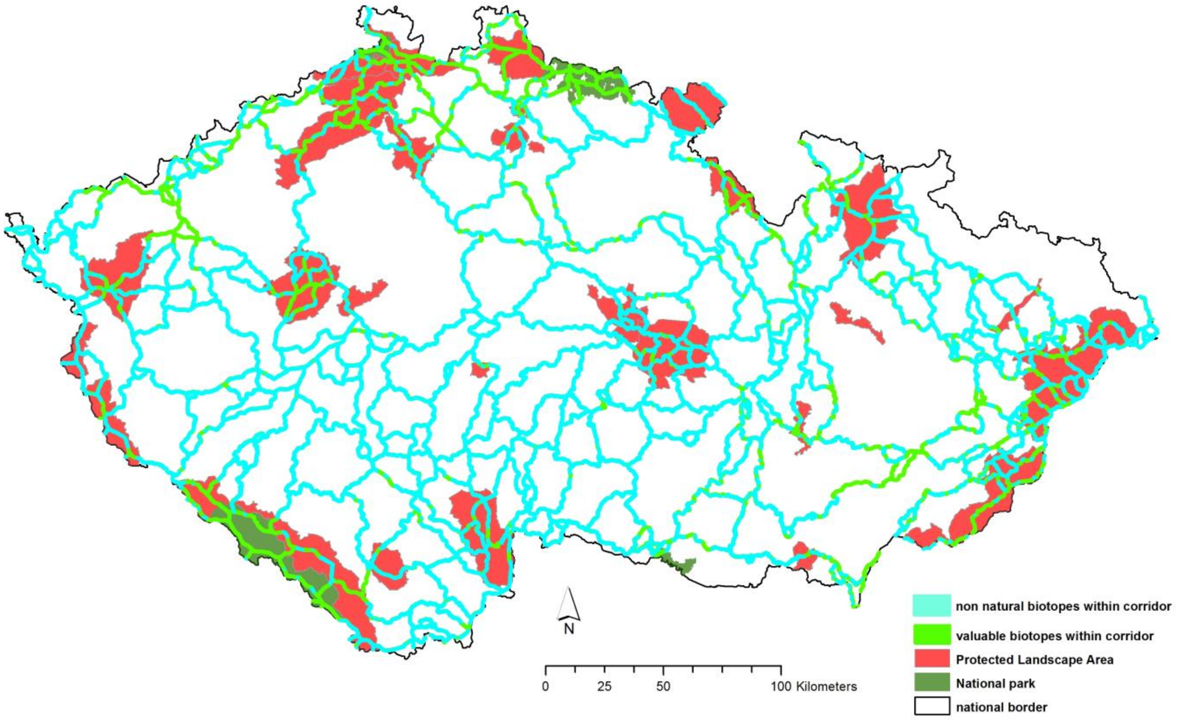


Figure 70. Map showing non natural (light blue) and natural biotopes (light green) within corridor network in the Czech Republic.

Discussion:

From the above presented map is obvious that natural biotopes consists minor portion of the whole corridor surface area. Most of the natural habitats within corridor network are located in the mountainous border areas, which are usually also protected such as national parks or protected landscape areas. These areas turned out to be also the most suitable for the long-term occurrence of large carnivores in the country and serve as core areas of high biodiversity importance. The natural biotopes can also be found in large military training areas e.g. western Bohemia (in the northeast direction from Protected Landscape Area Slavkovský les, which is the western most protected Landscape areas in the country). This area is proposed as SCI CZ0414127 Hradiště. One of the areas outside the nationally large scale protected areas network, consisting of valuable forest biotopes, lies in Eastern part of the country. This relatively large forested mountainous ridge in middle altitude (up to 550 m) called Ždánický forest (also SCI CZ0624237 Ždánický les) and Chřiby (SCI CZ0724091) is composed especially by valuable Oak-hornbeam forests (biotope L3) and Beech forests (biotope L5), where large carnivores can find rather suitable stepping stone area. The last area outside the national large scale protected landscape areas network, consisting of the most valuable alluvial forests in the Czech Republic, is located in lowlands of the most South-Eastern tip of the country, close to the Austrian and Slovakian border. This site is regarded to be also important stepping stone area for large carnivore's occurrence during migration from the Carpathian region to the western parts of the country (see chapter 3.1., fig. 58) and it was also designated as SCI CZ0624119 Soutok – Podluží.

In conclusion, the areas with significant presence of the natural biotopes have been all proposed as SCIs and are often protected also on the national level. Therefore, they can serve as a refugee for large carnivores' populations (for details see Chapters 3.1. and 3.2.).

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Authors of the photos from first page: Bear – Mgr. František Jaskula; Moose – Ing. Václav Hlaváč; Red Deers – RNDr. Martin Strnad

ANNEX 1. List of excluded sites due to presence of D in column population (first to third column from the left) and list of included sites designated for large carnivore (fourth and fifth column from the left – "non D sites").

SITECODE	SPECIES NAME	POPULATION	SITECODE	SPECIES NAME
AT1211A00	Lynx lynx	D	AT1201A00	Lynx lynx
AT1211A00	Ursus arctos	D	AT1203A00	Ursus arctos
AT2101000	Lynx lynx	D	AT1203A00	Lynx lynx
AT2101000	Ursus arctos	D	AT1212A00	Ursus arctos
AT2103000	Ursus arctos	D	AT2102000	Ursus arctos
AT2106000	Lynx lynx	D	AT2102000	Lynx lynx
AT2106000	Ursus arctos	D	AT2105000	Ursus arctos
AT2108000	Lynx lynx	D	AT2105000	Lynx lynx
AT2108000	Ursus arctos	D	AT2112000	Ursus arctos
AT2109000	Lynx lynx	D	AT2120000	Ursus arctos
AT2109000	Ursus arctos	D	AT2204000	Ursus arctos
AT2112000	Lynx lynx	D	AT2210000	Ursus arctos
AT2115000	Lynx lynx	D	AT2243000	Ursus arctos
AT2115000	Ursus arctos	D	AT3111000	Ursus arctos
AT2116000	Ursus arctos	D	AT3111000	Lynx lynx
AT2118000	Lynx lynx	D	AT3115000	Lynx lynx
AT2118000	Ursus arctos	D	AT3121000	Lynx lynx
AT2120000	Lynx lynx	D	CZ0314024	Lynx lynx
AT2123000	Lynx lynx	D	CZ0314123	Lynx lynx
AT2123000	Ursus arctos	D	CZ0314124	Lynx lynx
AT2129000	Lynx lynx	D	CZ0724089	Canis lupus
AT2129000	Ursus arctos	D	CZ0724089	Ursus arctos
AT2209000	Ursus arctos	D	CZ0724089	Lynx lynx
AT2215000	Ursus arctos	D	DE3742302	Canis lupus
AT3121000	Canis lupus	D	DE3944301	Canis lupus
AT3122000	Lynx lynx	D	DE4051301	Canis lupus
DE4129302	Lynx lynx	Missing value	DE4545304	Lynx lynx
DE7315342	Lynx lynx	D	DE4546304	Lynx lynx
DE7415341	Lynx lynx	D	DE4552301	Canis lupus
DE7715341	Lynx lynx	D	DE4552302	Canis lupus
DE7914341	Lynx lynx	D	DE4554301	Canis lupus
DE7915341	Lynx lynx	D	DE4554303	Canis lupus
DE7920342	Lynx lynx	D	DE4648303	Canis lupus
DE8013341	Lynx lynx	D	DE4648303	Lynx lynx
DE8113341	Lynx lynx	D	DE4650304	Lynx lynx
DE8113342	Lynx lynx	D	DE4951301	Lynx lynx
DE8114341	Lynx lynx	D	DE4951302	Lynx lynx
DE8115341	Lynx lynx	D	DE5048302	Lynx lynx
DE8211341	Lynx lynx	D	DE5049302	Lynx lynx
DE8213342	Lynx lynx	D	DE5050301	Lynx lynx
DE8214342	Lynx lynx	D	DE5050302	Lynx lynx
DE8214343	Lynx lynx	D	DE5050303	Lynx lynx
DE8314341	Lynx lynx	D	DE5050304	Lynx lynx
PLB040003	Canis lupus	D	DE5051301	Lynx lynx
PLB060005	Canis lupus	D	DE5148302	Lynx lynx
PLB060007	Canis lupus	D	DE5148304	Lynx lynx
PLB060008	Canis lupus	D	DE5149301	Lynx lynx
PLB120008	Canis lupus	D	DE5153301	Lynx lynx
PLB120008	Lynx lynx	D	DE5248306	Lynx lynx
PLB120008	Ursus arctos	D	DE5937301	Lynx lynx
PLB140007	Canis lupus	D	DE5937304	Lynx lynx
PLB180002	Canis lupus	D	DE5937371	Lynx lynx
PLB180002	Lynx lynx	D	DE6336301	Lynx lynx
PLB180002	Ursus arctos	D	DE6441301	Lynx lynx
PLB240002	Canis lupus	D	DE6739301	Lynx lynx
PLB240002	Lynx lynx	D	DE6812301	Lynx lynx
PLB240002	Ursus arctos	D	DE6844373	Lynx lynx
PLB300002	Canis lupus	D	DE6946301	Lynx lynx
PLB320008	Canis lupus	D	DE7043371	Lynx lynx
PLH020047	Canis lupus	D	DE7045371	Lynx lynx
PLH020047	Lynx lynx	D	DE7145371	Lynx lynx
PLH060094	Canis lupus	D	DE7148301	Lynx lynx
PLH060094	Lynx lynx	D	DE7246371	Lynx lynx
PLH060097	Lynx lynx	D	DE7248302	Lynx lynx
PLH060099	Canis lupus	D	DE8342301	Lynx lynx
PLH080008	Canis lupus	D	PLB040003	Canis lupus
PLH080060	Canis lupus	D	PLC120001	Canis lupus
PLH120001	Canis lupus	D	PLC120001	Ursus arctos
PLH120001	Ursus arctos	D	PLC120001	Lynx lynx
PLH120012	Canis lupus	D	PLC140001	Lynx lynx
PLH120012	Lynx lynx	D	PLC180001	Canis lupus

PLH120012	Ursus arctos	D	PLC180001	Ursus arctos
PLH120013	Canis lupus	D	PLC180001	Lynx lynx
PLH120013	Ursus arctos	D	PLC200004	Canis lupus
PLH120016	Canis lupus	D	PLC200004	Lynx lynx
PLH140011	Canis lupus	D	PLH020015	Canis lupus
PLH140029	Canis lupus	D	PLH020050	Canis lupus
PLH140035	Canis lupus	D	PLH020063	Canis lupus
PLH180013	Ursus arctos	D	PLH020072	Canis lupus
PLH180026	Canis lupus	D	PLH020090	Canis lupus
PLH180026	Lynx lynx	D	PLH060013	Canis lupus
PLH180026	Ursus arctos	D	PLH060017	Canis lupus
PLH180048	Canis lupus	D	PLH060017	Lynx lynx
PLH200004	Lynx lynx	D	PLH060031	Canis lupus
PLH200010	Canis lupus	D	PLH060034	Canis lupus
PLH200018	Canis lupus	D	PLH060034	Lynx lynx
PLH200019	Canis lupus	D	PLH060043	Canis lupus
PLH220026	Canis lupus	D	PLH060092	Canis lupus
PLH220064	Canis lupus	D	PLH060092	Lynx lynx
PLH240005	Ursus arctos	D	PLH060093	Canis lupus
PLH240023	Ursus arctos	D	PLH060093	Lynx lynx
PLH260011	Canis lupus	D	PLH060107	Canis lupus
PLH260015	Canis lupus	D	PLH080007	Canis lupus
PLH280012	Canis lupus	D	PLH080011	Canis lupus
PLH280012	Lynx lynx	D	PLH080032	Canis lupus
PLH280016	Lynx lynx	D	PLH080036	Canis lupus
PLH280029	Canis lupus	D	PLH080037	Canis lupus
PLH280048	Lynx lynx	D	PLH080042	Canis lupus
PLH280049	Lynx lynx	D	PLH080044	Canis lupus
PLH320067	Canis lupus	D	PLH120001	Lynx lynx
			PLH120013	Lynx lynx
			PLH120018	Canis lupus
			PLH120018	Ursus arctos
			PLH120018	Lynx lynx
			PLH120019	Canis lupus
			PLH120019	Ursus arctos
			PLH120019	Lynx lynx
			PLH180001	Canis lupus
			PLH180001	Ursus arctos
			PLH180001	Lynx lynx
			PLH180012	Canis lupus
			PLH180012	Lynx lynx
			PLH180013	Canis lupus
			PLH180013	Lynx lynx
			PLH180014	Canis lupus
			PLH180014	Ursus arctos
			PLH180014	Lynx lynx
			PLH180017	Canis lupus
			PLH180054	Canis lupus
			PLH200004	Canis lupus
			PLH200005	Canis lupus
			PLH200005	Lynx lynx
			PLH200006	Canis lupus
			PLH200006	Lynx lynx
			PLH200007	Canis lupus
			PLH200008	Canis lupus
			PLH220078	Canis lupus
			PLH240005	Canis lupus
			PLH240005	Lynx lynx
			PLH240006	Canis lupus
			PLH240006	Ursus arctos
			PLH240006	Lynx lynx
			PLH240023	Canis lupus
			PLH240023	Lynx lynx
			PLH260010	Canis lupus
			PLH280005	Canis lupus
			PLH280005	Lynx lynx
			PLH280016	Canis lupus
			PLH280048	Canis lupus
			PLH280049	Canis lupus
			PLH280052	Canis lupus
			PLH300006	Canis lupus
			PLH300021	Canis lupus
			PLH320046	Canis lupus
			PLH240005	Lynx lynx
			PLH240006	Canis lupus
			PLH240006	Ursus arctos
			PLH240006	Lynx lynx

			PLH240023	Canis lupus
			PLH240023	Lynx lynx
			PLH260010	Canis lupus
			PLH280005	Canis lupus
			PLH280005	Lynx lynx
			PLH280016	Canis lupus
			PLH280048	Canis lupus
			PLH280049	Canis lupus
			PLH280052	Canis lupus
			PLH300006	Canis lupus
			PLH300021	Canis lupus
			PLH320046	Canis lupus