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Article

Generating Resistance Surfaces for Wildlife Corridor Extraction

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Summary: Experts of wildlife migration often delineate a corridor directly and solely from remote sensing images. Resistance surfaces on the other hand are an intermediate product, if the corridor should be extracted (semi-)automatically, by establishing a knowledge database about spatial behaviour of wildlife. The advantage of a spatial explicit knowledge database is the development of spatial rules in combination with wildlife behaviour, creating a basic database. This database should help to transfer discussions from different expert opinions to more concrete discussions about parameters of spatial rules. The aim of such a knowledge database is the ability to repeat/reproduce the experiment, the reduction of subjectivity of a single expert and the possibility to apply the same method for a large region on a detailed level. Furthermore, the automatic extraction of corridors allows the evaluation of different scenarios like the implementation of new wildlife passages. This study discusses the formulation of spatial rules for wildlife migration in a GIS to generate the basic information of a resistance surface. The application of this method is also discussed in a project called Alpine Carpathian Corridor, where the aim was to safeguard the wildlife migration corridor including intensively used areas (of the landscape).

Zusammenfassung: *Widerstandsmodelle für die Extrahierung von Wildtierkorridoren.* Wildtier-Experten können einen Wildtierkorridor oftmals direkt aus Fernerkundungsdaten auf Basis ihres Wissens extrahieren. Widerstandsmodelle stellen ein Zwischenprodukt dar, wenn der Korridor automatisiert extrahiert werden soll, um damit die Subjektivität des Experten zu reduzieren. Das basiert auf dem Aufbau einer Wissensdatenbank über das räumliche Verhalten von Wildtieren und die Formalisierung dieser Regeln in einem GIS. Der Vorteil dieser Quantifizierung ist die Nachvollziehbarkeit, die Anwendbarkeit auch für sehr große Gebiete bei einer hohen räumlichen Auflösung und die Übertragbarkeit des Regelwerkes bis zu einem bestimmten Grad auch auf andere Regionen. Bei dem Projekt Alpen-Karpaten-Korridor, bei dem es um die Vernetzung der beiden großen Lebensräume Alpen und Karpaten ging, fand die Formalisierung des Regelwerkes Anwendung. Die Herausforderung dabei war, einen Wildtierkorridor auch durch intensiv genutzte Bereiche der Landschaft zu führen und der Raumplanung geeignete Grundlagen für die Umsetzung des Korridors bereit zu stellen.

1 Introduction

In the last decades cultural landscapes were changing due to many factors like increasing infrastructure facilities, spatial expansion of settlement and industrial areas or intensified agriculture (e.g. Banko et al. 2004). One popular way of safeguarding wildlife is to declare corridors to enable the exchange between core areas of species habitat, to enhance gene flow or to reduce extinction risk (e.g. Hilty et al. 2006, Beier & Noss 1998, Vogt et al. 2007, Fleury & Brown 1997). For this reason, the safeguarding of even small, natural landscape features and their importance for wildlife and species migration became obvious (e.g. Andren 1994, Fahrig 2001, Baum et al. 2004, Kramer-Schadt et al. 2011). The composition of core areas and natural landscape patches, in interaction with mostly human induced disturbances of settlements or technical infrastructure, like road network, generates a complex

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landscape matrix for movement patterns (Forman & Godron 1986). The landscape connectivity describes the movement between these patches in a structural and functional way (Taylor et al. 1993). The wildlife corridor itself is part of the landscape connectivity, with focus on the connection between specified locations (Anderson & Jenkins 2006).

Corridor delineation in accordance with Beier & Loe (1992) can be based on different methods and input data (Abt & Sandfort 2011). Field surveys (e.g. Sawyer et al. 2009, Molinari & Molinari-Jobin 2001) or telemetry data (Musiega & Kazadi 2004) are visually interpreted or buffered. Due to the lack of quantitative individual based data for large regions, corridor extraction is commonly applied by using land cover information and their derived resistance values (e.g. Janin et. al. 2009, Rabinowitz et al. 2010, Driezen et al. 2007, Wang & Zeller 2009).

Main input data for a (semi-)automatic extraction of wildlife corridors are land cover, derived from different input data like aerial photographs, satellite images or cadastral maps. In addition ancillary data like fences, traffic density or road mitigation measurements are used. The land cover has to be transferred to resistance values to provide the possibility of modelling their suitability for wildlife migration (e.g. Rayfield et al. 2010). Additionally, the final resistance value depends on spatial interactions between adjacent land covers. The resistance surface models are finally used as input datasets for the application of different methods for corridor extraction like least cost path algorithms (e.g. Ray et al. 2002), circuit theory (McRae & Beier 2007) and graph theory (e.g. Goetz et al. 2009). A least cost path algorithm needs source and target regions and the map of resistance values in between. Starting from the source region, the resistance values are accumulated in that way, that the accumulated resistance values are minimized. This procedure is repeated for the target region. The accumulated resistance values are summarized for both regions. The lowest values of this summarisation indicate the route with the lowest accumulated resistance values from the source and the target region. Circuit theory is based on the same input data, resistance values and regions, and applies the method of electrical circuits known from electrical engineering. An advantage of circuit theory compared to least cost path algorithms is the extraction of multiple routes (Howey 2011). The application of graph theory creates a network, where the core habitats are knots. The connection between the knots known as the graphs and their attributes are computed using the resistance value map.

An extracted corridor can vary according to the selected method, but regardless which method is applied, the resistance value map is always the base for further computation. This study emphasises the importance of the resistance surface, independent of the selected method of corridor extraction. The study focusses on the creation of the resistance value maps and discusses the relationship of land cover classes and resistance values, their spatial relation and dependency, and the potential for establishing different scenarios, e.g. for the placement of mitigation measurements.

The application of this method will be presented by some of the results of the Alpine – Carpathian – Corridor project. The Alpine – Carpathian – Corridor project aims to re-establishing the wildlife corridor between two core areas in regions with intensive human activities. The numerous stakeholders: inhabitants, industry, forestry, hunters, etc. and their different interests in this region (e.g. Centrope 2014) make it necessary, to define the steps of corridor delineation in such a way, that it is broadly comprehensible. This requirement was established by the formulation of a knowledge database for wildlife movement and the consequential GIS model of the resistance surface as the base of this delineation.

2 Input Data

Land cover is considered as the main input dataset, because it provides fundamental information concerning the landscape matrix and spatial information about small patches of suitable areas for wildlife (Yadav et al. 2012). However, using only land cover based on remotely sensed images (considered as areal data) does not have to correspond with the general situation of landscape connectivity in this area (Brooks 2003) due to the fact that features like fences or traffic density are barely recognizable in a 30 m spatial resolution dataset. Therefore, ancillary data will be used to refine the land cover. Nevertheless, the land cover provides not only groundwork for this study, but also provides information about the potential of landscape connectivity, which will be discussed in a follow up chapter. However, to evaluate landscape regarding its potential as well as its existing condition for connectivity, it is necessary to include features such as landscape elements with barrier function, e.g. fences and roads, and connection functions, such as mitigation measurements of fenced highways (over- and underpasses and their quality). In that way different scenarios of wildlife corridors can be established. These potential scenarios are determined by different regional planning actions, which influence the resistance value. Actions with increasing effect on the resistance value are changes from grassland to infrastructure but there are also actions with decreasing effect on the resistance value like the establishment of protected areas.

2.1 *Land Cover Data (areal)*

Land cover data is the basic spatial dataset for modelling landscape connectivity and wildlife migration. Presuming an accurate dataset, according to geometric and thematic aspects, essentially land cover data should be up-to-date and secondly as detailed as possible to provide the highest accurate resistance maps. However, main limitations are accessibility and costs. CORINE land cover data (Bossard 2000, European Environment Agency 2007a) is often used in wildlife studies because it is free of charge and easy to access. A disadvantage of this dataset for wildlife studies, at a scale of 1 : 50,000, is the degree of spatial generalisation. The raster dataset available dates from 2006, and has a spatial resolution of 100 m x 100 m (1 ha). However, the smallest delineated patches, the minimum mapping unit, are 25 ha (European Environment Agency 2007a) and 5 ha for land cover changes (European Environment Agency 2007a). CORINE land cover provides in that way useful data for habitat suitability models with focus on larger core areas, e.g. Falucci et al. (2007). For studying wildlife migration or connectivity between core areas, smaller patches of forest, hedges, grassland and their spatial configuration are essential. These smaller patches function as stepping stones, which are especially essential in landscapes with intensive agricultural activities, by improving the quality of a migration corridor. On the other hand, small and scattered patches of built-up areas can reduce and even stop migration. The spatial information of such small patches improves the quality and is therefore essential for the generation of accurate resistance maps.

In account of this insight/information, a homogeneous land cover dataset of about 10,000 km^2 was generated from multi-seasonal Landsat TM5 and Landsat ETM7+ images. Through this new land cover dataset, the spatial accuracy was improved to 30 m x 30 m and the minimum mapping unit was reduced to ~ 0.2 ha (2 pixels). As a result the extraction of smaller but important patches for wildlife migration was possible.

Fig. 1 demonstrates the advantage of the generated land cover dataset compared to the CORINE 2006 land cover raster. The homogeneous yellow area of non-irrigated arable land of CORINE 2006 contains smaller (less than 25 ha) but quite important features for the landscape connectivity of mammals (see also stepping stone theory, Mac Arthur & Wilson 1967, or metapopulation theory, Levins 1969). The colour scheme of the classes is in accordance with the colour table/palette suggested by the European Environment Agency (2007b). The black circles contain predominately woody patches, despite the most southeast circle contains partially built-up area. The features in the black circles are especially of importance for the GIS-model, because they have a spatial influence on their surroundings, according to Tab. 1. In our case, considering the main species of interest (red deer), forest eases the movement through its shelter function and built-up area hampers the movement by its disturbance function.

The total study area was covered by four standard scenes of Landsat (WRS-2 path/row: 190 26/27, 189 26/27). In total, 17 different Landsat scenes of 2009 were processed to reduce effects of cloud cover or uncertainties due to phenological variation in the classification. By doing this the quality of the land cover data was improved, especially for important categories of the GIS-model for the resistance model. Each scene was classified with a k-nearest-neighbour (kNN) algorithm (Koukal et al. 2010) independently. Afterwards, the majority for each pixel was chosen as the final land cover class.

The necessary land cover classes for the wildlife study were defined independently from CORINE 2006 nomenclature in accordance with wildlife aspects. The list of land cover classes is summarized in Tab. 1.

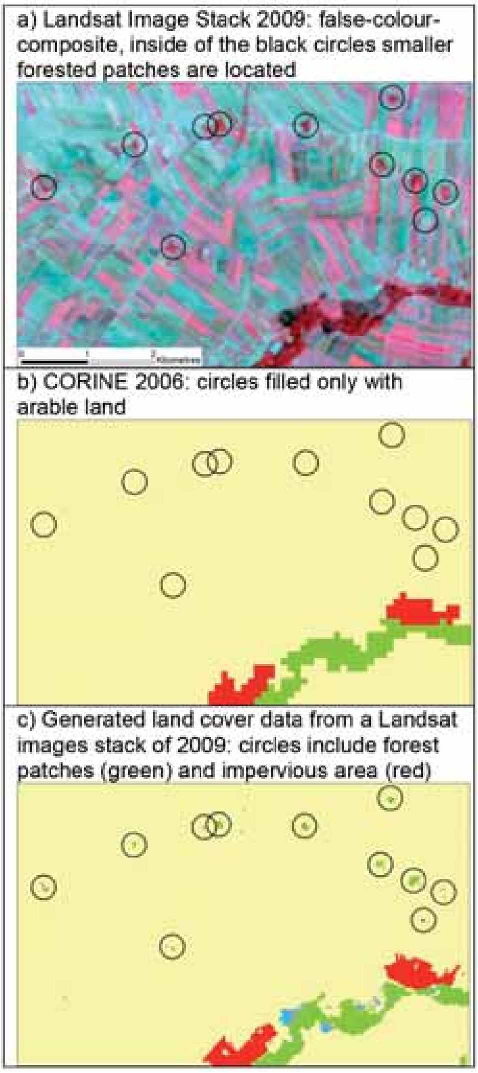

Fig. 1: Comparison of CORINE 2006 raster land cover data with the generated land cover dataset. Detail of an agriculture dominated landscape. Yellow: arable land, green: forest, red: settlement and impervious area, blue: water bodies and reed. The black circles are areas of interest (a: Landsat image, NASA Landsat Program 2009; b: CORINE land cover raster data, European Environment Agency; c: land cover derived from Landsat image).

2.2 *Ancillary Data*

Land cover derived from satellite images is usually limited to extensive objects which can be separated by their spectral properties (Lillesand & Kiefer 1994). Using only this information, the derived resistance map can provide information about the theoretical potential of the landscape for wildlife migration. Therefore, the suitability of resistance maps for describing the actual or future situation depends on the consideration of ancillary data. Ancillary data (e.g. Rogan et al. 2003) are typically linear or point features in the landscape with high impact on the permeability of landscapes, like roads, and attributes of these features, like traffic density. Additionally, data from regional planning can be implemented, for instance protection status or the rededication of arable land to built-up area.

The implementation of ancillary data is limited by its accessibility (costs, copyright, etc.) or can be collected through field work. These features of ancillary data have often only a small areal effect although they have a high impact on the connectivity. Common features are fences which impose a challenge to distinguish by means of remote sensing and have the potential to completely interrupt otherwise ideal wildlife corridors. Additionally, there is generally less public information available about fences. In this study the fences were located through field work, in combination with data from hunting associations and former projects. Especially, fences located around forest areas are critical: the positive effect of these forests and its surroundings is dissolved and is even degraded to inaccessible area, considering our main species of interest.

Highways and express roads require a fence by Austrian law and form therefore barriers.

Tab. 1: Land cover, their resistance values and spatial influence according to "area classes".

Land cover	resistance value	SPI: spatial influence, R: resistance value
Forest	0.01 – 0.2	900 – 10 000 m²: R 0.20 → SPI: 300 m 10 000 – 25 000 m²: R 0.15 → SPI: 700 m 25 000 – 50 000 m²: R 0.10 → SPI: 1 200 m 50 000 – 100 000 m²: R 0.05 → SPI: 1 350 m > 100 000 m²: R 0.01 → SPI: 1 500 m
Reed, wetland	0.2	0
Grassland	0.3	0
Agriculture	0.4	0
Water body	0.4 / 0.7	0.4: distance from river bank: 0 – 150 m 0.7: distance from river bank > 150 m
Vineyard	0.6	0
Quarry, etc.	0.9	0
Graveyard, fenced areas, etc.	1	0
Settlement, industrial areas	1	900 – 13 500 m²: R 1.0 → SPI: 100 m 13 500 – 27 000 m²: R 1.0 → SPI: 200 m 27 000 – 90 000 m²: R 1.0 → SPI: 300 m > 90 000 m²: R 1.0 → SPI: 500 m

Here, wildlife passages are important features for migration (e.g. Clevenger et al. 2001). Wildlife mitigation measurements vary between small, existing bridges or underpasses to green bridges (Wöss et al. 2002), explicitly made for wildlife crossing. Not only the width and height of the wildlife passage are of importance, in addition aspects like the top surface of the passage floor, e.g. concrete or natural soil (Völk et al. 2001) influence wildlife passage. In Austria the Federal Road Administration (ASFINAG) is also legally engaged to keep these passages free from blockages, like storage of farming vehicles. These wildlife passages were qualitatively separated into four classes: useful, moderate, weak, not useful. This classification was based on field work in accordance with requirements of the wildlife species for migrating red deer (*Cervus Elaphus*).

Roads were considered as linear features and were accessed by open street maps (Open Street Map (and) contributors, CC BY-SA (Creative Commons, ShareAlike)). Due to high traffic density estimated by field work, unfenced roads were separated into three categories resulting in different resistance values.

3 Resistance Values

Consisting of land cover and ancillary data this information had to be transferred into a metric variable related to wildlife. This transformation is based on the demands of the selected species. However the parameters chosen for one single species are often in opposition to another species. This dilemma exists not only between large mammals and amphibians but in between different mammal species themselves. Red deer will cross rivers and water bodies without hesitation whilst lynx (*Lynx Lynx*) will attempt to avoid contact with water as long as possible.

Furthermore, the aim of this study is to discuss generating resistance maps for wildlife corridor extraction. Therefore, the resistance values have to be related to migration. This is a clear distinction to methods where the resistance is only the inverse of the suitability value (see e.g. Corridordesign 2007). Migrating wildlife has different needs than local non-migratory wildlife populations. Migrating wildlife is more sensitive to disturbances, like wind parks. Perceiving these as a combination of movement, noise and light effects, whereas local populations have adapted to the disturbance and can be even found grazing beneath the wind turbines. For local population it is easier to find passages or underpasses at highways while migratory species requires guiding features, like hedge rows, to find and accept such mitigation measurements.

The resistance value is assumed as a function of land cover *in situ* and in the surrounding, giving the "stress" of crossing an area during migration. Furthermore, the resistance value is also depending on the local land use plans and protection status. A crux for working with resistance (low values are suitable for migration, high values restrain migration) is the definition of the resistance value for each land cover class.

The generated values and assumptions are based on previous studies of the Institute for Surveying, Remote Sensing and Land Information (e.g. Grillmayer et al. 2002 and Köhler 2005) in combination with the federal recommendations for public roads (FSV 2007) and additional expert knowledge (Völk et al. 2001).

3.1 *General*

In this study the main interest is on safeguarding the possibility of genetic exchange between species populations of the Alps and the Carpathians. Beside bears, wolves and lynx, red deer was the main target species and nearly fits the assumption for a generic focal species (Watts et al. 2010). Red deer is the most sensitive mammal considering landscape connectivity, i.e. closeness to forested areas, distance to settlements, and quality of wildlife passages. In comparison to red deer, bears have very low requirements for underpasses with a recommended passage height of 4 m (see Völk et al. 2001). Additionally, to calculate a resistance model a knowledge database of spatial rules is necessary. Especially the spatial behaviour of migrating species is of interest, not only of local populations. Therefore, track tracing data by itself is not enough for the formulation of the knowledge database. Collar data and gene samples of numerous migrating species are necessary, data which is hardly available for many species. Because red deer has a long tradition in research studies, expert knowledge was readily available and implemented to the knowledge database. A study of Köhler (2005) evaluates already basic values and spatial rules. Hence red deer was chosen as the species of interest and the resistance values and spatial rules are based on this knowledge database. The resistance value represents the average probability of crossing through a pixel of given length (here 30 m) and ranges from very low 0.01 to 1.

The small number of necessary land cover classes results from their relevance and their ability of quantification for wildlife migration. A low resistance value belongs to forested areas, while large, contiguous forest patches have the lowest value of 0.01. The value of 0 was not given, because even in appropriate areas there is still resistance for migration compared to core habitat. Furthermore, we did not give 0 values due to computational reasons. Reeds and wetlands have lower resistance values compared to grassland because of their sheltering function, especially larger reed zones. Agriculture, having a value in between the best and worst land cover, is definitely the most heterogeneous class, ranging from open, ploughed land without shelter and food to e.g. maize with useful shelter/protection and fodder availability. The value of 0.4 is here determined as an average. Vineyards might have a lower value of resistance although it is often protected by additional construction features and the ease of crossing is depending on the main orientation of the vineyard rows. While crossing along these rows is easier, the perpendicular crossing is more challenging and results therefore in a higher value compared to agriculture. While abandoned quarries sometimes serve as a refugium for wildlife, active quarries with fences, steep and slippery slopes, light and noise disturbances result in a value of 0.9. The resistance value of 1 indicates an absolute barrier, impermeable for wildlife. Still this category is subdivided in two categories due to their spatial influence.

The study area was dominated by three main categories: forest, agriculture and settlement areas.

Rules are based on expert knowledge of migratory red deer, unpublished collar and tracking data, despite the argument of Janin et al. (2009), that "*resistance is often arbitrarily established on the basis of expert knowledge*".

The values were defined considering regional, political and historical aspects as well as the features of the migrating species and not local populations. These values are a generalisation; the exact value will definitely fluctuate due to seasonality and differences in between years (especially agriculture), spatial arrangement (vineyards) or partial fencing (quarries) and the behaviour of the individual species. Nevertheless, in comparison to expert judgements alone the formulation of spatial explicit rules provides the opportunity for a basic understanding, which can be modified in the future.

3.2 *Spatial Effect of Resistance Values*

Land cover types can be separated in two groups by their spatial effect: Stationary features, those that affect only the area of their occurrence and features with additional spatial influence on their surrounding agricultural land and grassland belong to the first group. While water bodies alongside river banks are in general accepted by wildlife, larger water bodies more than 150 m away from the banks have higher resistance values. Contrary are features that influence the vicinity, either in a negative way by increasing the resistance value or in a positive way by decreasing the resistance value. Land cover with positive influence on adjacent land cover types for wildlife migration is forested area. The spatial range of the positive influence depends on the area of the considered forest patch. Land cover with negative spatial influence on the surrounding is settlement, where the range of spatial influence depends on the considered settlement area. Even small areas like farm houses have already the highest resistance value due to their disturbance potential.

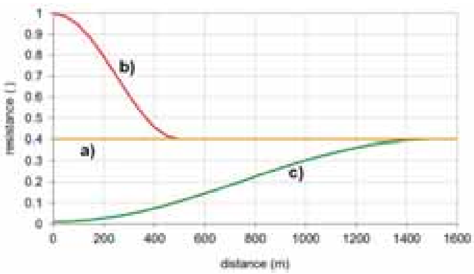

Fig. 2: Effect of spatial influence on agricultural land – profiles of resistance values for different adjacencies (left to 0 m); a) unaffected field – agricultural beside e.g. vineyard with a constant resistance value of 0.4; b) negative affected field (500 m) – large settlement (left of axis ordinate 0 m) nearby to agriculture – the resistance value descends from 1 to 0.4; c) positive affected field (1,500 m) – large forest (left of axis ordinate 0 m) nearby to agriculture – the resistance value gradually increases from 0.01 to 0.4.

The spatial effect is described in the last column of Tab. 1. A forest patch of 4 ha has a resistance value of 0.1. The spatial effect of this forest patch is effective up to a distance of 1,200 m. The positive influence of the land cover class will decrease from the borderline of the forest patch till the end of the spatial influence. Because the influence near the considered patch is in excess compared to the more distant locations it is not a linear function but a cosine function (see Fig. 2) between adjacent and more distant locations.

Working in a raster GIS with a distance raster for each area category of settlement or forest, the topological influence for the calculation of the resistance value can be considered as:

$$d_x = \left(1 - \frac{\cos\left(\frac{dist}{dist_{\max,cat}} \times f_1 \right) + 1}{2} \right) \quad (1)$$

d_x distance factor
dist distance from settlement
$dist_{max,\,cat}$ maximum distance for this area category of either settlement or forest
f_1 180 / π

for settlement influence:

$$R_{cal} = 1 - \left(\left(1 - R_L \right) \times d_x \right) \quad (2)$$

for forest influence:

$$R_{cal} = R_{Start} + \left(\left(R_L - R_{Start} \right) \times d_x \right) \quad (3)$$

R_{cal} calculated resistance value under consideration of the area category for settlement or forest

R_L static, local resistance value, without neighbourhood effect

R_{Start} resistance value of the considered forest patch $\rightarrow R_{Start} = f$ (forest patch area)

The calculations were performed for each area class of every land cover of Tab. 1 with spatial influence. If the spatial influences of different area classes are overlapping, the final resistance value was calculated according to the involved land cover class. Overlapping of different settlement area classes: the highest value will be assigned to the resistance surface. Overlapping of different forest area classes: the lowest value will be assigned to the resistance surface. If settlement and forest area classes are overlapping, the final resistance value will be calculated from the highest value of settlements and the lowest value from forest.

Furthermore, a positive spatial influence cannot cross a barrier, e.g. the positive influence of a large forest patch cannot reduce the resistance value on the other side of the highway – even if animals can sense the forest, they have no possibility to cross the barrier.

3.3 *Interaction between Different Spatial Influences*

Considering spatial influence leads automatically to complex interdependencies in natural landscapes and the issue of quantifying these interdependencies. The general rule was: if there is a negative spatial influence the positive influence cannot overrule it. However the negative influence will be reduced. The reduction values are estimated from collar data, expert interviews and field studies (Fig. 3).

Two land cover categories are able to reduce a negative influence: water bodies and forest. Water bodies can decrease the spatial influence of settlements by half of the original settlement value (see Fig. 3, profile b) from 500 m for large settlement areas to 250 m for smaller settlements. Forest patches decrease the negative spatial influence according to their size by two-thirds (see Fig. 3, profile c), finishing the negative influence at 170 m. Fig. 3, profile d, shows the effect of a forest patch adjacent to settlement, although being too small (100 m) to absorb all the spatial influence of the settlement. After 100 m of forest the spatial influ-

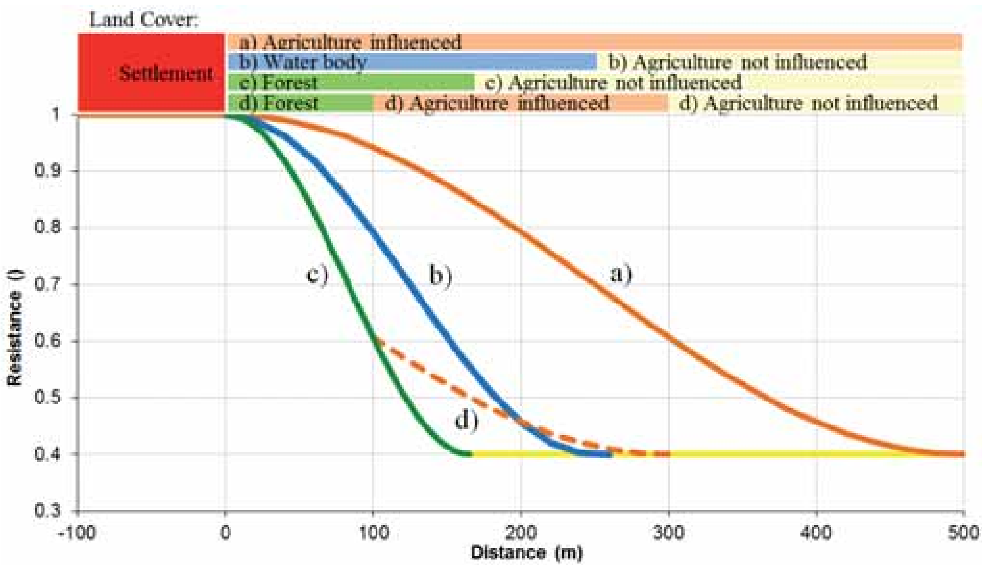

Fig. 3: Spatial "buffering" effect of different land covers and their interactions; top: land cover and their spatial extent; bottom: profiles of their resistance values; a) agriculture beside large settlement area: negative spatial influence for 500 m distance till agriculture has it original value of 0.4; b) between the settlement and agriculture a water body of 250 m width is located; c) between the settlement and agriculture a forest of nearly 170 m width is located; d) between the settlement and agriculture a forest of 100 m width is located.

ence of profile a) continues from the resistance value 0.6, resulting in a total spatial influence of 300 m for this spatial composition of large settlement – forest patch – agricultural land.

While the spatial influence of settlement on the surrounding can be reduced, the resistance value of the settlement area itself remains unchanged at the highest value of 1. On the other hand, for forested areas the spatial influence cannot be reduced to zero, however the resistance value of forested area itself can be increased through large settlement areas.

Roads and wildlife passages are considered at the end of creating a dataset of resistance values. Roads are separated in three categories: dirt roads with a resistance value of 0.3, because they can serve as "guiding" features, especially if they are covered with leaf litter. Paved roads receive a value of 0.6 and paved roads with heavy traffic a resistance value of 0.85. Because wildlife can come quite near to roads, especially with forest in the vicinity, even roads with high traffic intensity are not considered with negative spatial influence perpendicular to the main road axis. The resistance value can only increase, if overlapped by negative spatial influence of settlements, yet cannot decrease. Roads in forest remain with the same value as roads in agricultural fields.

Existing wildlife passages for crossing highways were surveyed and separated in four categories. Excellent, with resistance value of 0.3, providing enough width and suitable surface, moderate value 0.6 decreasing width and surface quality, and poor with value 0.9, including small widths, and decreasing quality due to paved roads or waterways. The fourth category is considered as not passable. New wildlife passages should belong to the excellent category.

Modelling connectivity is highly dependent on the availability and quality of geo input data. Especially linear barriers like roads, fences or paved riversides can easily interrupt the feasibility for wildlife migration. Additionally, in contrast to roads, such data is hardly available. By reason, that the hard barrier effect of fences it was necessary to collect this information through field studies. Fences can influence large forest patches and render them as inaccessible areas, e.g. due to enclosures. The ancillary data of fences is therefore required for statements about the status quo of landscape connectivity and have to be considered therefore as a required dataset.

Protected areas are the only land use category, beside forest, which is reducing the resistance value by 0.1 for forest, wetland, grassland and agriculture. The smallest resistance value is 0.01. Paved roads, settlement or fenced areas remain unchanged.

The creation of a resistance surface can be performed with any raster GIS with cost distance algorithms, in this study ArcGIS™ Spatial Analyst™ by Esri was used by writing Python scripts, simple text files provide the input parameters like resistance values and spatial influence distance.

3.4 *Combination of the Separate Geolayers and Different Scenarios*

For each category the resistance value was calculated and afterwards combined, to produce a single dataset. The combination rules between different land cover classes are:

- a positive spatial influence cannot cross a barrier, e.g. the positive influence of a large forest patch cannot reduce the resistance value on the other side of the highway,
- if there is an overlapping of negative influence layers from different area categories, the resistance value will be taken from the layer with the highest value,
- if there is an overlapping of positive influence layers from different area categories, the resistance value will be taken from the layer with the lowest value,
- if there is a negative spatial influence the positive influence cannot overrule it, but the negative influence will be reduced,
- road and wildlife passage datasets are the last layers in the sequence of overlapping. Especially for roads the resistance values can increase by nearby settlement area but cannot decrease. Wildlife passages are supposed to be unchangeable: even if the passage is located in forest area, the quality of the passage itself will not be improved.

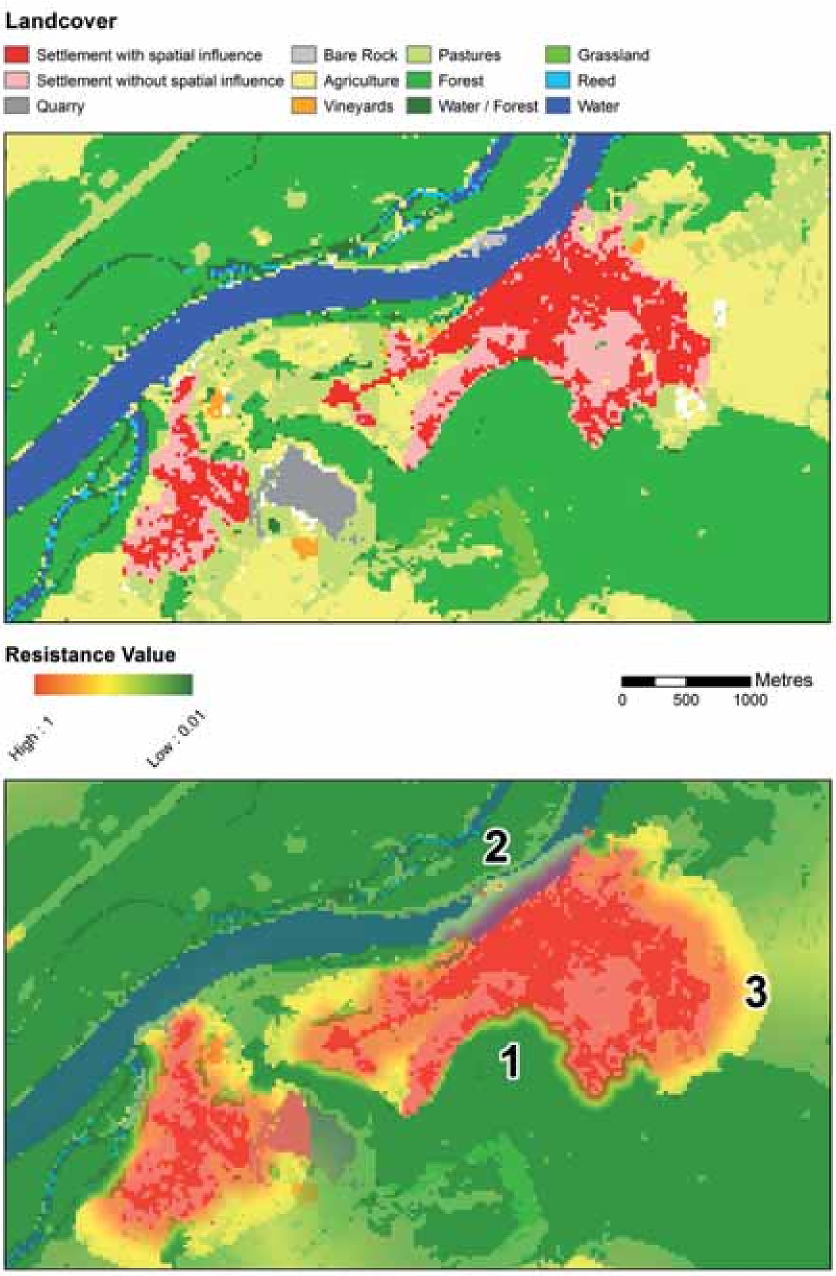

Fig. 4: Top: land cover map; bottom: resulting resistance map; red hue: negative spatial influence of settlement area; green hue: positive spatial influence of forest; location (1): settlement adjacent to forest: spatial influence of settlement reduced to one third of the original 500 m; location (2): settlement adjacent to water body: the negative influence of the settlement is river to half of the original value – on the opposite river side the riparian forest is not influenced by the settlement; location (3): Settlement adjacent to agriculture with the longest spatial influence.

4 Results

The method of generating different resistance value maps was applied in a study area, which covers both Austrian and Slovakian territory. Fig. 4 shows the effects of spatial interaction for the resistance map in detail in an area close to the river Danube. Here the spatial interactions of different land cover are demonstrated. The resistance value map can already be used to illustrate the spatial effect of spatial planning activities, like planting of forest area, independent of selected source and target regions for algorithms of corridor extraction.

The further figures focus on the result of different resistance surfaces for the corridor

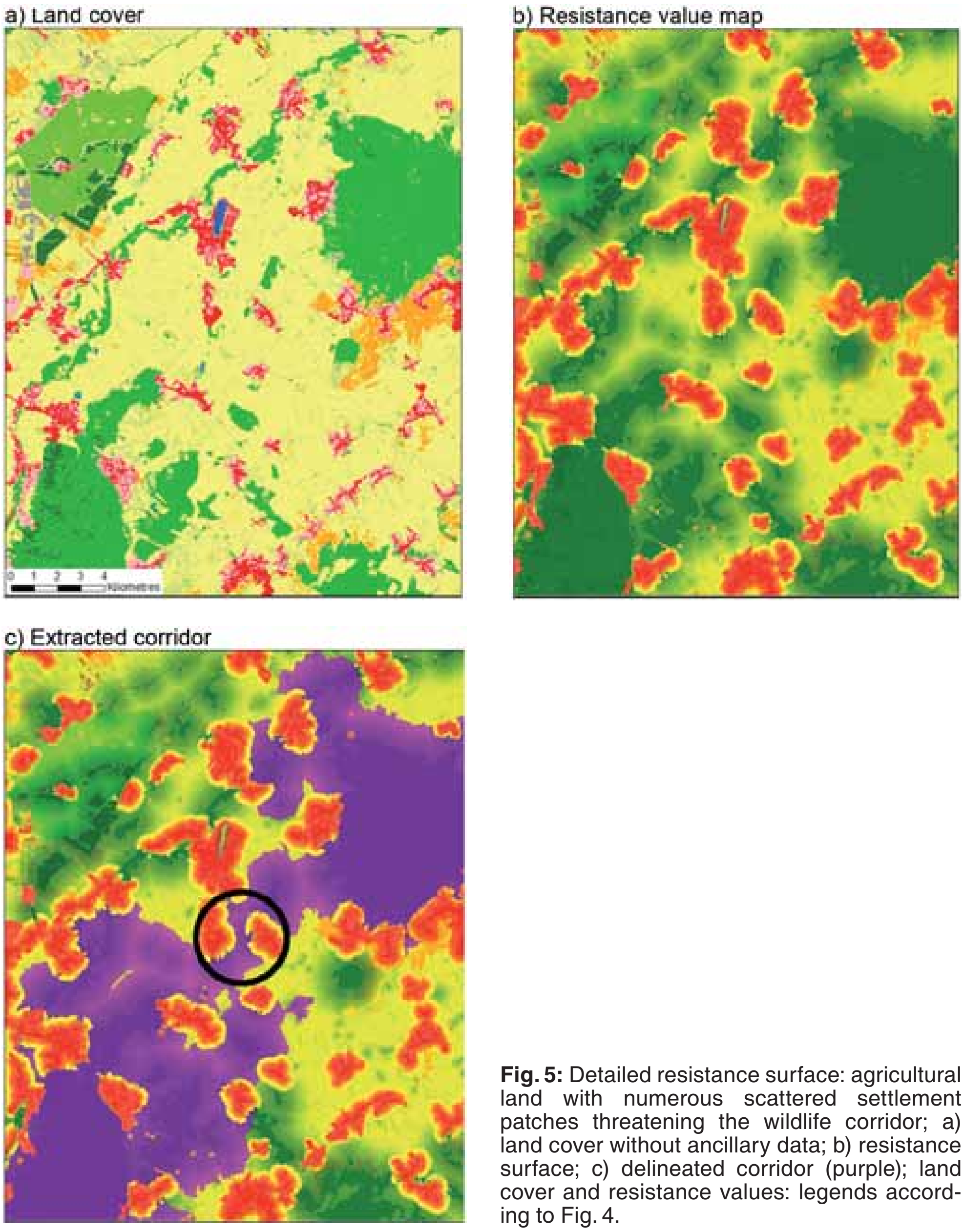

Fig. 5: Detailed resistance surface: agricultural land with numerous scattered settlement patches threatening the wildlife corridor; a) land cover without ancillary data; b) resistance surface; c) delineated corridor (purple); land cover and resistance values: legends according to Fig. 4.

delineation. The corridor delineation was exemplified by a least cost path algorithm, but any other algorithm might be used.

In Fig. 5 the forested core areas in the southwest and northeast corner should be connected. But the permeability of the landscape is reduced. Due to settlement agglomeration the resistance values are increased, not only for the settlement areas but also beyond the borders of the settlement. A corridor delineation (here with a least cost path algorithm) exemplifies this effect even more by showing the bottlenecks of the corridor. Fig. 5c (black circle) indicates where the width of the corridor decreases to less than 500 m but FSV (2007) recommends a corridor width of 500 m to 1,000 m between settlements. Here regional planning activities should be applied to halt at

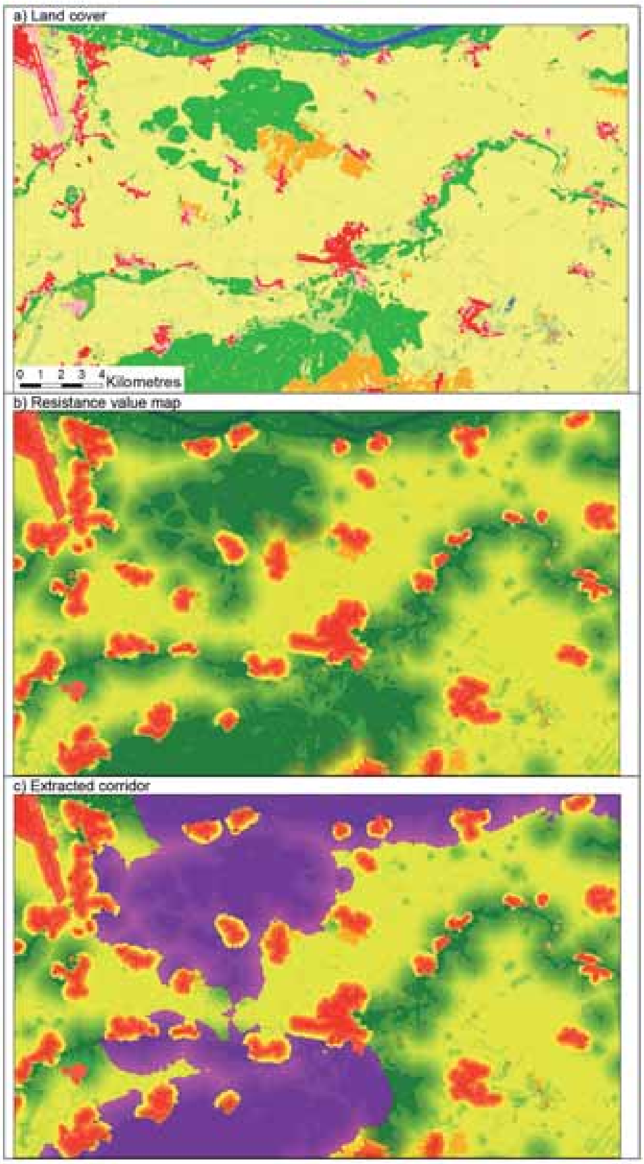

Fig. 6: Landscape potential; a) land cover without ancillary data; b) resistance surface; c) delineated corridor (purple); land cover and resistance values: legends according to Fig. 4.

least further expansion of the adjacent settlements. The implementation of forest patches in this area would not change the width of the corridor but helps to decrease the resistance values. In natural forest the minimum width of the corridor can even decrease to 100 m (FSV 2007). The consideration of the spatial effect of settlements is here essential. Without this consideration, the distance between the settlements is still above 500 m and seems to be wide enough for wildlife migration.

Fig. 6 indicates a bottleneck which prohibits wildlife migration. In the middle, from west to east a riparian corridor is situated. For the calculation of the resistance values only the land cover was implemented, without ancillary data like the layers of roads, wildlife passages, fences or spatial planning. Corridor delineation (here with a least cost path algorithm) demonstrates the shortest and "cheapest" (lowest accumulated resistance values) connection between north and south, with the bottleneck in arable land.

This layer combination for the resistance surface shows the spatial path of connection, without restrictions due to roads, fences, and other obstacles. Although it is an artificial construct, it indicates the "potential" of the landscape for connectivity. The layer combination is useful for regional planning regarding general decisions on land use. It shows where the landscape is well connected, neglecting limiting factors like roads and fences. This information can be useful for the placement of new wildlife passages and reduces the costs of implementing new forested patches in that way.

Fig. 7 shows the same area similar to Fig. 6 with the main intention, to connect the forested core areas from the south and north. The implementation of ancillary data (Fig. 7b) results in different resistance surface than Fig. 6, due to considering the highway as an absolute barrier, also existing wildlife passages are considered. Furthermore, large parts of the forest north of the highway are fenced and cannot be accessed by large mammals. The small red dots represent wind parks, which rises the resistance value and lowers the connectivity. The extracted corridor of the actual condition (Fig. 7c) is therefore diverted to the riparian corridor, where wind parks increase the hardship of wildlife migration.

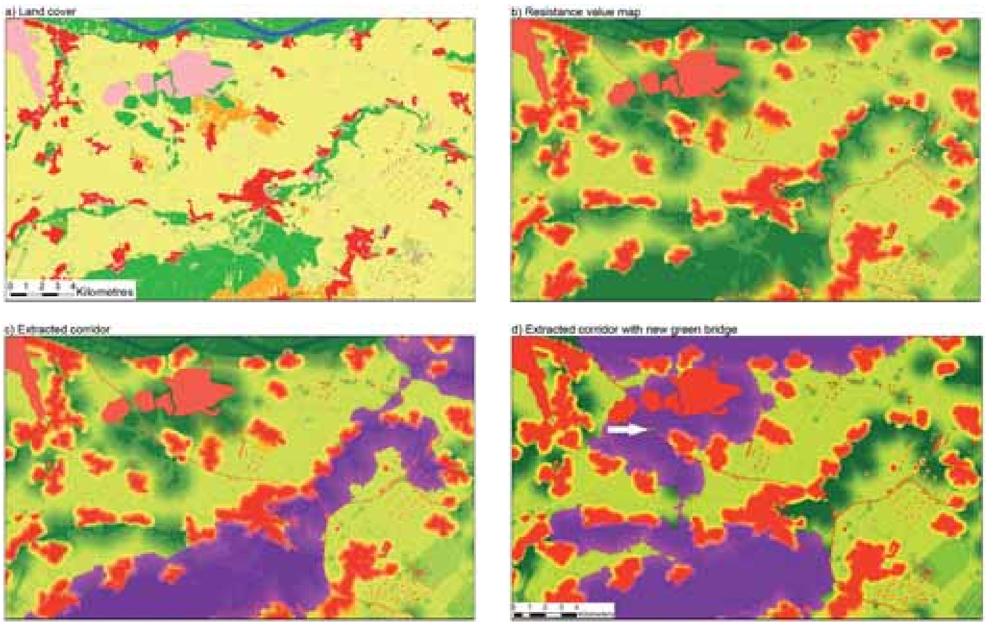

Fig. 7: Status quo and chances of enhancement; a) land cover and ancillary data; b) resistance surface; c) delineated corridor (purple); d) resistance surface like b) but considers a new mitigation measurement for crossing the highway (white arrow); purple: extracted corridor; land cover and resistance values: legends according to Fig. 4.

Fig. 7d shows the effect of considering a new location for a wildlife passage crossing the highway (white arrow). The rest of the landscape remains the same as for Fig. 7c. The acceptance of a wildlife passage for migration of animals depends not only on the quality of the passage itself but also on the circumstances of approaching this passage. Small forested patches or hedges function as guiding features in the landscape, providing also shelter. If these guiding features already exist, the acceptance of the wildlife passage will not even be faster but also additional costs for these features are avoided like the access to favoured parcels, planting, etc. are avoided. Fig. 6 provides this spatial information of existing landscape features supporting wildlife migration. The placement of the new wildlife passage inside the corridor area of Fig. 6 guarantees therefore an easier acceptance of the passage by wildlife. Additionally it reduces the costs of integration of the new passage in the landscape.

So the corridor extraction is depending on the quality of the resistance surface and the consideration of spatial effects and ancillary data. Beside the resistance surface, the extracted corridor is depending on the applied algorithm. Furthermore the initial regions have a substantial influence on the outcome (region locations, region shape, etc.).

A traditional least cost path algorithm is often used in wildlife analysis (Beier et al. 2009) it has its limitations in validating thresholds of ecological parameters. In addition it enhances only one path, the least cost path, even if there are more possibilities apparent (Pinto & Keitt 2009). Circuit theory on the other hand is often limited by hardware requirements because of large data processing demands.

5 Discussion

The Figs. 5 and 6 demonstrate the importance of the resistance surface. A delineated corridor, by applying a delineation algorithm, can only be as good as the basic input. The resistance surface functions as the basic input. Land cover data with proper spatial details is necessary, especially for land based wildlife movement, although incorporating ancillary data, like fences or wildlife passages, are crucial. The consideration of spatial interactions improves the account for regional planning actions. Despite the declaration of these spatial interdependencies is discussed in a controversial way in literature, the implementation in a GIS helps to understand the movements in a better way and provides the possibility to refine and adapt these spatial rules and assumptions for the future.

Due to the geometry of Landsat images, features smaller than 30 m x 30 m cannot be detected. But for future studies the new generation of satellite data such as Sentinel-2 with high temporal (three to five days) and high spatial resolution (10 m to 20 m) provides new opportunities. Temporal effects like seasonal and even diurnal differences of resistance values for agriculture become more accessible. To study seasonal effects more knowledge of animal behaviour will be needed like additional collar / GPS data and the quantification of these data to spatial rules. The knowledge database for generating resistance values demonstrated here, considers especially the spatial effect of extensive land covers. The inclusion of spatial effect for linear structures, like roads in combination with existing rules, might improve the quality of the resulting resistance value in some parts of the landscape but further research is needed.

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References

Abt, K.M. & Sandfort, R., 2011: Landschaftsfragmentierung und tierökologische Korridore – Ein

Überblick zum aktuellen Forschungsstand sowie zu ökologischen, planerischen und rechtlichen Aspekten. – Forschungsprojekt Alpen Karpaten Korridor, Universität für Bodenkultur, Wien, Österreich.

Anderson, A. & Jenkins, C.N., 2006: Applying Nature's Design: Corridors as a Strategy for Biodiversity Conservation. – Columbia University Press, NY, USA.

Andren, H., 1994: Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat – a review. – Oikos **71:** 355–366.

Banko, G., Kurzweil, A., Lexer, W., Mayer, S., Roder, I. & Zehtner, G., 2004: Status und Trends des quantitativen Flächenverbrauchs in Österreich. – Wissenschaft & Umwelt Interdisziplinär **8:** 43–52.

Baum, K.A., Haynes, K.J., Dillemuth, F.P. & Cronin, J.T., 2004: The matrix enhances the effectiveness of corridors and stepping stones. – Ecology **85:** 2671–2676.

Beier, P. & Loe, S., 1992: A checklist for evaluating impacts to wildlife movement corridors. – Wildlife Society Bulletin **20:** 434–440.

Beier, P. & Noss, R.F., 1998: Do habitat corridors provide connectivity? – Conservation Biology **12** (6): 1241–1252.

Beier, P., Majka, D.R. & Spencer, W.D., 2009: Uncertainty analysis of least-cost modeling for designing wildlife linkages. – Ecological Applications **19** (8): 2067–2077.

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

Bossard, M., Feranec, J. & Otahel, J., 2000: CORINE land cover technical guide – Addendum 2000 – Technical Report No. 40, European Environment Agency, Copenhagen, Denmark.

Centrope, 2014: Central European region. – http://www.centrope.com/en (1.7.2014).

Clevenger, A.P., Chruszcz, B. & Gunson, K.E., 2001: Highway Mitigation Fencing Reduces Wildlife-Vehicle Collisions. – Wildlife Society Bulletin **29** (2): 646–653.

Corridordesign, 2007: Overview of corridor modelling. – http://corridordesign.org/designing_corridors/corridor_modeling/ (7.7.2014).

Driezen, K., Adriaensen, F., Rondinini, C., Doncaster, C.P. & Matthysen, E., 2007: Evaluating least-cost model predictions with empirical dispersal data: a case-study using radiotracking data of hedgehogs (Erinaceus europaeus). – Ecological Modelling **209:** 314–322.

European Environment Agency, 2007a: CLC2006 technical guidelines. – EEA Technical report, No 17/2007, ISSN 1725-2237, http://www.eea.europa.eu/publications/technical_report_2007_17 (1.7.2014).

European Environment Agency, 2007b: Corine land cover 2006 classes and RGB color codes. – http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-3/corine-land-cover-classes-and/clc_legend.csv (7.7.2014).

Fahrig, L., 2001: How much habitat is enough? – Biological Conservation **100:** 65–74.

Falucci, A., Maiorano, L. & Boitani, L., 2007: Changes in land-use/land-cover patterns in Italy and their implications for biodiversity conservation. – Landscape Ecology **22:** 617–631.

Fleury, A.M. & Brown, R.D., 1997: A Framework for the Design of Wildlife Conservation Corridors with Specific Application to Southwestern Ontario. – Landscape and Urban Planning **37** (8): 163–186.

Forman, R.T.T. & Godron, M., 1986: Landscape Ecology – Wiley, New York, NY, USA.

FSV (Oesterreichische Forschungsgesellschaft Strasse, Schiene, Verkehr), 2007: RVS 04.03.12 Wildschutz, Flora und Fauna an Verkehrswegen. – http://rvs.co.at/shop/produktdetail.aspx?ID Produkt= eafb2c26-1d55-4a0e-87bf-124cf7ab30fc (1.7.2014)

Grillmayer, R., Schacht, H. & Wöss, M., 2002: Forschungsprojekt Wildökologische Korridore. – Universität für Bodenkultur, Wien, Österreich.

Goetz, S.J., Jantz, P. & Jantz, C.A., 2009: Connectivity of core habitat in the Northeastern United States: Parks and protected areas in a landscape context. – Remote Sensing of Environment **113:** 1421–1429.

Hilty, J.A., Lidicker, Jr.W.Z., Merenlender, A. & Dobson, A.P., 2006: Corridor Ecology: The Science and Practice of Linking Landscapes for Biodiversity Conservation – Island Press, Washington, DC, USA.

Howey, M.C.L., 2011: Multiple pathways across past landscapes: circuit theory as a complementary geospatial method to least cost path for modelling past movement. – Journal of Archaeological Science Volume **38** (10): 2523–2535.

Janin, A., Lena, J.P., Ray, N., Delacourt, C., Allemand, P. & Joly, P., 2009: Assessing landscape connectivity with calibrated cost-distance modelling: predicting common toad distribution in a context of spreading agriculture. – Journal of Applied Ecology Volume **46** (4): 833–841.

Kramer-Schadt, S., Kaiser, T.S., Frank, K. & Wiegand, T., 2011: Analyzing the effect of stepping stones on target patch colonization in structured landscapes for Eurasian lynx. – Landscape Ecology **26:** 501–513.

Koukal, T., Adelmann, C., Bauerhansl, C. & Schneider, W., 2010: Vom Punkt zur Fläche – vom Pixel zur Karte: Klassifikation der Landbedeckung mit der kNN-Methode. – VGI – Österreichische Zeitschrift für Vermessung und Geoinformation **98:** 90–101.

Köhler, C., 2005: Habitatvernetzung in Österreich GIS Modellierung von Mobilitätswiderstandswerten für waldbevorzugende, wildlebende Großsäuger in Österreich. – Masterthesis, Institut für Vermessung, Fernerkundung und Landinformation (IVFL), BOKU – Universität für Bodenkultur, Wien, Österreich.

Levins, R., 1969: Some demographic and genetic consequences of environmental heterogeneity for biological control. – Bulletin of the Entomological Society of America **15:** 237–240

Lillesand, T.M. & Kiefer, R.W., 1994: Remote Sensing and Image Interpretation. – Third edition, Wiley, New York, NY, USA.

Mac Arthur, R.H. & Wilson, E.O., 1967: The theory of island biogeography. – Princeton University Press, Princeton, New Jersey, USA.

McRae, B.H. & Beier, P., 2007: Circuit theory predicts gene flow in plant and animal populations. – National Academy of Sciences of the USA **104:** 19885–19890.

Molinari, P. & Molinari-Jobin, A., 2001: Identifying Passages in the Southeastern Italian Alps for Brown Bears and Other Wildlife. – Bear Journal (Ursus) **12:** 131–134.

Musiega, D.E. & Kazadi, E.N., 2004: Simulating the East African wildebeest migration patterns using GIS and remote sensing. – African Journal of Ecology **42:** 355–362.

Pinto, N. & Keitt, T.H., 2009: Beyond the least-cost path: evaluating corridor redundancy using a graph-theoretic approach. – Landscape Ecology **24:** 253–266.

Rabinowitz, A. & Zeller, K.A., 2010: A range-wide model of landscape connectivity and conservation for the jaguar, Panthera onca. – Biological Conservation **143:** 939–945.

Ray, N., Lehmann, A. & Joly, P., 2002: Modelling spatial distribution of amphibian populations: a GIS approach based on habitat matrix permeability. – Biodiversity and Conservation **11:** 2143–2165.

Rayfield, B., Fortin, M.J. & Fall, A., 2010: The sensitivity of least-cost habitat graphs to relative cost surface values. – Landscape Ecology **25:** 519–532.

Rogan, J., Miller, J., Stow, D., Franklin, J., Levien, L. & Fischjer, C., 2003: Land-Cover Change Monitoring with Classification Trees Using Landsat TM and Ancillary Data. – Photogrammetric Engineering & Remote Sensing **69** (7): 793–804.

Sawyer, H., Kauffman, M.J., Nielson, R.M. & Horne, J. S., 2009: Identifying and prioritizing ungulate migration routes for landscape-level conservation. – Ecological Applications **19:** 2016–2025.

Taylor, P.D., Fahrig, L., Henein, K. & Merriam, G., 1993: Connectivity is a vital element of landscape structure. – Oikos **68:** 571–573.

Vogt, P., Riiters, K.H., Iwanowski, M., Estreguil, C., Kozak, J. & Soille, P., 2007: Mapping landscape corridors. – Ecological Indicators **7:** 481–488.

Völk, F., Glitzner, I. & Wöss, M., 2001: Kostenreduktion bei Grünbrücken durch deren rationellen Einsatz. – Straßenforschungsauftrag Nr. 3.195 des Bundesministeriums für Verkehr, Innovation und Technologie Straßenforschung, Heft **513**.

Wang, I.J., Savage, W.K. & Shaffer, H.B., 2009: Landscape genetics and least-cost path analysis reveal unexpected dispersal routes in the California tiger salamander (Ambystoma californiense). – Molecular Ecology **18:** 1365–1374.

Watts, K., Eycott, A., Handley, P., Ray, D., Humphrey, J. & Quine, C., 2010: Targeting and evaluating biodiversity conservation action within fragmented landscapes: an approach based on generic focal species and least-cost networks. – Landscape Ecology **25:** 1305–1318.

Wöss, M., Grillmayer, R. & Völk, F., 2002: Green bridges and wildlife corridors in Austria. – Zeitschrift für Jagdwissenschaft **48** (1): 25–32.

Yadav, P.K., Kapoor, M. & Sarmak, K., 2012: Land Use Land Cover Mapping, Change Detection and Conflict Analysis of Nagzira – Navegaon Corridor, Central India Using Geospatial Technology. – International Journal of Remote Sensing and GIS **1** (2): 90–98.

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