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DISTRIBUTION AND CONNECTIVITY OF EURASIAN LYNX (*LYNX LYNX*) IN THE ALPS

Workpackage 5: “Corridors and Barriers”

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CONTENT

1.1 Introduction

In this report the approaches taken to model the distribution and connectivity of *Lynx lynx* in the Alps are described. This was undertaken within the project Econnect. The analysis was conducted with the following guidelines in mind:

1. Analysis of species habitat needs in terms of habitat connectivity (e. g. maximum distances, characteristics of corridors/stepping stones).
2. Spatial analysis of current and potential habitats, their lack of connectivity and its reasons (qualitative and quantitative assessment)
3. Characterisation of the barriers by their origin, size, shape and degree of permeability and (economic) assessment of possibilities to diminish them.

In the consecutive sections the guidelines provided above are followed. In Section 1.5 a brief characterisation of *L. lynx* is provided, followed by its current and potential distribution in Section 1.6. Finally connectivity between patches of potential distribution is considered under different scenarios in Section 1.8.

1.2 Graph theory

In the following sections graph theory related terms are used. To clarify the meaning in an ecological context a brief description is provided. A graph consist of nodes or vertexes and edges. Edges may connect any two nodes. In ecological terms nodes are habitat patches. Any two connected patches have an edge between them. A graph is considered as a full graph if all edges are connected with each other. The degree of an edge or vertex gives information about the number of adjacent edges. For a general introduction to graph theory in ecology see also [8]. A planar graph is a graph which edges have been reduced so they do not intersect. Planar graphs have usually fewer edges, are better to illustrate and resemble ecological reality more closely [14]. Here a Delaunay triangulation was used to approximate planarity.

1.3 Study Area and resolution

For the spatial extend of the study area the area defined by the alpine convention [12] was taken. This encompasses an area of approximately 190.000 km^2. The model was implented at a resolution of 1 km^2 this was the same resolution as used by Zimmermann and Breitenmoser [17].

1.4 Software

All GIS analysis was done either with QGIS [10] or GRASS GIS [3]. Statistical analysis was conducted with R [11]. Connectivity analysis was done with the R package igraph[2], raster [4] and tripack [1]. Morphological spatial pattern analysis was done with GUIDOS [16]. Maps were produced with GMT.

1.5 Characterisation of *L. lynx*

The Eurasian Lynx is one of four lynx species that occur worldwide. Its distribution is restricted Europe and Eurasia, except of the Iberian Peninsula where the *Lynx pardius* is found. In comparison to the three other lynx species the Eurasian lynx is the biggest with a mean body mass measured in Switzerland for adult females 17 - 20 kg and adult males 20 - 26 kg [5]. In this report the term lynx is used a synonym with the Eurasian Lynx or *L. lynx*. Lynx has an average home range of 60 - 480 km^2 for females and 90 to 760 km^2 for males [5]. The maximum known dispersal distance of a lynx in the Alps is from the Tössstock (Switzerland) via the Swiss National Park to the Italian Trentino. This distance of approximately 200 km linear distance was taken as a reference for dispersal distance [6].

Concerning habitat preferences some authors suggest that the potential distribution of lynx can be equated with the distribution of forest in middle Europe and the Alps. Some eastern populations inhabitant step like habitats. However, more recent studies also suggest that female lynx reproduced in a home range with as little as 25-30 % forest [13].

Studies from Switzerland showed that a lynx’s diet consists of up to 20 different species of prey. However approximately 88 % originate from the two most important species of prey: chamois and roe deer [5]. The occurrence of lynx always brings a conflict with farmers and hunters. While there are occasional kills of livestock (figures for Switzerland suggested that this very low, below 0.04 % of the total diet), for hunters *L. lynx* is often seen as a competitor.

The Pan-Alpine Conservation Strategy for the lynx concluded that the lynx as species is not threatened in Europe as a whole, however, each population deserves to be preserved as an integral part of the ecosystem [7]. The main threats that were identified are:

- Habitat loss through habitat conversion (*i.e.* deforestation).
- Loss of prey through the decline of ungulates.
- Direct persecution as results of a predator prey conflict.

1.6 Distribution of *L. lynx*

Estimated presence distribution of the lynx can be obtained from Figure 1. This distribution maps were compiled for Europe by Pan-Alpine Conservation Strategy for Lynx [7] on a resolution of 100 km^2. To model the potential distribution for the lynx in the Alps (= alpine convention) a logistic regression published by Zimmermann & Breitenmoser [17] was used. Some adaptation was necessary, since the model was developed for the Jura. The probability of lynx occurrence is given by a logistic transformation of the linear predictor (LP):

$LP = -4.5391 + (0.0152 * shrub) + (0.0016 * altitude) + (0.1337 * declivity) + (0.0472 * forest)$

Where *shrub* is the frequency (between 0 and 16) of shrubs in each 1 km^2 cell, *forest* is the frequency of forest in each 1 km^2 cell, declivity is the slope in degrees and altitude the elevation in meters. To overcome the much higher altitudes in Alps, altitude above 1800 m (= maximum altitude in the Jura) was set to 1800. All areas above 2500 m were considered to be unsuitable for lynx and set as no data values. The shrub and forest layers where obtained from CORINE Landcover, declivity and altitude where obtained from SRTM.

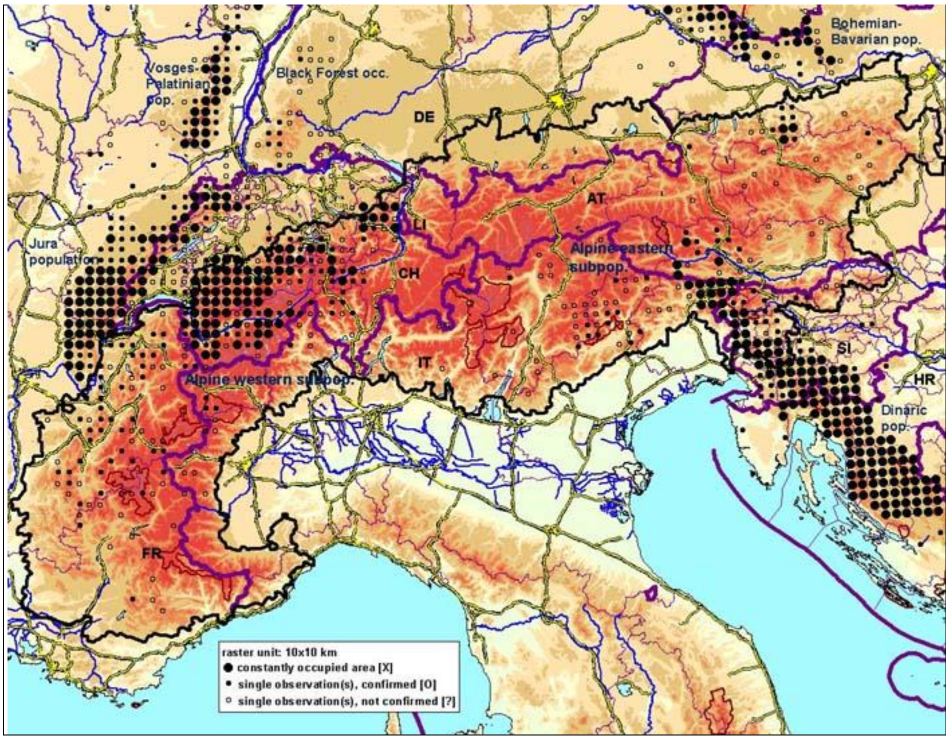

Figure 1: present distribution of lynx in the Alps (according to the Pan-Alpine Conservation Strategy)

In order to obtain a presence absence distribution map for the lynx, a threshold of 0.35 was set, as by Zimmermann and Breitenmoser [17]. In Figure 1 the potential distribution of Lynx for the alps is shown.

For validation 190 sightings of lynx from the Econnect pilot region the northern limestone alps were available. 130 had a resolution of 1 km^2 or less and the sighting was proved as a hard facts (i.e. picture trap, capture) or soft facts (i.e.

confirmed prey). Unconfirmed sightings (i.e. sightings) were neglected. 96 % of all sightings were within the area calculated as suitable for *L. lynx* by the model shown above.

While the number of sightings would have been sufficient to calculate a new model for the Alps with techniques such as Maximum Entropy [9], their distribution was too clustered. Trials gave similar predictions for the Northern Limestone Region, but gave much lower predictions to the western and central Alps.

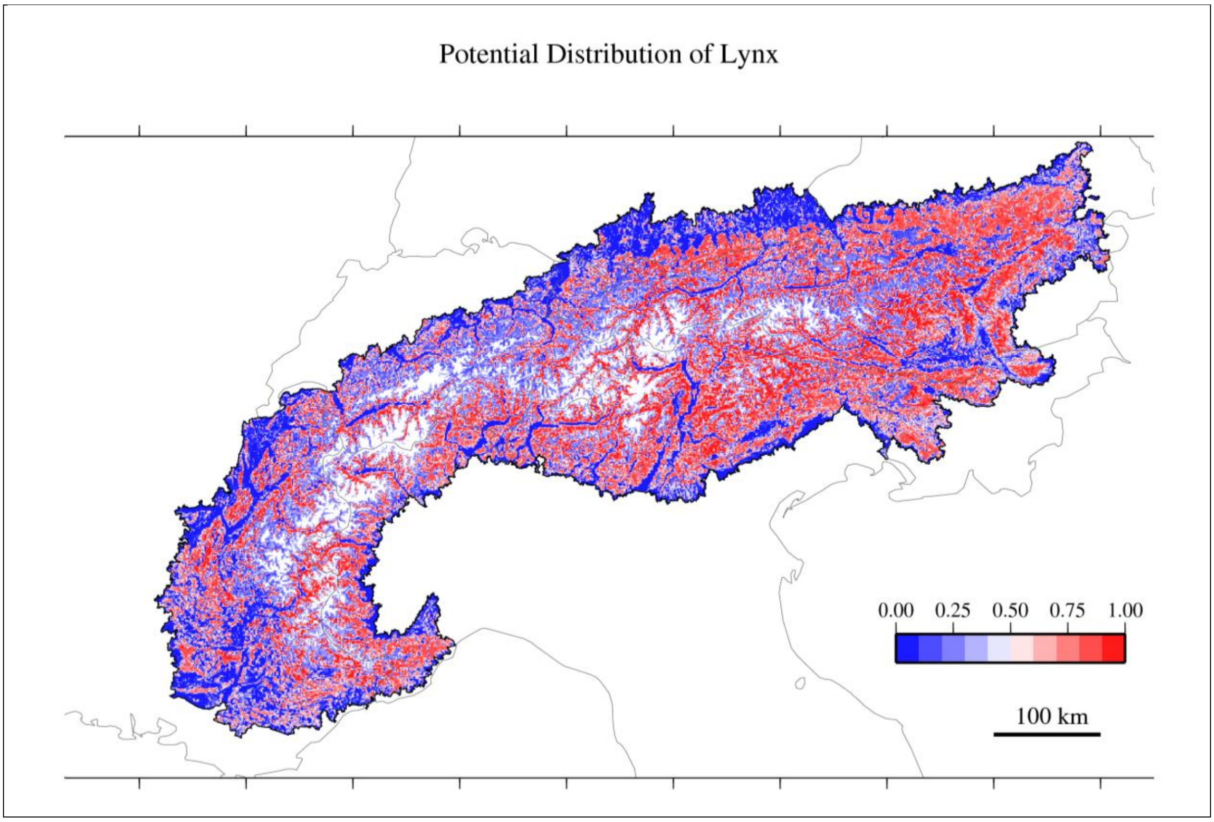

Figure 2: shows the potential habitat suitability for the lynx in the Alps. The resolution of the map is 30 seconds (approximately 1 km^2).

1.7 Morphological Spatial Pattern Analysis

At an alpine scale it is difficult to identify corridors visually. A graph based approach can give some insight about the importance of individual patches in a network. But there only topological connectivity is treated. To pin point pixels that serve as corridors between core areas an analysis such as the morphological spatial pattern analysis is needed. GUIDOS is an implementation of the morphological spatial pattern analysis algorithm. GUIDOS classifies a binary image (e.g. a forest map or a map of suitable *L. lynx* habitat) in different categories. The algorithm takes each pixel and compares it with the neighboring pixels based on set of mathematically formulated rules. For a detailed description of the algorithm see [15].

The different GUIDOS categories are described as follows:

Background (grey) Pixel that are classified as forest or unsuitable for black grouse (*i.e.* predicted MaxEnt occurrence probability is below a threshold).

Core (green) Pixels that are classified as forest or suitable black grouse habitat (*i.e.* predicted MaxEnt occurrence probability is above a threshold) and pixels are surrounded by habitat.

Branch (orange) Branches of 1 pixel width that originate in core area and terminate in background (*i.e.* pixels that are unsuitable in the habitat matrix).

Edge (black) Edges have on one side core area and on the other side background.

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.

In Figure 3 the results of the morphological spatial pattern analysis are shown. The results are summarized according to the degree of which they are protected in Table 1. For the conservation of *L. lynx* core areas and corridors (= bridges), should be given priority. In Figure 3 it can be seen that in the eastern Alps there are larger areas of adjacent core areas. The western part of the Alps is a lot patchier with regard to lynx habitat. This can be attributed to the fact that the eastern Alps are generally of less altitude. Consequently there is more lynx habitat.

It is import to be aware that red pixels (bridges or corridors) are not threatened per se, they are merely highlighted to state their importance of connecting two or more core areas. Whether or not they are threatened requires further investigation.

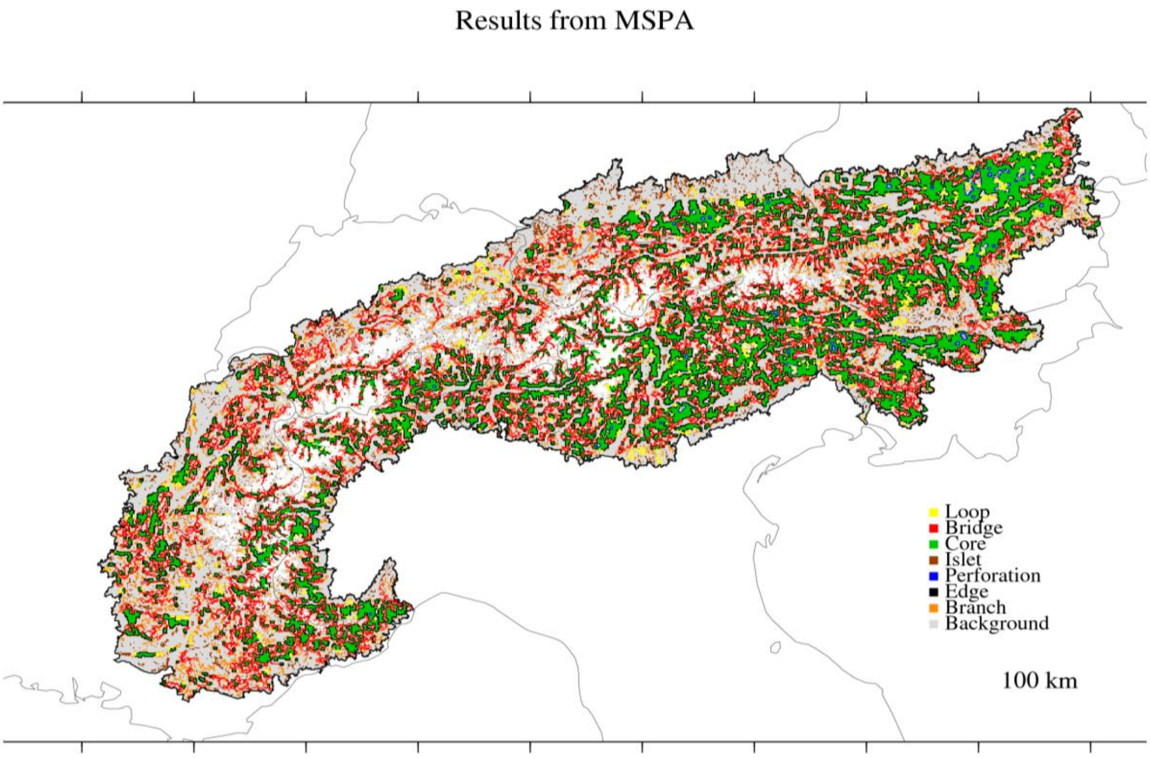

Figure 3: shows the results of a morphological spatial pattern analysis based on the potential distribution of L. lynx in the Alps. Econnect pilot regions are shown in orange. The resolution of the map is 1 km2.

Table 1: Crosstabulation of pixels that are suitable for lynx according to their degree of protection. The categories and colours are explained in Section 1.7.

			Bear habitat that falls within:							
Category	**Whole Alps**		Pilot Regions(1)		Nat. Des.(2)		Natura 2000		Any (3)	
	[km^2]	[%]	[km^2]	[%]	[km^2]	[%]	[km^2]	[%]	[km^2]	[%]
Background (grey)	79221.00	100	30711.00	38.8	11339.00	14.3	13576.00	17.1	16742.00	21.1
Branch (orange)	12304.00	100	5204.00	42.3	1814.00	14.7	2203.00	17.9	2959.00	24
Edge (black)	24895.00	100	10615.00	42.6	4663.00	18.7	4777.00	19.2	4642.00	18.6
Perforation (blue)	590.00	100	333.00	56.4	170.00	28.8	162.00	27.5	239.00	40.5
Islet (brown)	3466.00	100	1216.00	35.1	263.00	7.6	499.00	14.4	757.00	21.8
Core (green)	26868.00	100	12248.00	45.6	5274.00	19.6	5874.00	21.9	5553.00	20.7
Bridge (red)	27044.00	100	11024.00	40.8	4782.00	17.7	4811.00	17.8	5594.00	20.7
Loop (yellow)	3358.00	100	1468.00	43.7	526.00	15.7	610.00	18.2	826.00	24.6
sum	**177746.00**	**-**	**72819.00**	**-**	**28831.00**	**-**	**32512.00**	**-**	**37312.00**	**-**
sum without background	**98525.00**	**-**	**42108.00**	**-**	**17492.00**	**-**	**18936.00**	**-**	**20570.00**	**-**

1 Econnect pilot regions

2 Natural designated areas

3 A union of Econnect pilot regions, natural designated areas and natura 2000 areas

1.8 Barriers to the connectivity of *L. lynx*

A graph based approach to model the connectivity of *L. canadensis* has been done before [14]. To model the connectivity of lynx in the Alps, 272 source points were determined. Pixels were classified as sources if more than 70 % of all pixels within an 11 circular neighborhood had an lynx occurrence probability of more than 0.6 and if more than 85 % of pixels in the same neighborhood had a forest cover of more than 75 %. In cases were several adjacent pixels qualified as sources, they were merged into one source area. The centroid or source area was taken for the analysis. 83 % of the *L. lynx* sightings fell within a source area. These rules were established in order to make a selection on the suitable pixels and find points that were thought of particular suitability for *L. lynx*. A more in depth home range analysis or an expert questionnaire to identify sources areas of *L. lynx* may improve the analysis.

Five different cost grids were calculated. All grids were based on the inverse occurrence probability from the regression model. The different grids are summarised in Table 2.

Table 2: Different cost grids

Scenario	Barriers
1	No Barriers
2	Natural barriers (altitudes above 2500 m)
2a	Natural barriers and settlements
2b	Natural barriers and motorways
3	Natural barriers and settlements and motorways

Settlements were made impermeable by assigning them as no data. Motorways were given a resistance value of 20. In order to gain a deeper understanding of the effects that roads have on the connectivity of *L. lynx*, scenario 2b was run with resistance values for roads with (1,2,5,10,15,20,25,30,35,40,50). The results in Figure 4 show that up to a resistance value of approximately 15 motor ways are still somehow permeable. However, there is a reduction by approximately 20 % of connectivity already with a resistance value of 5. In the further course of this study a resistance value of 20 was used, unless stated differently.

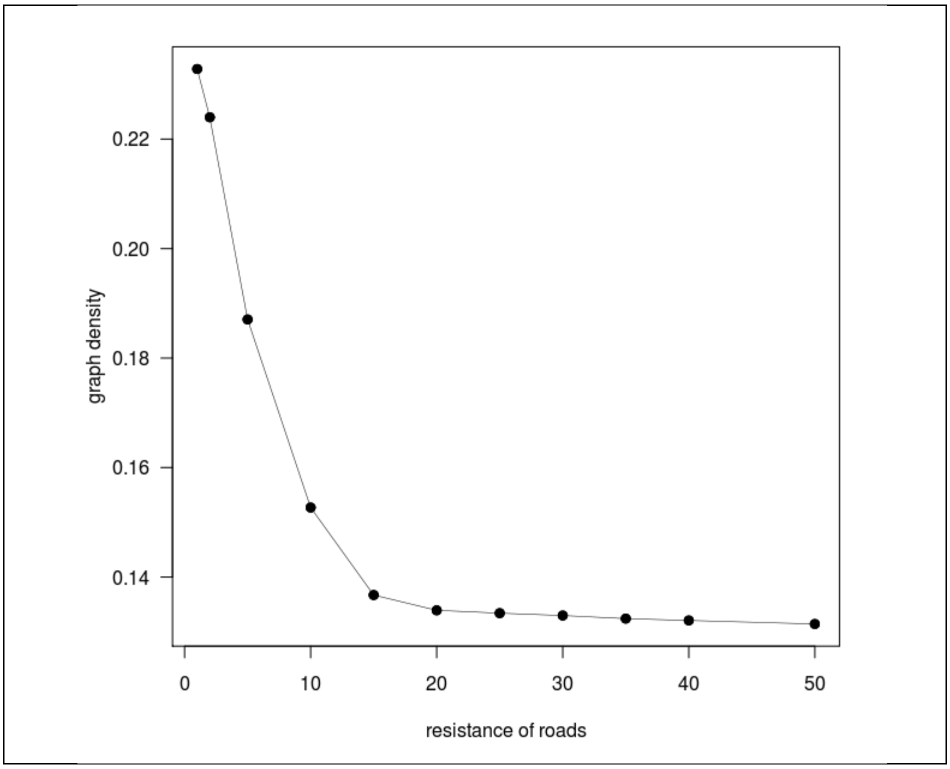

Figure 4: Sensitivity of motorway resistance. Up to a resistance value of approx. there is still some permeability of motorways.

A least cost surface was created for both grids, using the distance between Northeastern Switzerland and Trentino as a calibration. For cost grid 1 the maximum cost was 28, 30 and 32, respectively. Hence, to all points that fell within the least cost surface from a given point migration was possible. For all scenarios a graph was constructed to evaluate the overall effects of motorways on the connectivity of patches.

As measures of connectivity the graph density, number of edges from each vertex and the number of sub components were calculated.

The graph density is the ratio of the number of possible links and the number of actual links between patches. A graph density of 1 indicates a full graph (i.e. all patches are linked with each other). When motorways were included in the cost grid the graph density decreased from 0.23 to 0.13. Furthermore the effects of settlements were tested individually. While settlements on their own had very little effect on the connectivity of *L. lynx*, motorways on their own had almost the same effect on the connectivity as settlements and motorways. An overview is given in Table 3.

Table 3: The effects of natural barriers, settlements and motorways on the connectivity of lynx

Scenario	Description	Graph density
1	No Barriers	0.525
2	Natural barriers	0.236
2a	Natural barriers and settlements	0.245
2b	Natural barriers and motorways	0.131
3	Natural barriers and settlements and motorways	0.133

Number of edges (i.e. the number of other patches one patch is connected to) decreased for most patches when motorways were included in the graph. Some patches showed to be connected to more patches, this was due to the fact, that the cost distance for the second grid was slightly higher. Figure 6 shows the effects of motorways on the number of edges per vertex.

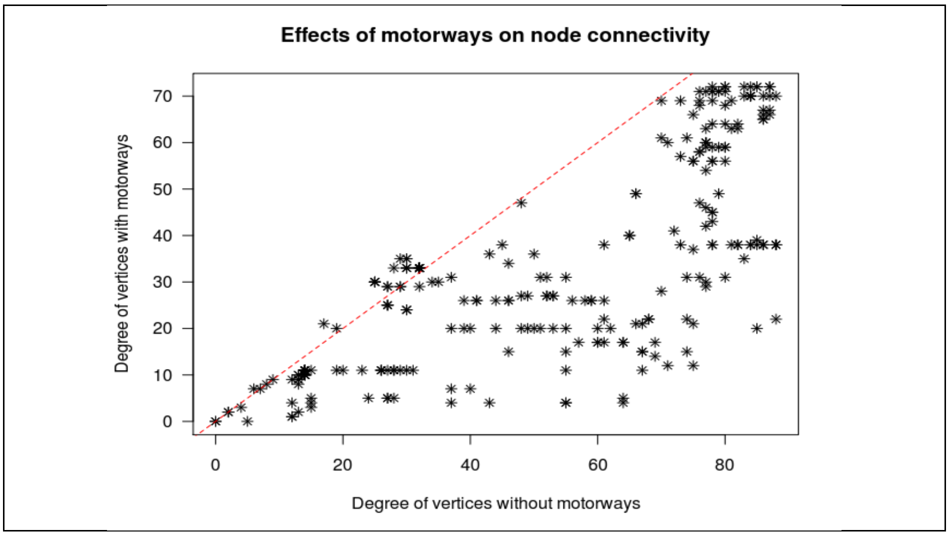

Figure 5: Number of links of each patch with scenario 2 and scenario 3. If motorways and settlement would have no effect on the potential connectivity of L. lynx a straight line would be expected.

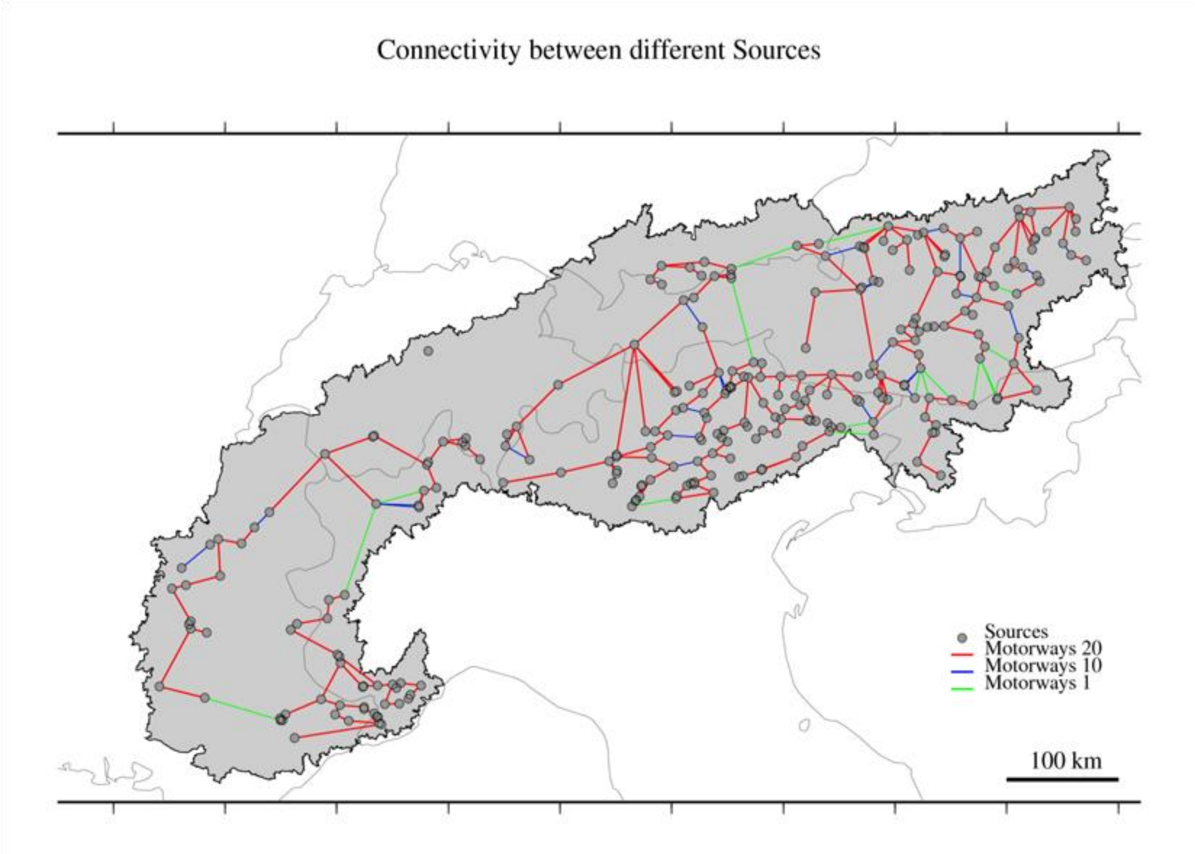

Figure 6: A planar graph for the connectivity of L. lynx in the Alps with different resistance values for motorways is shown. For the three scenarios a resistance value for motorways of 1, 10 and 20 was used. Edges in red are present in all three scenarios. Edges in blue are present of motorways have a resistance value of 1 or 10. Edges in green are only present if motorways have a resistance value of 1.

The reason why scenario 2a has a slightly higher graph density than scenario 2 is, that the calibration cost distance (i.e. the area between Tössstock and Trentino) is slightly higher in scenario 2a than in scenario 2. The same effect explains why in Figure 6 some patches have a higher vertex degrees (i.e. points that are above the red dashed line) in the scenario with motorways than in the scenario without motorways.

Using the first resistance grid, the graph had 2 sub components (i.e. two networks of patches). The first cluster contained 271 edges and the second cluster consisted of one single edge. With resistance grid 3 the number of clusters increased to 8. Four clusters had more than 45 edges and the remaining for clusters had less than 10 edges.

1.9 Conclusion

Despite of the fact that that the available dataset for *L. lynx* was far too small to predict the habitat suitability based on collected observation records, it was possible to compute a potential distribution for the alps using a existing model. The validation with observations of *L. lynx* yielded in satisfactory results (more than 95 % of sightings were predicted correct). However it is difficult to assess, if the model eventually slightly overestimates the potential distribution of *L. lynx* in the Alps.

Results from the morphological spatial pattern analysis give insight to the distribution of different pixel classes in Table 1. For example 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 connecting pixel (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 %.

According to the analysis of this project, the attention should be drawn to motorways as they are the major barriers for the migration of Lynx populations. Conservation should aim at the connection of core areas that are separated by motorways. Unfortunately no data of road-kills were available, as this information could support the statement that motorway not only split the potential migration routes of Lynx, but also depletes established Lynx populations.

1.10 References

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