PERSPEKTIVEN FÜR UMWELT & GESELLSCHAFT umweltbundesamt

DISTRIBUTION AND CONNECTIVITY OF THE BROWN BEAR (URSUS ARCTOS) IN THE ALPS

Workpackage 5: "Corridors and Barriers"

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econnect
Restoring the web of life

Alpine SPACE
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1. CONTENTS

1.1 Introduction

In this report the approaches taken to model the distribution and connectivity of *Ursus arctos* 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. Characterization 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 presented above are followed. In Section 5 a brief characterization of *U. arctos* is provided, followed by its current and potential distribution in Section 6. Finally connectivity between patches of potential distribution is considered under different scenarios in Section 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 [7]. 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 [12]. 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 [10] was used. This encompasses an area of approximately 190.000 km^2. The model was implemented at a resolution of 1 km^2. All alpine wide models were conducted in a resolution of 1 km^2.

1.4 Software

All GIS analysis was done either with QGIS [8] or GRASS GIS [3]. Statistical analysis was conducted with R [9]. Connectivity analysis was done with the R package igraph[2], raster [5] and tripack [1]. Morphological spatial pattern analysis was done with GUIDOS [14]. Maps were produced with Generic Mapping Tools (GMT).

1.5 Characterization of *U. arctos*

The brown bear (*Ursus arctos*) belongs to the family of the *Ursidae*. There are several recognized subspecies. Among others the Kamchatka Brown Bear (*U. arctos beringianus*), the Grizzly Bear (*U. arctos horibilis*) and the European Brown Bear (*U. arctos arctos*), which is being treated here. The natural habitat of brown bears are open and forested areas. Currently in Europe brown bears occur predominately in forests. This is probably due to dense human populations and not based on the species natural habitat preferences per se. The occurrence of brown bears is governed by the availability of food, land cover and undisturbed caves for denning. Brown bears are omnivorous and their principal diet consists of primarily *Gramoids* and forbs in spring, berries and fruits in autumn. Main food sources are acorns (*Quercus spp.*), beeches (*Fagus sp.*) and chestnuts (*Castanea sp.*). Meat is eaten occasionally by brown bears, either as prey or carcase. Female bears reach weights of 75 to 160 kg and male bears reach weights of 120 up to 350 kg. Despite their body mass, bears are able to move fast, climb and swim [6].

Densities of brown bears are thought to vary with food availability. While homeranges in northern Europe can reach extends of up 1000 km^2 and for females 225 km^2, much smaller home-ranges are found in Croatia (males 130 km^2 and females 60 km^2). These numbers should be treated with caution, since measurements become more accurate with the introduction of GPS to animal tracking.

Dispersal distances of *U. arctos* in the Alps were taken from previous modelling studies [15]. Mean dispersal distances for males: 118 ± 17 km and females 46 ± 11 km. Additionally 95 percentile distances were provided with a mean for males of 236 ± 23 km and for females 110 ± 20 km. Previous studies [15] identified main obstacles to dispersal of bear in the Eastern Alps. These are densely populated valleys with motorways in particular: Mürz-Mur Valley (Austira), Ljubljana-Postojna highway, Etsch Valley, Villach Udine and the Inn Valley.

Main threats for bears in Europe have been evaluated by the Action Plan for Conservation of the Brown Bear in Europe [11]. In total 11 threats and limiting factors were identified. Following a short summary:

Demographic and genetic viability Small population sizes as such are a problem. Studies from Sweden showed, that at least 6-8 females are required to reduce the risk of extinction through random stochastic effects within 100 years below 10 %. Additionally almost all western European brown bear population went through genetic bottlenecks. In the wild no evidence of inbreeding depression was found.

Fragmentation Infrastructure that fragments bear habitat can be more detrimental to bears in some cases than the loss of habitat. Home ranges are being artificially shrunk, and dispersal is made a lot harder. This has negative effects on the genetic variability of bears. Additionally road kills of bears can harm small populations.

Habitat loss Habitat loss is attributed to the expansion of human activities such as agriculture, forestry, resource extraction, road construction and recreation. This results that bears may avoid areas and hence decrease their range. Alternatively bears may become accustomed to humans and conflicts between bears and humans arise.

1.6 Distribution of *U. arctos*

A crude approximated present distribution of the brown bear in the Alps can be seen in Figure 1. This estimates are based on various sources and were compiled by KORA in Switzerland. Informations on the resolution of the map were not provided

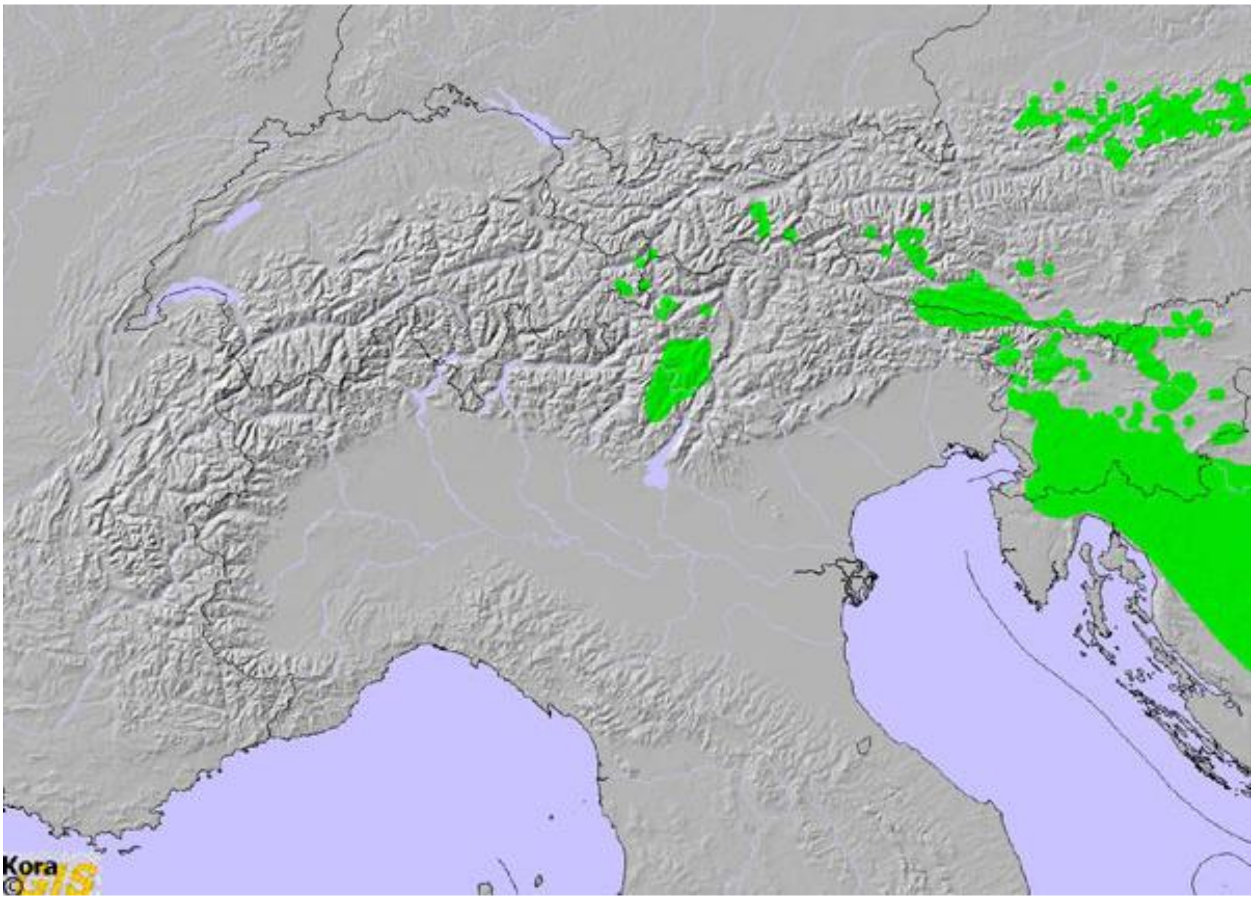

Figure 1: Presence distribution of U. arctos in the Alps, based on estimates by KORA. The map was retrieved from KORA GIS. Information on the resolution were not present

To model the potential distribution of U. arctos in the Alps a logistic regression model developed for the bear in the eastern Alps [4] was used in a refined, yet unpublished version. The probability that a grid cell is potential habitat for U. arctos, with reference to coniferous forests is given by:

$$Z = \beta_0 + \beta_1 * x_1 + \ldots + \beta_n * x_n$$

coefficients and intercept are provided in Table 1. A linear stretch was applied in order to obtain a smoother distribution between 0 and 1,

$$z = ((z - \min(z) / (\max(z) - \min(z))$$

the probability that given cell is potential bear habitat is given by

$$P (bear = 1) = (e^{z} / (1 + e^{z})) = 1 / (1 + e^{-z})$$

CORINE land cover was reclassified into 6 classes and no data. For each gird cell the proportion for each land cover class within a 10 km buffer was calculated. All coefficients of the models are given in Table 1.

Table 1: Coefficients of the logistic regression model

n	β_n	x_n	unit	description
0	-0.895	-	-	intercept
1	-1.983	agriculture	proportion	CLC categories: 211 212 213 221 222 223 231 241 242 243 244
2	-0.267	broadleaf	proportion	CLC categories: 311
3	-0.186	mixed	proportion	CLC categories: 313
4	-1.368	scrub	proportion	CLC categories: 321 322 323 324
5	-1.831	open	proportion	CLC categories: 331 332 333 334 335
6	0.488	distance roads	km	distance to next road, distances $<$ 2 km are set to 2 km.
7	0.542	distance settlement	km	distance to next settlement, distances $<$ 2 km are set to 2 km
8	0.016	slope	degree	slope obtained from DEM
9	0.629	elevation	km	DEM from SRTM
10	-1.438	$elevation^2$	km^2	elevation squared

No thresholds were supplied by [4]. In order to obtain a presence absence map and additional observations or telemetry tracks for bears in the Alps were not accessible. Due to the lack of data to support a more robust method the median (=0.49) was chosen as a threshold value.

A continuous map of the potential distribution of U.arctos in the Alps is shown in Figure 2.

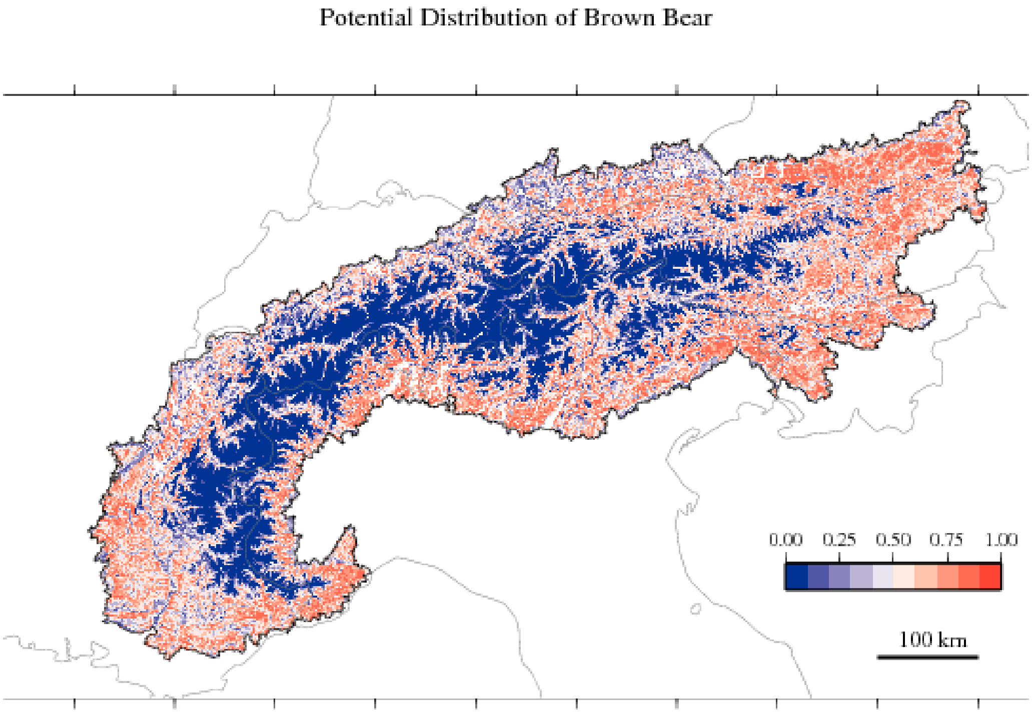

Figure 2: shows the potential habitat suitability for the brown bear in the Alps. Resolution of the map is 1 km².

1.7 Morphological Spatial Pattern Analysis

At an alpine scale it 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 U. arctos habitat) in different categories. The algorithm takes each pixel and compares it with the neighbouring pixels based on set of mathematically formulated rules. For a detailed description of the algorithm see [13].

The different GUIDOS categories are described as follows:

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

Core (green) Pixels that are classified as forest or suitable bear habitat (i.e. predicted 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. For the conservation of *U. arctos* 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 are a lot patchier with regard to *U. arctos* habitat. This can be attributed to the fact, that the eastern Alps are generally of less altitude. Consequently there is more *U. arctos* 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.

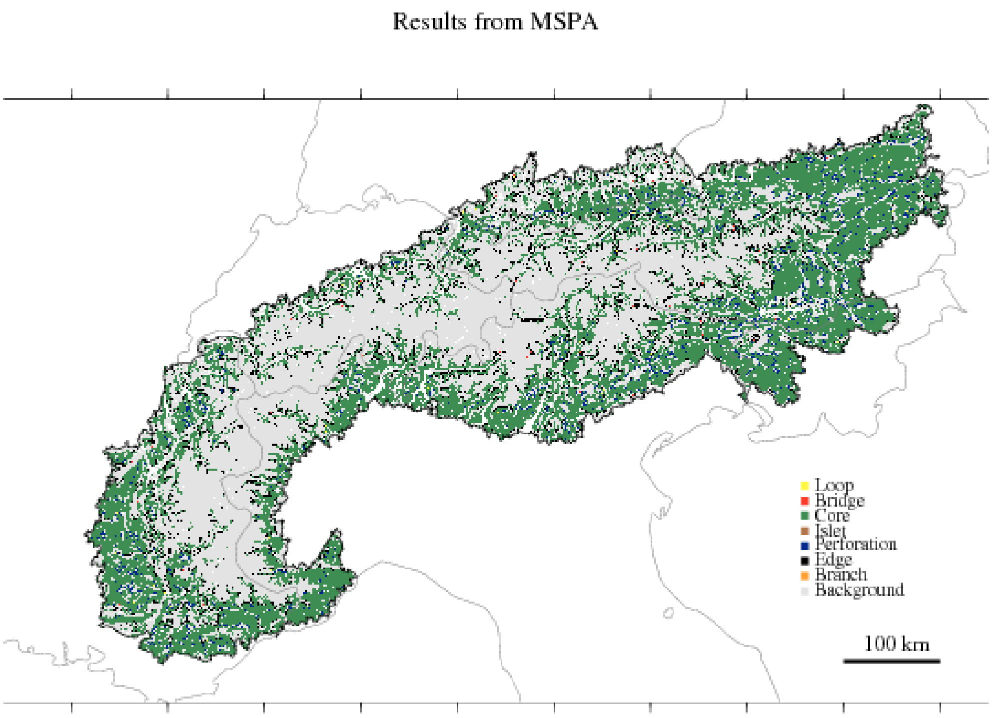

Figure 3: shows the results of a morphological spatial pattern analysis based on the potential distribution of U. arctos in the Alps.The resolution of the map is 1 km^2.

From the results presented in Figure 3 further analysis my reveal areas that are important for connectivity but currently not under any legal protection. In Figure 4 corridors and core areas are shown that fall not within any classified bear habitat. All bear habitat that is within an Econnect Pilot Region, Natura 2000 or any other designated area is considered classified. Classified areas are shown in yellow. However, legal protection does not protect the bear against illegal shootings.

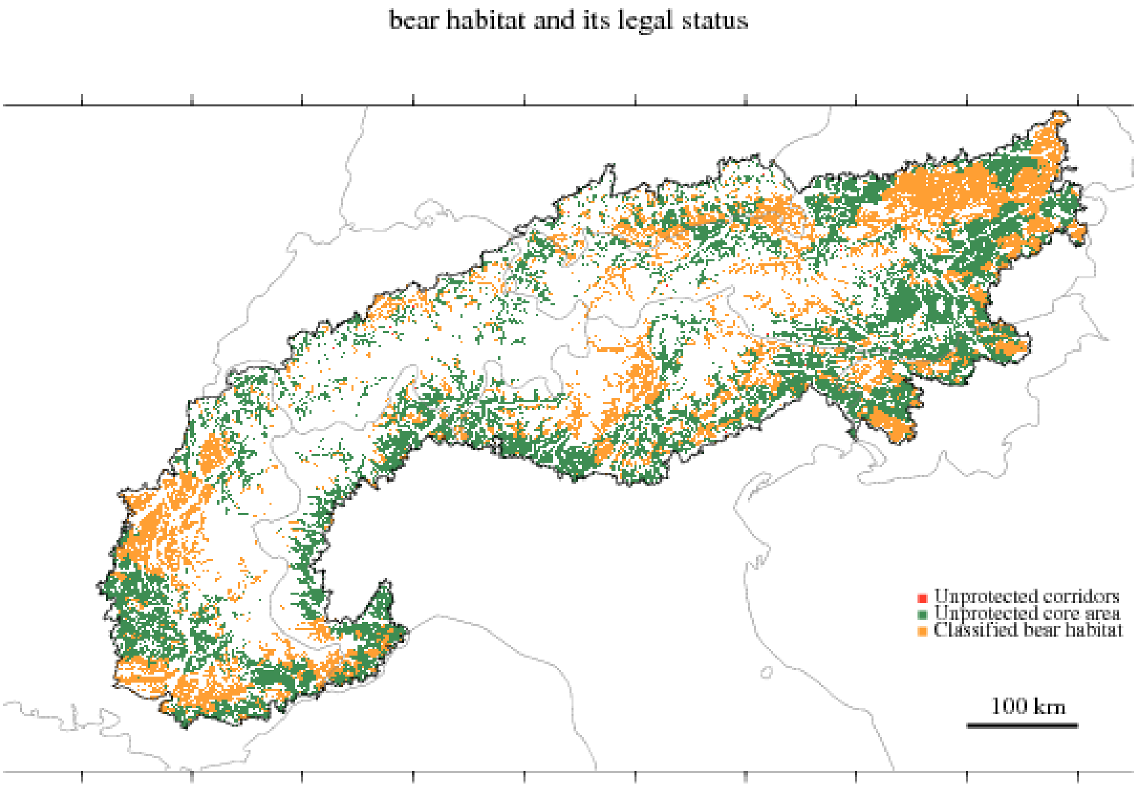

Figure 4: shows pixels of bear habitat that are not classified in red (corridors) and green (core areas) for the Alps. Bear habitat that falls within a classified area is shown in yellow. The resolution of the map is 1 km² .

Finally a more comprehensive summary of the results from the morphological spatial pattern analysis are shown in Table 2. The area and percentage of bear habitat for each GUIDOS category is summarized.

Table 2: Cross tabulation of pixels that are suitable for bear according to their degree of protection. The categories and colours are explained in Section 7

	Whole Alps		**Bear habitat that falls within:**							
			Pilot Regions[a]		**Nat. Des.**[b]		**Natura 2000**		**Any**[c]	
	[km²]	**[%]**	**[km²]**	**[%]**	**[km²]**	**[%]**	**[km²]**	**[%]**	**[km²]**	**[%]**
Background (grey)	95337.00	100	47415.00	49.7	20896.00	21.9	22646.00	23.8	26169.00	27.4
Edge (black)	11599.60	100	4576.50	39.5	1945.90	16.8	1783.10	15.4	2212.60	19.1
Perforation (blue)	4405.40	100	1767.50	40.1	567.30	12.9	812.90	18.5	881.90	20
Core (green)	72176.20	100	26337.00	36.5	9068.30	12.6	11559.40	16	13186.80	18.3
Bridge (red)	85.60	100	77.50	41.8	37.40	20.1	27.30	14.7	36.40	19.6
Loop (yellow)	126.10	100	46.60	36.9	16.60	13.2	17.10	13.5	24.30	19.3
sum	183829.87	-	80220.06	-	32531.56	-	36845.81	-	42511.00	-
sum without background	88492.87	-	32805.06	-	11635.56	-	14199.81	-	16342.00	-

a *Econnect pilot regions*

b *Natural designated areas*

c *A union of Econnect pilot regions, natural designated areas and Natura 2000 areas*

1.8 Barriers to the connectivity of *U. arctos*

A graph based approach to model the connectivity of Lynx canadensis has been done before [12]. To model the connectivity of brown bear in the Alps, 59 source points were determined. Pixels that had a potential occurrence probability of 0.80 or higher were chosen as sources. More than 500 pixels qualified as sources. To reduce the number of sources, pixels were buffered with a 10 km buffer and merged. This resulted in 55 polygons. The centroids of these polygons were used in further course. Centroids located outside the study area were manually moved to the study area. From each source the connectivity to other sources was determined. The resistance cost for each cell x was obtained by $1-P_{bear}(x)$. Motorways were given the values of 0.5, 1, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100.

In order to translate the dispersal distance in given in km by Wiegand et al. into cost distances, 50 source points were sampled with replacement as start points. From these start points a second point within the study area, with a bear occurrence probability of > 0.5 and away by a given euclidean distance D, was found. D was drawn from a normal distribution of distances following the parameters given by Wiegand et al. This was done for males, where P95 = 236 ± 25 km. The maximum cost distance for a motorway resistance of 0.5 was 88. This cost distance was used for all further computations.

For each motorway resistance the graph density was calculated. A graph density of 1 indicates a full graph while a graph density of 0 indicates no connectivity at all. With increasing resistance costs for motorways the graph density decreased. Once resistance costs for motorways reached 80 the graph density stabilised with a connectivity decrease of 69%.

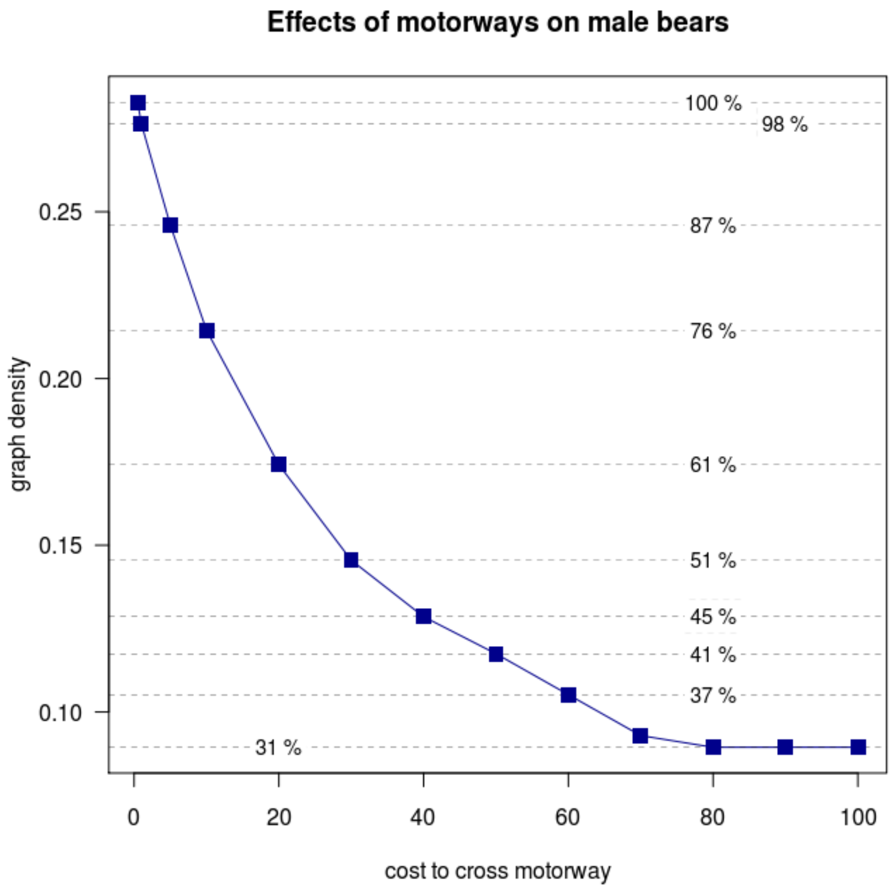

Figure 5: The effects of motorways on the connectivity in the Alps. The blue squares represent the graph density. The numbers show the percentage connectivity. 100 % connectivity is assumed with a resistance cost of 0.5

As a second measure of connectivity, after the graph density, number of edges from each vertex were considered. Number of edges (i.e. the number of other patches one patch is connected to) decreased for most patches when motor-ways became more difficult to cross. As expected, the higher the costs to pass a motorway the lower the more severe were effects on connectivity. In Figure 6 effects are shown for a resistance value of 20 and 100.

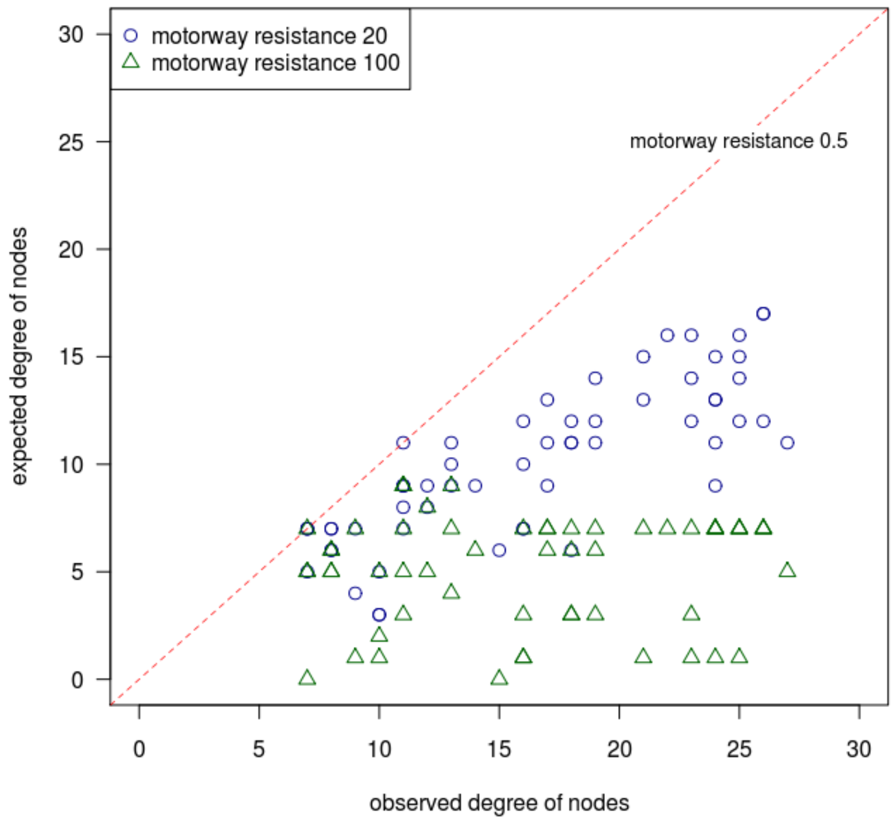

Figure 6: Number of links of each patch with scenario 2 and scenario 3. If motorways and settlement would have no effect on the potential connectivity of U. arctos a straight line would be expected.

To visualize the effects of motorways a planar graph constructed with the help of a Delaunay Triangulation. In Figure 7 a planar graph for the connectivity between source points for the Alps is shown. Three different resistance values (1,20,100) were used.

Connectivity between different Sources

The higher the resistance values for motorways were, the more components the graph for the Alps had. While there was a graph with only 1 component when the resistance value for motorways was 1, the number of components increased to 11 with a resistance value of 80 (see Fig. 7).

Motorways are the main anthropogenic barrier for bears in the Alps. Settlements and high elevation had low occurrence probabilities and hence they were more difficult to cross. While motorways are certainly no absolute barrier to bears, they separate home-ranges, lead to reduced gene flow and can cause additional mortality.

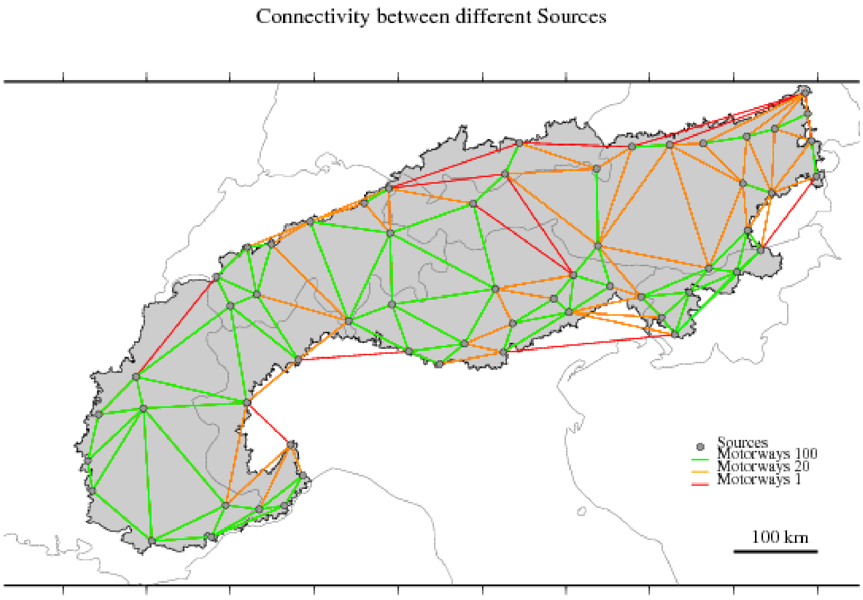

Figure 7: A planar graph for the connectivity of U. arctos in the Alps with different resistance values for motorways is shown. For the three scenarios a resistance value for motorways of 1, 20 and 100 was used. Edges in green are present in all three scenarios. Edges in red are present of motorways have a resistance value of 1 or 20. Edges in red are only present if motorways have a resistance value of 1.

1.9 Conclusion

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

Concerning connectivity between some source patches in the Alps, a graph based approach was chosen. Motorways reduced the degree of connectivity and increased the number of components with no connection in the Alps.

Motorways are certainly the main anthropogenic barrier for bears in the Alps. However, bears usually do find a way to cross motorways. So motorways cannot be seen as absolute barriers. Within the course of this study it became evident, that the main problem for the bear in the Alps is whether or not the bear is accepted within the population and managing authorities. Being not tolerated may yield in illegal shootings of bears. Legal protection of bear habitat is crucial and of course illegal shootings cannot be tolerated. The maybe most important factor for the protection of this species is acceptance in the human population. Acceptance can surely be supported by political decisions, like the implementation of protective legislation.

1.10 References

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