Creation of Ecological Corridors in the Ukrainian Carpathians

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Abstract In order to develop a methodology for the creation of functional and consolidated ecological corridors for the Carpathians, a pilot study has been conducted at two locations in Ukraine creating corridors connecting Ukrainian protected areas with protected areas in Romania and Poland. The methodology was based on landscape ecological modelling, using the habitat requirements of brown bear, European bison, lynx and wildcat to locate the most suitable corridor areas. Manageable corridors were created by identifying interconnected land management units with a minimum of obstacles for wildlife and conflicts with land use, and forming the shortest possible connection. The location of the corridors and their management plans were developed in consultation with the users and owners of the land. Approval and inclusion of the corridors in the spatial planning system was achieved following a model elaborated after analysis of the Ukrainian institutional and regulatory framework related to ecological network development.

1 Introduction

Several biological theories such as the theory of island biogeography and the meta-population theory deal with the limitations in space and time of animal populations (MacArthur and Wilson 1967; Hanski 1998, 2005). These theories support the generally accepted opinion that the survival of large mammals depends on large land areas with appropriate habitat providing food and other functions during all seasons for a population big enough to maintain sufficient genetic variability to cope with environmental changes, disease and inbreeding.

The Carpathians are one of the largest continoues natural areas in Europe with a high biological diversity represented by the last large European populations of large mammals such as brown bear (*Ursus arctos*), lynx (*Lynx lynx*), and wolf (*Canis lupus*). For Europe, the Carpathians do not only form an important reservoir of these species, but they also play a role connecting wildlife areas in Eastern, Western and Southern Europe. During the last century significant changes occurred in the Carpathians regarding land use and land cover. The most striking trends in the Carpathian landscape since the 1990s are:

- privatisation and fragmentation of land,
- farmland abandonment,
- encroachment of farmland and pastures by forests,
- developing road infrastructure and urbanisation,
- unsustainable development of tourism and recreational facilities.

As a result, the Carpathians tend to turn into a fragmented landscape of isolated forest blocks with little possibilities for animals to move from one to another. To cope with current and fragmentation and future habitat loss, most Carpathian countries have established a framework for the development of an ecological network including legislation, spatial planning and policy targets (Jongman and

Kamphorst 2002; Bennett and Mulongoy 2006; van Maanen et al. 2006; Simeonova et al. 2009). Generally this has led to the consolidation of protected area systems established mainly in marginal areas with a low human population density. However, since complexes of protected areas are usually separated by zones with high human influence, such as agriculture, settlements and infrastructure, the connectivity between these protected areas has hardly been improved. In many cases fragmentation continues due to expanding traffic infrastructure, tourism facilities, settlements and other development.

The objective of our study is to develop a methodology for the creation of ecological corridors connecting (protected) core areas within the Carpathian ecological network, considering landscape ecology, land use, ownership and legislation. The specific purpose of this work is to help closing the gap between the possibilities offered by advanced scientific modelling techniques available today for corridor mapping (van Maanen et al. 2006; Beier et al. 2007, 2008) and the realities and requirements related to the creation and consolidation of ecological corridors in the actual land management system (Bennett and Mulongoy 2006; Lombard et al. 2010; Mackey and Watson 2010). The study is carried out as a pilot study in the Ukrainian Carpathians, to allow realistic investigation and testing of procedures required to deal with legislation, stakeholders and other aspects of the land use system. The general methodology developed is meant to be applicable as a model for corridor development in the Carpathians.

In most Carpathian countries, frameworks for ecological network development have been realized following initially the Landscape Stabilisation Approach and since 1995 the Pan-European Biological and Landscape Diversity Strategy (Bennett and Mulongoy 2006). Ecological networks have been designed in all countries, based on Natura 2000 in EU countries. Most of these frameworks include provisions for the development of connections between core areas for conservation. In most countries specific legislation addressing connectivity has been adopted, but this has not been effective everywhere (Jongman and Kamphorst 2002; Bennett and Mulongoy 2006; Jędrzejewski et al. 2009). Corridor development is most advanced in Czech Republic, Slovakia and Hungary, where ecological corridors connecting protected areas have been created and are functional. In the other countries corridors have only been established on pilot basis, but in many cases, corridors remain features on maps waiting for implementation. This can be explained by the lack of experience of those responsible for the development of ecological networks in dealing with land use issues outside protected areas, and the lack of understanding of how to deal with administrative mechanisms to match land use with conservation (Nassauer and Opdam 2008; van der Windt and Swart 2008).

The planning of ecological corridors usually involves GIS (Geographical Information System) modeling techniques (Marulli and Mallarch 2005; Hepcan et al. 2009; Gurrutxaga et al. 2010; Roy et al. 2010), which are predominantly focused on the identification of the ecological linkages in a landscape through a least-cost approach, relying on the suitability assessment of landscapes for selected species based on the parameters provided by species experts (Schadt et al. 2002;

Beier et al. 2008). Modeling results can be validated and optimized using the reliability theory (Jordan 2000), uncertainty analysis (Schadt et al. 2002; Beier et al. 2009), network flows (Phillips et al. 2008), graph theory (Urban et al. 2009; Rayfield et al. 2010), or Markov chains (Billionnet 2010). Special software has been designed in several occasions to assist the GIS modeling of the ecological corridors (e.g. Majka et al. 2007).

2 Study Area

The Ukrainian part of the Carpathian Ecoregion covers approximately 21,000 km^2 (Kruhlov 2008), which is about 10 % of the whole ecoregion area. The Ukrainian Carpathians are crucial for the ecological connectivity as they occupy the narrow part of the mountain arc linking its massive northern and southern sections, thus forming a bottleneck for animal migration within the Carpathians, as well as between the Southern, Western, and Eastern Europe (Webster et al. 2001). This part of the Carpathians consists of a series of parallel low and medium mountain ridges (usually up to 1,500 m a.s.l.) stretching in the NW–SE direction and predominantly formed by flysch. They are mainly covered with beech and spruce forests; however, several elevated ridge tops (higher than 1,500 m) have subalpine and alpine vegetation (Herenchuk 1968). Human settlements are rather densely dispersed and they are represented mainly by medium and large villages (1–3 thousands of inhabitants) located in river valleys. The economy of the region is mainly determined by forestry, recreation, and nature conservation (Kubijovyc 1984; Burdusel et al. 2006; Anon. 2007). Forest fragmentation is limited, but forests are disturbed by clear-cuts in widely-spread cultural spruce stands (Kuemmerle et al. 2006). The area of these clear-cuts is gradually increasing as well as abandoned agricultural land is gradually changing into forest (Kuemmerle et al. 2008). Forests are state-owned, while agricultural land (mostly grassland) is predominantly private.

Terrestrial mammals occurring in the Ukrainian Carpathians include rare species such as brown bear (*Ursus arctos*), lynx (*Lynx lynx*), wildcat (*Felis sylvestris*), European mink (*Mustela lutreola*), otter (*Lutra lutra*) and European bison (*Bison bonasus*). There are also populations of red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), wolf (*Canis lupus*), fox (*Vulpes vulpes*), pine marten (*Martes martes*), ermine (*Mustela erminea*), Carpathian squirrel (*Sciurus vulgaris carpathicus*) and common dormouse (*Muscardinus avellanarius*). Species of amphibians and reptiles include Carpathian newt (*Lissotriton montadoni*), Alpine newt (*Mesotriton alpestris*), yellow-bellied toad (*Bombina variegata*), spotted salamander (*Salamandra salamandra*), Aesculapian snake (*Zamenis longissimus*), and smooth snake (*Coronella austriaca*). During the last 20 years populations of large mammals decreased due to human influence such as poaching and other disturbances. Particularly, numbers of red deer and roe deer have dropped drastically, and elk has almost disappeared from the Ukrainian Carpathians (Domnich

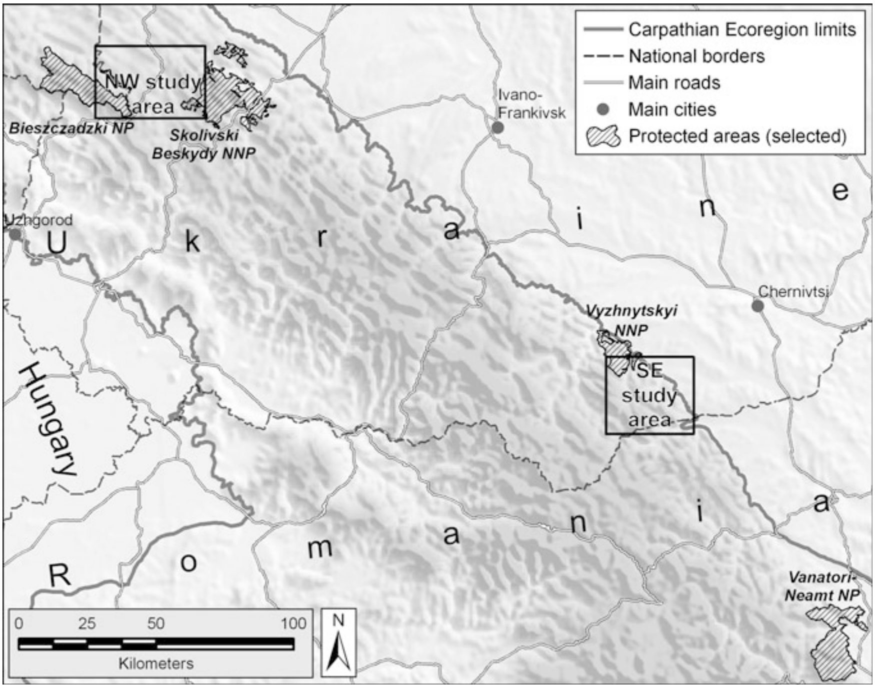

Fig. 1 The Ukrainian Carpathians showing the pilot areas and the related protected areas

et al. 2009). Downward trends of carnivores are also observed but accurate data are lacking (Nowell and Jackson 1996; Servheen et al. 1998; Anon. 2004; Bashta and Potish 2005, 2007).

The pilot study has been carried out at two locations in the north-west and the south-east of the Ukrainian Carpathians (Fig. 1), establishing local level ecological corridors between selected protected areas in Ukraine, Poland and Romania. The location in the north-west is the area between Skolivski Beskydy National Nature Park in Ukraine and Bieszczadzki National Park in Poland, while in the south-east the area between Vyzhnytskyi National Nature Park and the border with Romania is covered in order to create the Ukrainian part of a corridor towards Vanatori-Neamt Natural Park. Characteristics of the landscape of the two locations are presented in Table 1.

3 Methods

In this study, ecological networks and particularly ecological corridor areas are considered as natural, socio-economic and legal entities, since they exist in the landscape inhabited, transformed and managed by humans. Corridor modelling has

Table 1 Landscape features of the pilot study areas (Kuemmerle et al. 2006, 2007, 2008, 2009; Hostert et al. 2008; Kruhlov 2008)

Landscape feature	North-west area	South-east area
Meso-ecoregions	Sian-Stryi Verkhovyna and Internal Beskydy	Bukovyna internal mountains and Pokuttia-Bukovyna external mountains
Rocks	Flysch	Flysch
Elevation average and range (m a.s.l.)	750 (580–1,100)	830 (560–1,200)
Landform	Low mountains and medium mountains	Medium mountains and dissected low mountains
Climate	Moderately cool	Moderately cool and moderately warm
Natural vegetation	Beech–spruce forests	Beech–spruce and beech forests
Human population	~12,000 (17 villages)	~2,000 (2 villages)
Dominant land use	Forestry and agriculture	Forestry
Actual land cover	Grassland, forest and settlement	Forest and grassland and settlement
Disturbances	Forest clear-cutting, hunting	Forest clear-cutting, hunting
Land cover change trend	Forest encroachment on grassland, moderate expansion of built-up areas	Stable

been based on the habitat requirements of selected species, referred to as model species hereafter[1], which are considered to represent the overall habitat requirements of all species to be facilitated by the corridor. In the modelling process, available corridor area is identified for each of these model species in a stepwise process, subsequently eliminating land of low connectivity due to physical barriers, habitat suitability, human disturbance, future development and unwillingness of land users and land owners to contribute to the corridor protection (Fig. 2). Hence, manageable corridors are obtained by completing the following steps:

1. identification and delineation of possible corridors, using habitat suitability criteria determined for selected model species,
2. tailoring the corridor boundaries to the extent of existing administrative, ownership, and management units in order to create manageable areas to realise and maintain connectivity,
3. determining and implementing required protection measures and arrangements with regard to legislation and management.

Following earlier corridor modelling practice in other areas (e.g. van Maanen et al. 2006; Beier et al. 2007, 2008) four model species were identified: brown bear, European bison (further referred to as bison), lynx, and wildcat. These species have rather rigid and distinctive habitat requirements, together covering

[1] The terms "umbrella species" and "focal species" are sometimes also used in this context (van Maanen et al. 2006; Beier et al. 2008).

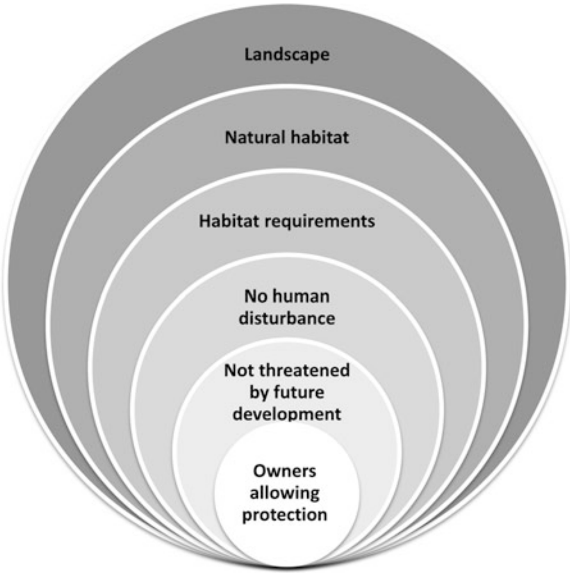

Fig. 2 Stepwise approach for corridor modeling, subsequently eliminating land of low connectivity due to physical barriers, habitat suitability, human disturbance, future development and unwillingness of land users and land owners

the requirements of all large terrestrial mammal species of the Carpathians and therefore they can be regarded as "umbrella" for those species. For each of the model species an ecological profile has been prepared describing habitat requirements based on expert knowledge as well as publications on habitat utilization (Slobodian 1988, 1993; Turianyn 1988; Nowel and Jackson 1996; Servheem et al. 1998; Anon. 2004; Bashta 2004; Pucek et al. 2004; Bashta and Potish 2005; Ray et al. 2005; van Maanen et al. 2006; Krasinska and Krasinski 2007; Klar et al. 2008; Kuijper et al. 2009). Habitat suitability and resistance values for landscape features were represented as a separate raster geo-dataset in a GIS. The habitat suitability values were established by experts for each model species and assigned to the respective geo-datasets using a standardized scale from 1 to 100 with 0 as a restrictive value (Table 2).

The raster datasets on habitat suitability determined by the species experts were additively overlaid to establish one overall habitat suitability data layer for each of the model species. Assuming that the focal species have different tolerance to human presence, the additive overlay was adjusted for this feature as follows. Bison was considered as the most tolerant to human disturbance and therefore its human proximity factor received the weight of 1.0, for lynx this factor was set to 3.0, while for the bear and the wildcat it was estimated at 2.0. The additive overlay was adjusted with the weight factor of 1.0 for all other the landscape features.

Subsequently, possible corridors were manually drafted based on habitat suitability maps for each species, and these "species corridors" were merged into a single "robust" corridor (van Maanen et al. 2006; Nassauer and Opdam 2008). The course of these preliminary corridors has been evaluated by the species experts to identify so-called "bottleneck areas" which are relatively narrow

Table 2 Landscape features and their suitability values for model species

Landscape feature	Category	Suitability values (1–100)			
		Bear	Bison	Lynx	Wildcat
Land cover types derived from Landsat TM/ETM + images (Kuemmerle et al. 2006; Hostert et al. 2008) and supplemented with hydrography, transportation network, and settlement pattern from topographic map of 1:200,000 scale	Coniferous forest	100	70	100	50
	Deciduous and mixed forest	100	100	100	100
	Grassland and shrub land	20	50	10	20
	Other	0	0	0	0
Forest/grassland ratio calculated in % for 250 m radius circle neighborhood from the land cover dataset (above)	100/0 %	100	75	100	75
	75/25 %	75	100	50	100
	50/50 %	50	75	10	75
	25/75 %	25	50	0	25
	0/100 %	0	10	0	0
Altitudinal bioclimatic belts (elevation intervals in m a.s.l.) stratified from the SRTM 3-arc-second digital elevation model (Jarvis et al. 2008)	0–350	50	100	50	100
	350–700	80	100	80	100
	700–1,100	100	50	100	50
	1,100–1,300	100	30	100	30
	1,300–1,500	80	10	80	10
	1,500–1,800	30	0	30	0
	>1,800	10	0	10	0
Terrain roughness (m) calculated as an elevation magnitude within a 250 m radius circle from the SRTM data	0–50	50	100	50	100
	50–100	100	50	100	80
	100–200	100	30	100	50
	>200	100	10	100	30

Human proximity is calculated using a cost-distance function, where distance is estimated to settlements and roads, and cost is defined by the terrain's slope. The proximity values are standardized to a 1–100 scale

corridor parts crossing agricultural and settled areas. Field checks of these "bottleneck areas" have been made to determine the least problematic passages for the animals. As a result, the best corridor option for all four model species has been determined based on habitat suitability and the most passable bottleneck areas.

In order to function and to be able to cope with land use changes and development projects in the future, ecological corridors need to meet the following conditions (Jongman and Kamphorst 2002; Bennett and Mulongoy 2006; Mackey and Watson 2010):

- be composed of manageable units,
- of which boundaries follow administrative, natural or landownership boundaries,
- accepted and respected by all stakeholders,
- recognized and respected by spatial planning authorities,
- recognized and approved by local and higher administration,

- managed according to agreed and effective management arrangements.

To comply with these criteria, the "raw" corridors as they were modelled above are fitted in the existing land use system by identifying adjacent manageable land units (e.g. forest blocks) within the area covered by the corridor area based on habitat suitability and the best bottlenecks, forming a chain between the protected areas to be connected. The selection of these areas to determine the final corridor boundaries is achieved through direct consultations with land owners and land users with the aim to agree on a final course of the corridor using boundaries of municipalities and forest management units, taken from administrative and forestry maps. Areas where no agreement on compatible land use could be reached or where future incompatible developments were unavoidable could be excluded from the corridor following the consultations.

The Ukrainian laws supporting the development of the Ukrainian ecological network are the Laws "On the State Programme of Ukraine's National Ecological Network Development for 2000–2015" (2000) (Government of Ukraine 2000) and "On the Ecological Network of Ukraine" (2004) (Government of Ukraine 2004). These laws define the different elements of the ecological network and ensure the Government's support on the development of the ecological network (Brusak et al. 2006). To facilitate the implementation of these laws, the Ministry of Environmental Protection of Ukraine has issued the directive "Methodological Recommendations for the development of regional and local Econet schemes" (Order 13/11/2009 No. 604) (Government of Ukraine 2009). When corridors are endorsed by the relevant authorities (particularly the Land Resources Department and Regional Council), incompatible land use can be sanctioned and future projects have to take into account the integrity of the corridors. In order to determine the procedure to be followed for the creation of ecological corridors, which are recognized by the law and authorities, the sections of these Methodological Recommendations relevant for corridor development were extracted (Deodatus and Protsenko 2010) and combined with the modelling methodology for corridors applied (van Maanen et al. 2006). The different steps were further elaborated in consultation with government staff during the implementation of the procedure.

4 Results

The main result of this study is a methodology for the creation of ecological corridors developed in the context of landscape, ecology, land use and legislation, based on a pilot connecting protected areas in two different locations.

Habitat suitability maps prepared for different model species showed very similar suitability patterns in each pilot. Habitat suitability scores were generally higher for bison and lower for lynx, which is most probably related to human proximity. Nevertheless, merging "species corridors" into one "robust" corridor was straight forward in both areas.

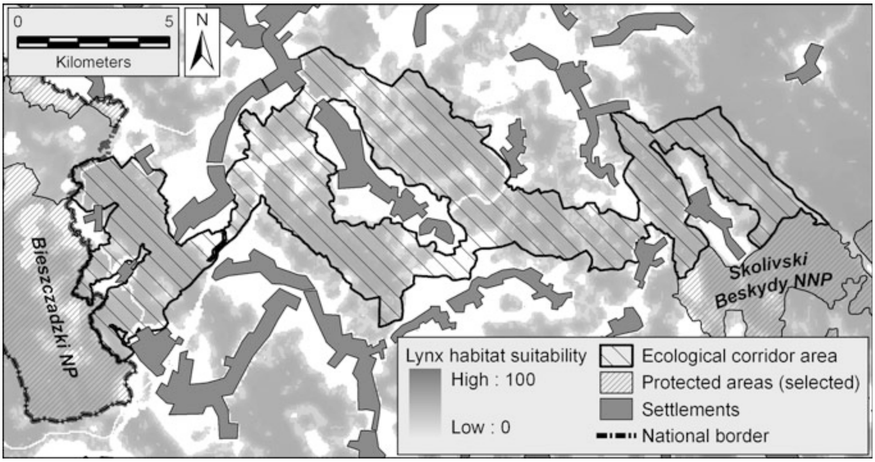

Fig. 3 The approved north-eastern corridor area related to the habitat suitability for lynx and the final corridor geometry tailored to land management units

The main barriers for connectivity were formed by residential areas mainly located in river valleys and to a lesser extent by agricultural areas, particularly when tree cover was poor. The potential corridor area in the south-eastern pilot is mainly covered by forest and has limited residential and agricultural areas. Only one "bottleneck area" with low connectivity due to a road and farmland was found here. The potential corridor area in the north-western pilot however, with a higher human occupation counted nine of such bottleneck areas. Field checks proved easy accessibility for animals of the bottleneck in the south-eastern pilot, as the hay-fields in the valley bottoms were only partly fenced, and patches of trees and shrubs provided cover for eventually crossing animals. Local people witnessed that the place is frequently crossed by deer and boars. In the north-western pilot four of the nine bottlenecks were hardly accessible for the animals, due to the high occurrence of agricultural land, residential area, fences and roads. Therefore the course of the final corridor here has been determined by the location of the other five "bottlenecks" which appeared to provide sufficient conditions for animal passage (Fig. 3). Consultations with land users and the local administration resulted in both pilots in agreement on the final corridor boundaries aligned with existing management units such as forestry management units and municipality borders.

After agreement on the location of the ecological corridors, approval has been received from local authorities and relevant technical authorities, including the spatial planning authorities. According to the Ukrainian regulations, a file has been elaborated for this purpose according to the specifications presented in the Directive "Methodological Recommendations for the development of regional and local Econet schemes" (2009) of the Ministry of Environmental Protection of Ukraine. Through extraction of relevant sections from this directive, a model has

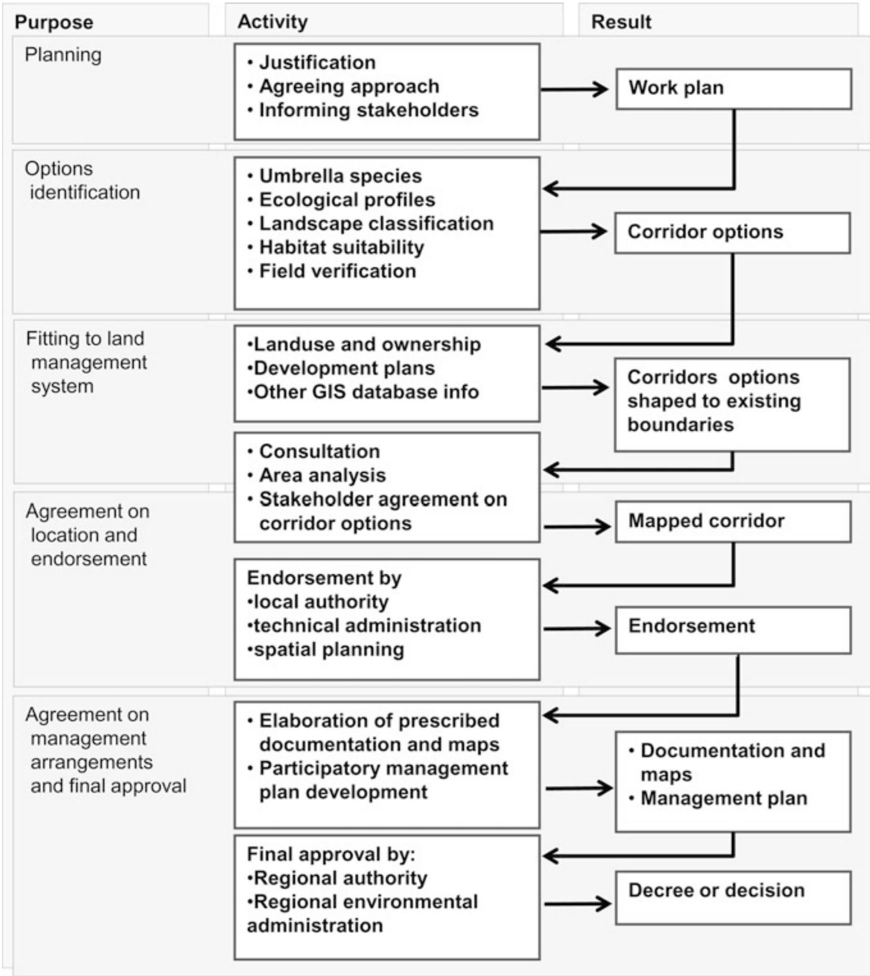

Fig. 4 The model for ecological corridor creation elaborated in the Ukrainian Carpathians, including corridor location identification, corridor management and inclusion in the regulatory land management system

been derived adapted to the application of ecological corridor creation, which resulted in the draft directive "Methodological Recommendations for Ecological Corridor Scheme Development". The file compiled according to this directive (the Ecological Corridor Scheme) includes a number of maps with prescribed formats as well as text sections presenting justification, general environmental context information, stakeholders, and a management plan of the proposed corridor. This file played a central role in the process leading to endorsement and to the inclusion of the ecological corridor into the spatial planning system. In the final stage of the procedure, corridor maps, corridor description and management plans have been approved by the relevant level state authorities ensuring their management on the long term. An outline of the entire procedure developed (Fig. 4) disposed of country-specific terminology and procedures can be considered as a guideline for corridor development in Carpathian countries.

5 Discussion

Several authors (Hanski 2002; O'Donell 2007; Nassauer and Opdam 2008; van der Windt and Swart 2008) claim close collaboration between scientists and government officers to be instrumental for effective ecological network development, as it provides opportunities for synergy and appropriate policy development and implementation. In the corridor development process presented in this chapter researchers and administrators fulfilled an indispensable role in ecological corridor development, contributing specific and highly complementary knowledge and experience. Since the use of GIS is increasingly important in spatial planning, administrators can benefit on the one hand from qualified staff from research institutes and from new technology. On the other hand, collaboration makes research staff more familiar with tuning their work to administrative requirements, leading to more effective use of scientific results. The process of corridor development is also an opportunity to create broad public support for ecological corridors by using major events for radio or television broadcastings. Governmental as well as non-governmental stakeholders developed commitment and understanding with regard to biodiversity conservation and the creation of an ecological network, while they were intensively involved in the corridor development process.

This study has shown that pilot projects are very useful to understand the constraints and gaps in the current framework for ecological corridor development and help to improve the methodologies used. Generally GIS has been a very useful and time-efficient tool that helped to focus the selection process to identify appropriate corridor area. Moreover GIS is a very flexible tool for the composition of cheap high-quality maps and on-screen support to decision processes through desktop comparison of corridor options. At the same time, the use of GIS has its limitations. It helps ordering information, but this process should be controlled and interpreted critically by the users, by comparing GIS output with field information. The finalisation of the corridors requires therefore "handwork", by visual map interpretation. The identification of "bottleneck areas" for field verification proved to be a useful approach, which, on the one hand, ensured realistic results of the corridor mapping and, on the other hand, helped to optimize time and resources required for field work.

To ensure the perpetual functioning of ecological corridors, agreements need to be reached on their management (Jędrzejewski et al. 2009; Mackey and Watson 2010). This can be done in a management plan specifying crucial elements such as stakeholders, responsibilities, measures and timing. Management plans are often based on a zoning system and it is usually convenient to match management zone boundaries as much as possible with land ownership and land use, to minimize the arrangements to be made with stakeholders. In western Carpathian countries (Hungary, Czech Republic and Slovakia) management plans or other arrangements are included in the respective legislation on ecological corridor development (Jongman and Kamphorst 2002). In Ukraine, however, both laws on ecological network development refer but indirectly to the use of management plans (Deodatus and Protsenko 2010). Therefore, the inclusion of an ecological corridor management plan has been proposed as compulsory in the Ecological Corridor Scheme in the "Methodological Recommendations for Ecological Corridor Scheme Development". The major challenge to make corridors work is the establishment of management arrangements accepted by all stakeholders (Bennett and Mulongoy 2006; Chettri et al. 2007; Lombard et al. 2010) and their enforcement. The final challenge is to adapt arrangements and supporting documentation to the requirements of the spatial planning authorities. Their acceptance and integration of the designed corridors into spatial management plans can assure their existence and functioning in the future, making them more resistant to threats such as infrastructure and other development plans (Nassauer and Opdam 2008).

Connectivity issues are usually (at least technically) more easily dealt with in agricultural areas as agriculture is not necessarily conflicting with connectivity (Lombard et al. 2010). Agriculture in most of the Carpathians has mainly an extensive character which is potentially compatible with wildlife presence. However, it may cause sometimes conflicts between wildlife and land users (poaching, crop damage, cattle predation). Handling this type of conflicts as well as the consolidation of extensive farming can be supported through an adequate High Nature Value farming policy in wildlife areas such as corridors (Hoogeveen et al. 2002; Andrews and Rebane 2005). A very useful tool reducing wildlife-human conflicts in this case and creating sometimes also opportunities for farmers is the land-swap instrument, which involves the swap of nature areas (parts of forests or protected areas) for agricultural land located in strategic parts of corridors. If crossings between ecological corridors and transport infrastructure cannot be avoided, constructions are recommended to enable connectivity such as wildlife overpasses and underpasses (Iuell et al. 2003; Jędrzejewski et al. 2009).

6 Conclusions

A pilot project to develop ecological corridors from paper plans to land allocated to connect biodiversity core areas agreed by all stakeholders provides a setting to develop and test a model for ecological corridor creation including lessons learned for wider application. Crucial for the functionality of corridors with regard to species migration are the ecological characteristics of the species selected to determine the habitat suitability criteria of the model. In this Ukrainian study, the establishment of two corridors has been realized as a result of combining the spatial modelling of corridors based on ecology and landscape with the administrative process that leads to inclusion of these corridors in the governmental land management system. By doing so, contributions of scientist and government authorities in the process are better geared to their purpose. The engagement of all stakeholders optimized the design and support for the establishment of the corridors. GIS maps provided effective support in this process, giving stakeholders accurate information on the location of optimal habitats of biological species and barriers. Field verification for the validation of this information and its interpretation proved to be essential. The actual choice of corridor location and boundaries should be realized through a dialogue of relevant authorities, land owners and land users to establish acceptance and future support. Using “bottleneck areas” as a key for corridor identification contributed very much to the efficiency of this process by focusing attention of consultations and analysis on these areas, enabling the exclusion of unsuitable corridor parts at an early stage. GIS maps indicating habitat suitability were very effective to locate these areas. Established corridors only make sense when their management is covered by agreements among stakeholders. The elaboration of management plans is therefore part of the model for corridor creation, and alignment of corridors with existing land management unit boundaries such as forest management units and municipality borders turned out to be instrumental.

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