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DISTRIBUTION, HABITAT SUITABILITY, AND CONNECTIVITY OF WOLVES *(CANIS LUPUS)* IN THE *ALPS*

Workpackage 5: "Corridors and Barriers"

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1.1 Introduction

Wolves recently recolonized the Western Alps through dispersal from the Apennines (FABBRI et al. 2007) after being extirpated throughout most of Western Europe and in the Alps during the 20th century. Effective management of this protected species relies on understanding distribution, on the underlying dynamics of colonization and abandonment of portions of the landscape, and on the development of a habitat suitability model that explains these patterns. This information can be used to improve the understanding of the habitat connectivity required for the recolonization and maintenance of a dynamic wolf population over the Alps.

Wolf populations, as well as other highly mobile and territorial animals, apparently move across many unfavourable areas, but establishment success is restricted to higher quality habitats (MLADENOFF et al. 1995). Regional landscape analysis and prediction of favourable wolf habitats has been conducted in North America (MLADENOFF & SICKLEY 1998; MLADENOFF et al. 1995, 1999) and in Europe (CORSI et al. 1999). These researchers emphasized the importance of long-term monitoring data and large-scale analysis to solve complex spatial questions in wolf resource management and conservation. In particular in Europe, where intense anthropogenic habitat modification has occurred over hundreds of years, a large-scale occupancy analysis and the development of a habitat model are important to understand and manage fragmentation and connectivity issues.

The main goals of this work were defined in the framework of the "ECONNECT Project", and the analysis were conducted following these guidelines:

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

Spatial analysis of current and potential habitats, and the development of a habitat suitability model for wolves over the Alps, were developed following the work published by MARUCCO (2009) and MARUCCO & MCINTIRE (2010). These studies were conducted in the framework of a large "Wolf Piemonte Project" based in the Italian Alps, where accurate wolf data was collected on a large scale over 10 years (MARUCCO 2009, MARUCCO et al. 2010). However, the models developed by MARUCCO (2009) and MARUCCO & MCINTIRE (2010) were applied to the Italian Alps only. To fulfil the above tasks, a GIS wolf prediction map based on occupancy modelling estimates was developed over the entire alpine range following MARUCCO (2009), which was used for wolf habitat suitability interpretations. Then, the spatially explicit, individual-based model (SE-IBM) developed by MARUCCO & MCINTIRE (2010) was extended, adapted, and validated to produce a habitat suitability map of wolf packs over the entire alpine range, which was based on the occupancy habitat suitability map, and on demographic processes such as dispersal, social structure, and habitat selection of wolves. This final map was used for the connectivity analysis.

This final SE-IBM was fundamental to conduct the analysis on the habitat suitability required by wolf packs, which are the main reproductive units in wolf social dynamics. To study wolf connectivity, movement, and wolf potential habitat needs, it is fundamental to distinguish between wolf pack requirements and wolf dispersals patterns. For wolves, a highly social and territorial species structured in packs with a single breeding pair, this behavioural aspect affects density, home-range configurations, and movements (MECH & BOITANI 2003). Territorial wolf packs established in an area are one of the main cause of mortality for dispersal wolves in natural ecosystems (MECH & BOITANI 2003). For these reason an individual-based model (IBM) was developed, as a way to link social system complexity, such as wolf pack presence, to spatial dynamics and movement regulations (GRIMM & RAILSBACK 2005). In fact, for wolves it is fundamental to analyse pack requirements for territorial establishment (which have been accounted for in this spatial analysis), and distinguish between potential presence of wandering solitary wolves and established packs in habitat suitability analysis. At the same time connectivity needs to be interpreted within the strict regulations of wolf sociality and dispersal movement patters, very different than for the other solitary large carnivores. This analysis will incorporate these elements in the final spatial evaluation to effectively account for the major barriers for wolf movement, which generally are from anthropogenic or landscape origin.

1.2 Study area

The spatial extend of the study area is the Alps area as defined by the alpine convention, which is the same used for other studied species within the ECONNECT Project. This encompasses an area of approximately 190.000 km².

1.3 Software

All GIS analysis were done either with QGIS or ArcGIS 9.2. The SE-IBM was constructed using the Spatially Explicit Landscape Event Simulator (SELES) (FALL & FALL 2001) and R. The morphological spatial pattern analysis was done with GUIDOS (VOGT 2008).

1.4 The natural recolonization of Wolves in the Alps: current distribution and dispersal

Current wolf distribution can be visualized in Figure 1. This distribution map was constructed by the Wolf Alpine Group (WAG) (Unpublished data). Currently, settled wolf packs are only present in the Western Alps of Italy and France (Figure 1). In the rest of the Alps, dispersers might be detected occasionally, but based on definition, only a solitary individual that settle the territory for at least two season can be considered stabilized and therefore drawn in the common WAG map. Currently, no cases as this definition are identified over the alpine chain, other than the ones described in Figure 1.

The area occupied by wolves in the Alps is connected in the south-west to the Apennines Mountains, the main source for the wolf population in the Alps (FABBRI et al. 2007). The connection with the Apennine population is constituted by an ecological corridor represented by the Ligurian Apennines mountains, and gene flow between the Apennines and the Alps is moderate (corresponding to 1.25–2.50 wolves per generation) (FABBRI et al. 2007). Recently, an interesting slight connection has been documented with the Dinaric population from Slovenia, and few wolves from this population have been documented in the eastern Alps of Austria (Rauer, pers.comm.) and Italy (Groff, pers.comm.). In the future the connection between the Italian population, Dinaric population, and Carpatian population is a probable event of extreme interest that might be documented over the Alps.

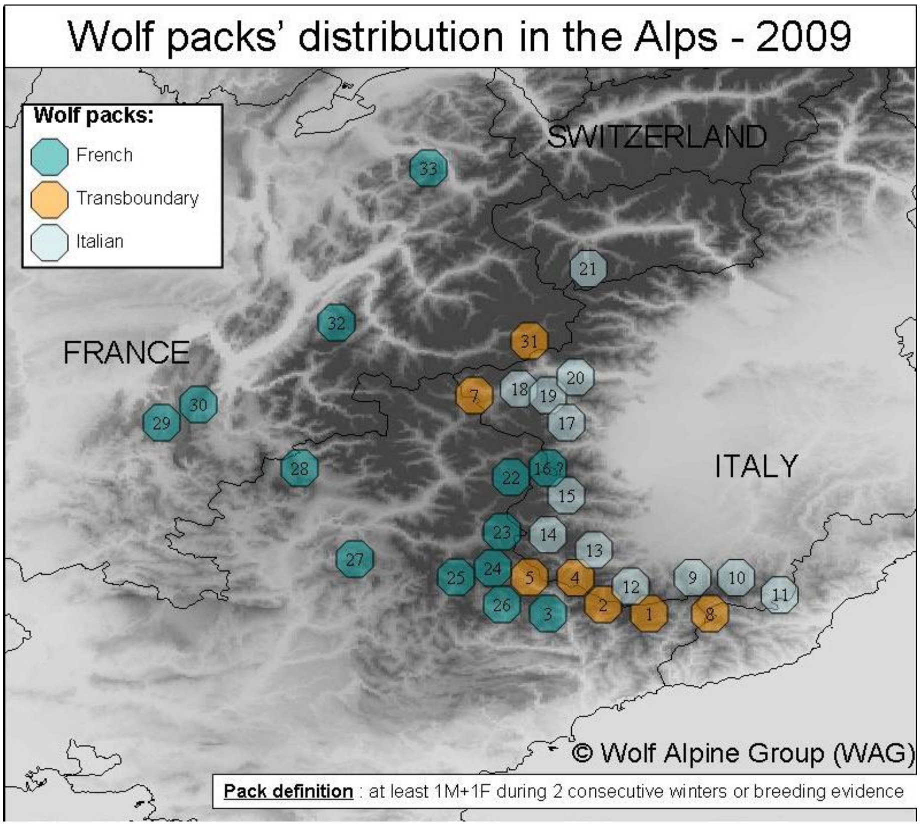

Figure 1: Wolf packs' distribution in 2009 in the Alps (Wolf Alpine Group, WAG, Published LCIE Web site http://www.lcie.org, 2011 April).

1.5 Spatial analysis of current and potential habitat

A first habitat suitability model (1.5.1.) was developed, based on wolf occurrence data using a **multi-season occupancy model,** extending the work from MARUCCO (2009) to the Alps, which considered wolf detection-nondetection data following MACKENZIE et al. (2006). Second, this model was used as the habitat layer for building a **spatially explicit, individual-based model (SE-IBM)** (1.5.2.) based entirely on information collected through a 10-year intensive study of the wolf population in the Italian Alps (MARUCCO & MCINTIRE 2010). The model was developed based on demographic processes, social structure, spatial information, and habitat selection of wolves.

1.5.1 Multi-season occupancy model

MARUCCO (2009) developed a wolf habitat suitability model for the Italian Alps, applying an unconditional multi-season occupancy model to estimate wolf occupancy dynamics and detection probabilities (MacKenzie et al. 2006), based on detection-non detection data collected using a robust design over 5 years in the Western Italian Alps. In the best model, human disturbance (β = -5.553, SE = 2.186) and rock-area cover (β = -4.129, SE = 1.392) had negative effects on occupancy, while the presence of red deer (*Cervus elaphus*) (β = 0.694, SE = 0.306) and forested-area cover (β = 0.596, SE = 0.458) had a positive effect (Marucco 2009).

For this analysis, this **multi-season occupancy model** was applied to the entire alpine study area (Figure 2). The occupancy parameter estimates of the best model were used to produce predictive maps of wolf potential habitat on the Alps mountain range. Multi-season occupancy modelling allowed to directly model the temporal dynamics of the occupancy process and to control for the issue of "pseudo-absence", modelling directly the detection probability. This approach, designed to estimate detection probabilities, improved the accuracy of the occupancy estimates, accounted for pseudo-absence (a problem generally encountered with logistic regression approaches – Keating & Cherry 2003), and for temporal variation in presence.

For a detailed description of the model framework see MacKenzie et al. (2003). In brief, (to understand where the occupancy model come from):

the multi-season occupancy models developed by MacKenzie et al. (2003) is used to estimate the probability of wolf occupancy of a cell, the probability of extinction and colonization, and the probability of detection as functions of independent covariates. Marucco (2009) summarized records of wolf sign detection (1) and non-detection (0) into "encounter histories" similar to mark-recapture studies ($\mathbf{X}_i$; e.g. 0011 1010 1111 0110 0010). Marucco (2009) used a maximum likelihood modelling procedure that relies on detection history data to estimate occupancy (ψ), colonization (γ), extinction (ε) and detection probability (p) (MacKenzie et al. 2003):

$$L(\psi_1, \varepsilon, \gamma, p|\mathbf{X}_1 \ldots \mathbf{X}_n) = \prod_{i=1}^{N} \Pr(X_i)$$

where ψ_1 is a vector of site occupancy probabilities for the first primary sampling period, γ and ε are matrices of colonization and extinctions of "wolf presence" in sites, and *p* is a matrix of detection probabilities. A set of a priori candidate models were developed and evaluated using a hierarchical approach (Olson et al. 2005). Models were ranked and weighted according to the Akaike information criterion (AIC, Burnham & Anderson 2002). The best models with $AIC_c < 2$ were averaged to obtain averaged parameter estimates and standard errors (Burnham & Anderson 2002). All occupancy analysis were performed using program PRESENCE
(**http://www.mbr-pwrc.usgs.gov/software/doc/presence/presence.html**).

1.5.1.1 Covariate measurements and GIS analysis

Habitat features were measured for each cell using the same grid origin for each covariate raster map using a geographic information system (GIS) software (ArcGis 9.2. ESRI, Redlands, CA, USA). The 4 main variables selected were: two landscape coverage (rock cover area and forest cover area), human disturbance, and presence of red deer (*Cervus elaphus*). To characterize the landscape coverage of the study area, the CORINE Land Cover 2000

(CLC2000, version 8/2005) was used at the original scale of 1:100,000 and integrated with the land cover data available from GEOSTAT produced by the Federal Swiss Statistics Office, and a final dataset was produced covering the entire study area with a cell size of 100 x 100 m and with 15 land-cover classes corresponding to the 2nd level CORINE nomenclature (BOSSARD et al. 2000). Two covariates were measured: a forested-percent cover and a rocky-percent cover, where for each continuous covariate the proportion of the cover for each 5 x 5 km cell was evaluated. A dataset on roads from the Teleatlas dataset for the Alpine Arc was used (Copyright Teleatlas, Release 02/2009), where dirt roads were not considered. Settlements were derived from the CORINE layer and added to the roads raster, to characterize overall human disturbance of the study area. Lakes were considered in this layer. A human disturbance raster map of 100 x 100 m cell size was then produced, and the proportion of cells containing roads, settlements and lakes for each 5 x 5 km cell of the study area was evaluated. To characterize the presence of red deer in the study area, different datasets were made available from different sources (Italy: the Regional Wildlife Databank of the Osservatorio Regionale Sulla Fauna Selvatica of the Piemonte Region and PEDROTTI et al. 2001; Germany: KINSER et al. 2010; Slovenia: JERINA 2007, ADAMIC & JERINA 2010; Switzerland: Federal Office for the Environment; Austria: Federal Research and Training Centre for Forests, Natural Hazards and Landscape, Federal Forest Office; France: Office National de la Chasse et de la Faune Sauvage). A final raster map with a grid of 5 x 5 km cells of wild ungulate presence over the entire Alps was produced. Data on presence were determined from data on dead recoveries, censuses (year-round simultaneous observations, drive-censuses), hunted individuals, and agricultural and vehicle damages. This layer is the weakest peace of information in the analysis due to the diversity in the quality and type of information over the different countries within the Alps. However, the large scale might overcome the low level of precision of this last dataset.

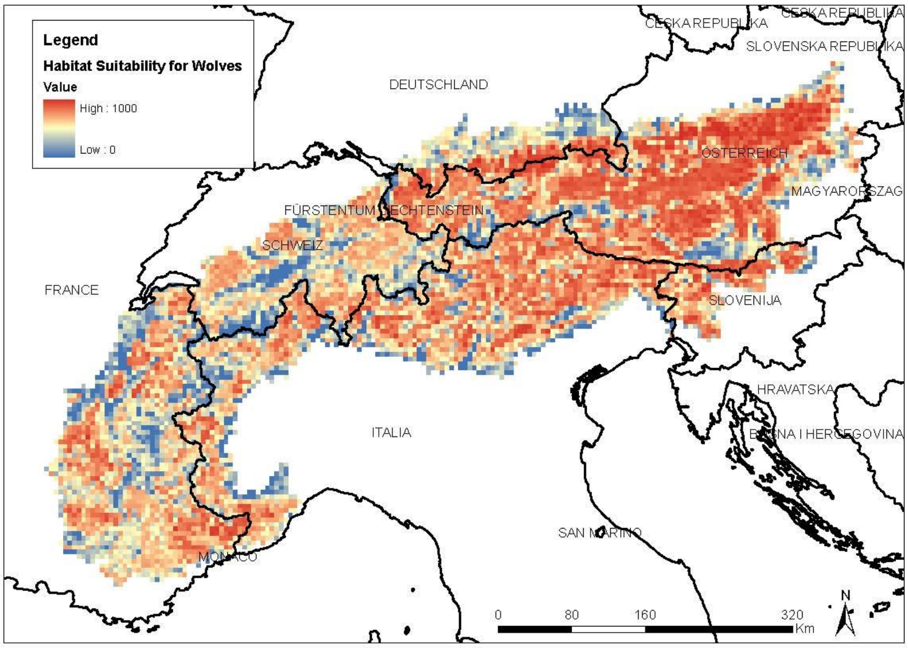

Figure 2: Wolves habitat suitability map based on an occupancy analysis.

1.5.2 Spatially explicit, individual-based model

The **spatially explicit, individual-based model (SE-IBM)** developed by MARUCCO & MCINTIRE (2010) was adapted for this analysis, and the study area extended to the entire Alps ecosystem (Figure 3), using the wolf habitat suitability map described in Paragraph 1.5.1. The model was based entirely on information collected through a 10-year intensive study of the alpine wolf population (MARUCCO & MCINTIRE 2010). The model was based on demographic processes, social structure, spatial information, and habitat selection of wolves. For model structure purposes, we used a finely divided version of the habitat suitability model (1 km² raster cells) to allow for flexible shapes of territories. Starting from random wolf locations of dispersals, 10,000 simulations were performed for predictions of pack locations and development of the habitat suitability map for packs over the Alps (Figure 3), to analyze the movement pattern and dispersal directions of wolves and barrier presence. The main improvements provided by the SE-IBM model, compared to another habitat suitability analysis on wolves, are that it directly considers wolf packs habitat needs, it incorporates the geometry of wolf territories, which have to be able to fit next to each other considering the high exclusive territorial behaviour of wolf packs, and that the probability of use is directly affected by connectivity (i.e., places that are surrounded by 360 degrees of available habitat will have higher use probability).

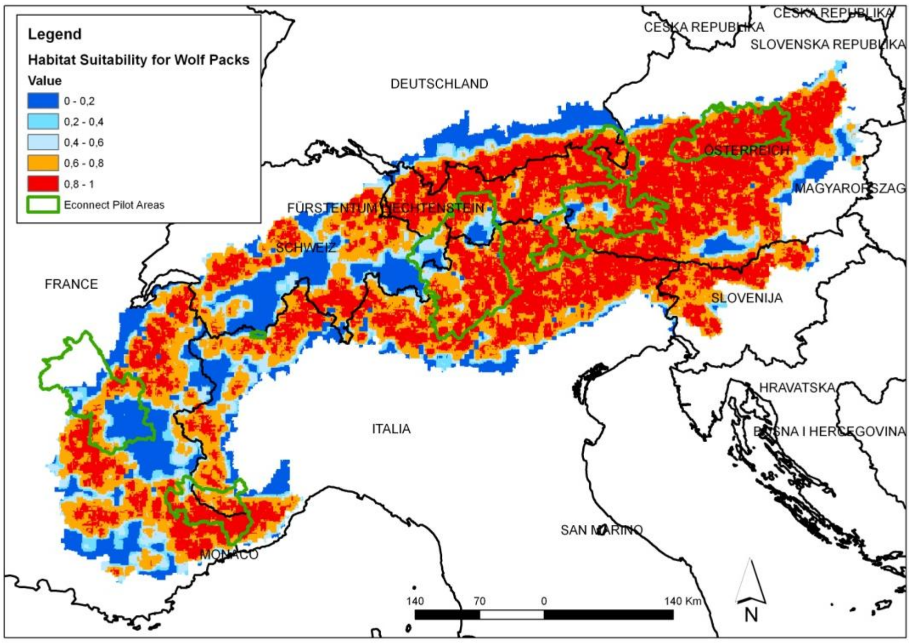

Figure 3: Wolf packs habitat suitability map based on the SE-IBM model.

1.6 Morphological Spatial Pattern Analysis (MSPA)

In sections 1.6 and 1.7, graph theory related terms are used. For a general introduction to graph theory in ecology see MINOR & URBAN (2008). Following SIGNER (2010), a brief description of graph theory and related terms is provided to clarify the meaning in an ecological context: "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." (SIGNER 2010).

The wolf packs habitat suitability map based on the SE-IBM model (Figure 3) was used and processed for the MSPA analysis using GUIDOS, which is an implementation of the MSPA algorithm. As suggested by SIGNER (2009), a threshold value of 0.5 was chosen arbitrarily, to be consistent with previous ECONNECT analysis on Lynx connectivity (SIGNER 2010). However, for further investigations, a threshold value of 0.8 was also chosen to detect the more important wolves core areas and define the connectivity between those. All cells with an occurrence probability above 0.5 in the first analysis, and 0.8 in the second analysis, were classified as 2, cells with an occurrence probability below these threshold values were classified as 1, and no data cells where classified as 0. GUIDOS processed the binary input image using the mathematical morphology algorithm described and outlined in the MSPA Guide (VOGT 2008).

The different GUIDOS categories are described following VOGT et al. (2007 a,b):

Background (grey): Pixel that are classified as unsuitable for wolf packs (i.e. predicted SE-IBM occurrence probability is below the given threshold).

Core (green): Pixels that are classified as suitable wolf pack habitat (i.e. predicted SE-IBM occurrence probability is above the given 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.

The results of the morphological spatial pattern analysis are shown in the following Figures 4a and 4b. In particular, a different threshold was used for the two analysis: in Figure 4a, where a threshold of 0.5 was used, bigger core areas are present and connectivity is higher; in Figure 4b, where a threshold of 0.8 was used, smaller and more fragmented core areas are present, which indicate the key patches for the settlements of wolf packs (i.e. the most important units for wolf recolonization and expansion). Results are summarised in Table 1 and 2. It would be desirable to have core areas and bridges protected to a higher degree.

Table 1: Percentages of the different GUIDOS categories over the study area and pixel frequency, considering a 0.8 and 0.5 threshold. Categories and colours are explained in section 6.

	0.8 threshold		**0.5 threshold**	
	%	**Frequency**	**%**	**Frequency**
CORE-green	25.69	251	70.41	12
ISLET-brown	0.34	223	0.01	6
PERF-blue	3.16	496	1.06	40
EDGE-black	7.02	873	3.2	103
LOOP-Yellow	1.57	496	0.09	48
BRIDGE-Red	1.22	254	0.01	4
BRANCH-Orange	1.71	1,332	0.15	132

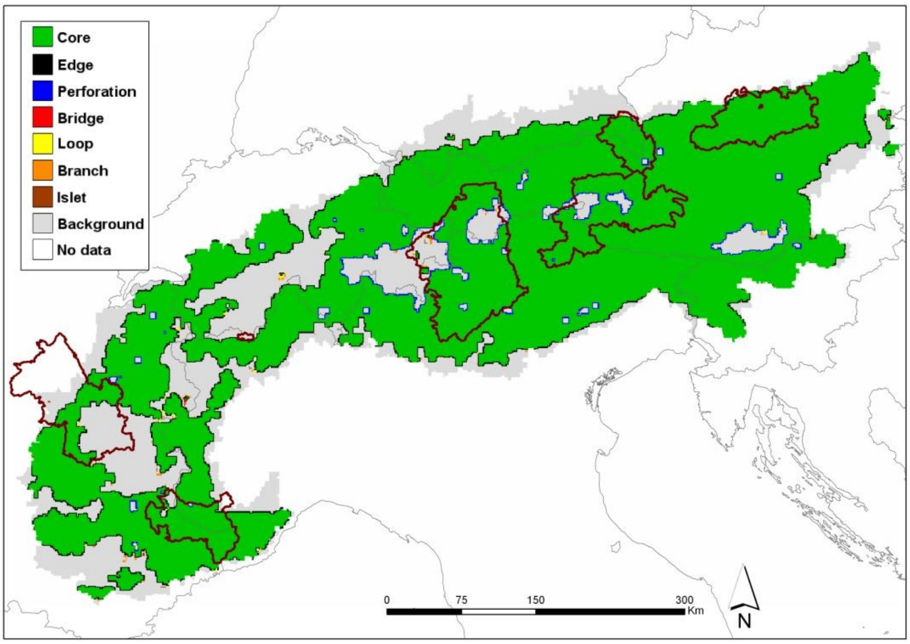

Figure 4a: This map represents the results of a morphological spatial pattern analysis based on the wolf packs habitat suitability map in the Alps, where the threshold value was set at 0.5. ECONNECT pilot regions are shown in dark red. The resolution of the map is 1 km^2.

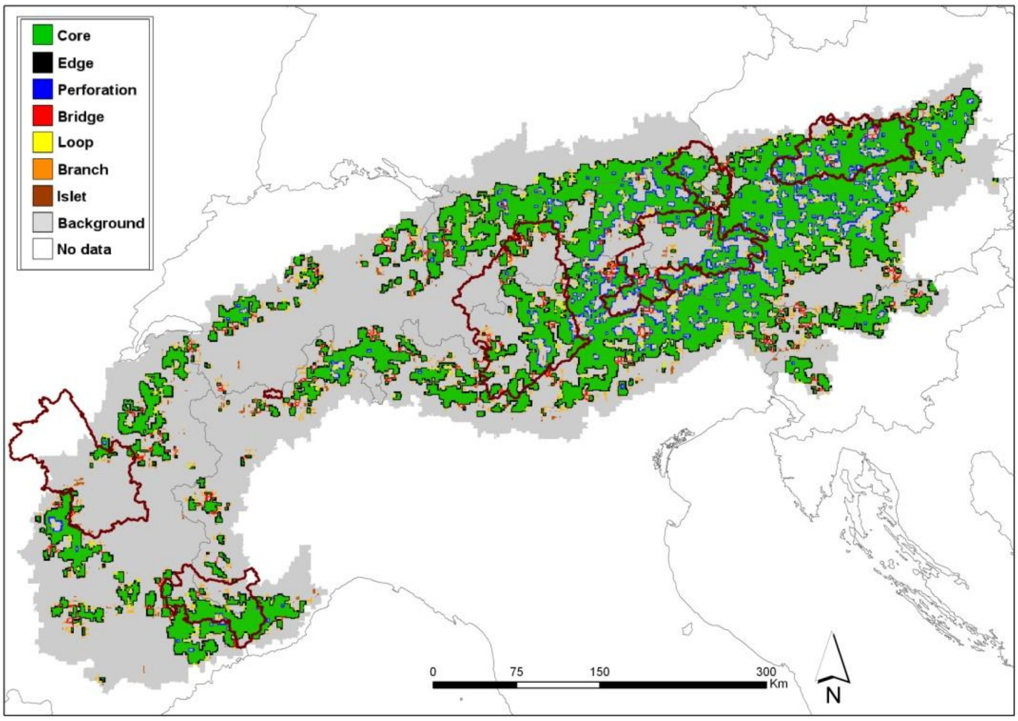

Figure 4b: This map represents the results of a morphological spatial pattern analysis based on the wolf packs habitat suitability map in the Alps, where the threshold value was set at 0.8. ECONNECT pilot regions are shown in dark red. The resolution of the map is 1 km^2.

Table 2: The first section gives the areas in km^2 that are suitable for wolves according to the MSPA categories defined above, with a threshold of 0.8. The sections labelled with % gives the relative amount of each category that falls within a given protective area.

Total area in km²	**Core** (green)	**Edge** (black)	**Perforation** (Blue)	**Bridge** (red)	**Loop** (Yellow)	**Branch** (Orange)	**Islet** (Brown)	**Background** (Grey)	**No data** (white)	**Total area** (km²)
Alps	48357	13200	5945	2291	2966	3228	636	111562	3227	191412
The Northern Limestone Region	2945	124	600	61	149	62	3	866	31	4841
The french Department IsÞre	213	186	0	19	5	67	60	4685	2556	7791
The Monte Rosa region	0	0	0	0	0	0	0	90	0	90
The transboundary area Berchtesgaden-Salzburg	897	271	94	48	22	40	2	700	0	2074
The southwestern Alps Mercantour/Alpi Marittime	1396	345	32	31	54	85	5	1465	124	3537
The Rhaethian Triangle	2861	1116	172	241	192	237	33	6152	0	11004
The Hohe Tauern Region	2115	168	758	127	140	147	32	3061	0	6548
TOT ECONNECT Pilot Regions	10427	2210	1656	527	562	638	135	17019	2711	35885
Categories % within each area	**Core** (green)	**Edge** (black)	**Perforation** (Blue)	**Bridge** (red)	**Loop** (Yellow)	**Branch** (Orange)	**Islet** (Brown)	**Background** (Grey)	**No data** (white)	**Total area** (km²)
Alps	25,26	6,90	3,11	1,20	1,55	1,69	0,33	58,28	1,69	100
The Northern Limestone Region	60,83	2,56	12,39	1,26	3,08	1,28	0,06	17,89	0,64	100
The french Department IsÞre	2,73	2,39	0,00	0,24	0,06	0,86	0,77	60,13	32,81	100
The Monte Rosa region	0,00	0,00	0,00	0,00	0,00	0,00	0,00	100,00	0,00	100
The transboundary area Berchtesgaden-Salzburg	43,25	13,07	4,53	2,31	1,06	1,93	0,10	33,75	0,00	100
The southwestern Alps Mercantour/Alpi Marittime	39,47	9,75	0,90	0,88	1,53	2,40	0,14	41,42	3,51	100
The Rhaethian Triangle	26,00	10,14	1,56	2,19	1,74	2,15	0,30	55,91	0,00	100
The Hohe Tauern Region	32,30	2,57	11,58	1,94	2,14	2,24	0,49	46,75	0,00	100
TOT ECONNECT Pilot Regions	29,06	6,16	4,61	1,47	1,57	1,78	0,38	47,43	7,55	100
Categories % in each area with respect to the Alps	**Core** (green)	**Edge** (black)	**Perforation** (Blue)	**Bridge** (red)	**Loop** (Yellow)	**Branch** (Orange)	**Islet** (Brown)	**Background** (Grey)	**No data** (white)	
Alps	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	
The Northern Limestone Region	6,09	0,94	10,09	2,66	5,02	1,92	0,47	0,78	0,96	
The french Department IsÞre	0,44	1,41	0,00	0,83	0,17	2,08	9,43	4,20	79,21	
The Monte Rosa region	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,08	0,00	
The transboundary area Berchtesgaden-Salzburg	1,85	2,05	1,58	2,10	0,74	1,24	0,31	0,63	0,00	
The southwestern Alps Mercantour/Alpi Marittime	2,89	2,61	0,54	1,35	1,82	2,63	0,79	1,31	3,84	
The Rhaethian Triangle	5,92	8,45	2,89	10,52	6,47	7,34	5,19	5,51	0,00	
The Hohe Tauern Region	4,37	1,27	12,75	5,54	4,72	4,55	5,03	2,74	0,00	
TOT ECONNECT Pilot Regions	21,56	16,74	27,86	23,00	18,95	19,76	21,23	15,26	84,01	

1.7 Habitat Connectivity for wolves in the Alps and barriers

The MSPA analysis was converted into a *Network* (Figure 5*)* for further connectivity analysis in a graph-theory framework (VOGT 2008). A *Network* is composed of *Nodes* (i.e. MSPA class: Core) and *Links* (i.e. MSPA class: Bridge, which are connectors between different Cores) and the remaining MSPA classes are neglected. A connected set of nodes and links is called a *Component*. Here, we conducted a Component analysis (Figure 5a and b), where individual components of the network are displayed in alternating colors. The color black is used for node-only components having no links. We conducted the analysis both with a threshold of 0.5 and 0.8.

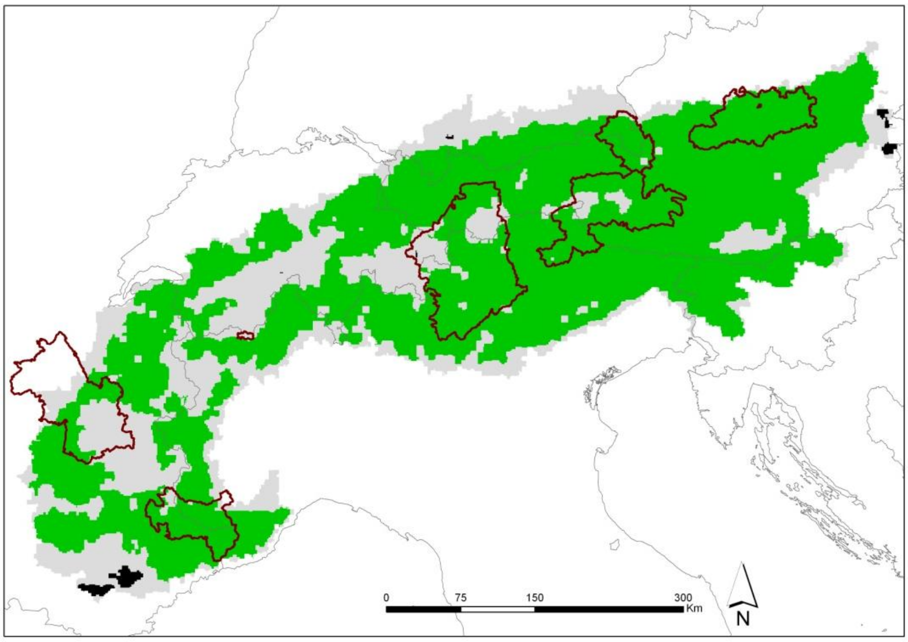

Figure 5a: Network analysis where individual components of the network are displayed in alternating colors. The analysis was conducted with a threshold of 0.5. ECONNECT pilot regions are shown in brown.

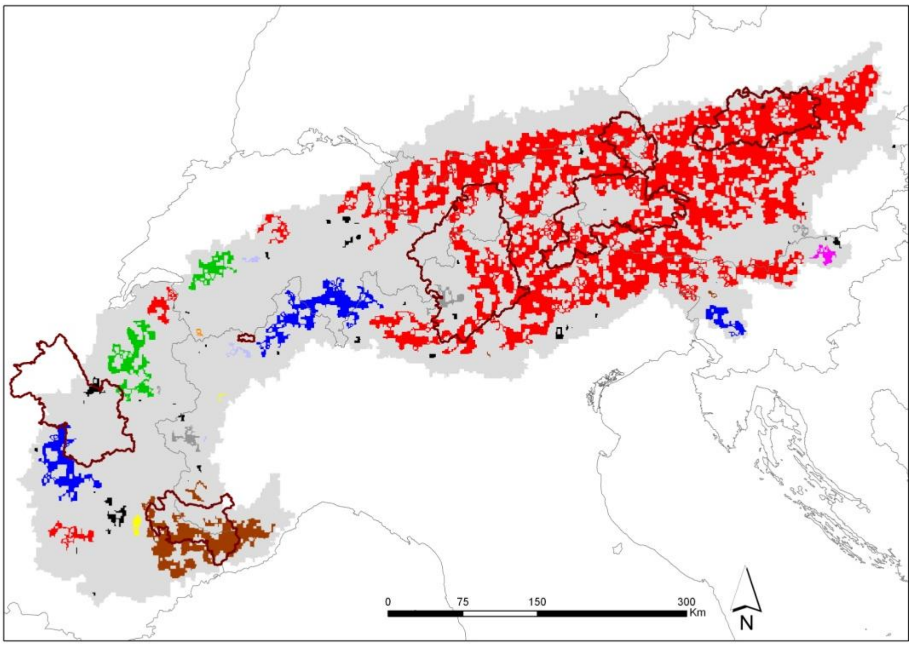

Figure 5b: Network analysis where individual components of the network are displayed in alternating colors. The analysis was conducted with a threshold of 0.8. ECONNECT pilot regions are shown in brown.

The individual components of the network based on the analysis with a threshold of 0.8 (Figure 5b) were considered the most important potential source areas for wolves in the Alps. The 150 cells with highest SE-IBM values within these source areas were taken for the analysis. These rules were established in order to make a selection on the suitable pixels that were thought of particular suitability for wolves. Then, for each cell the least-accumulative cost distance to the nearest source over a cost surface was calculated (Figure 6). The source raster (150 cells) identified the cells to which the least accumulated cost distance for every cell was calculated. The cost raster (or resistance raster) was based on the inverse values of the occupancy model (Paragraph 1.5.1.), where the value of each cell represented the cost per unit distance for moving through the cell. This resistance raster considers, for potential barriers for wolves, a combination of roads, settlements, high altitude rock areas, low forest coverage, and presence of lakes. The final wolf cost distance raster identified for each cell the least accumulative cost distance over a cost surface to the identified source locations (Figure 6). Therefore, this connectivity analysis identifies the areas which can be considered barriers in between potential sources for wolves (i.e. High values areas in Figure 6). The areas that can be considered as barriers for wolves are located mainly in the west-central Alps, and in Switzerland. This could also explain why the wolf recolonization over the years expanded constantly over the southern part of the Western Alps (Figure 1) and slowed down over the indicated barriers in the recent decade (Marucco, pers.comm.).

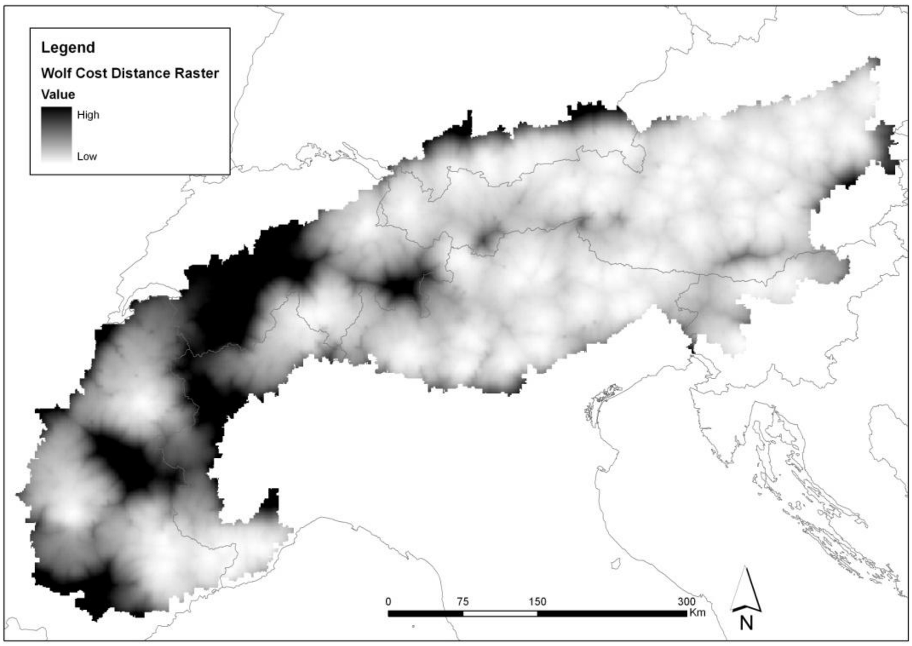

Figure 6: The wolf cost distance raster which identified for each cell the least accumulative cost distance over a cost surface to the identified source locations.

1.8 Conclusion

The SE-IBM, developed to produce the wolf pack habitat suitability map (Figure 3), was based on a high quantity of information collected over the Western Alps, and strongly validated with part of the dataset not used in the analysis. Therefore, the model is robust, also if it can be improved over time by additional data on wolves collected over the central and eastern Alps, if the recolonization process will reach these areas. Wolf pack needs to be considered the main unit of the analysis, because they represents the main reproductive units in wolf social dynamics (MECH & BOITANI 2003). For wolf habitat and connectivity analysis, it is fundamental to analyse pack requirements for territorial establishment (which have been accounted for in this spatial analysis), and distinguish between potential presence of wandering solitary wolves and established packs. Following these requirements, we identified the potential wolf source areas over the Alps (Figure 5b) and evaluated their connectivity.

The MSPA analysis was based on the SE-IBM wolf pack habitat suitability map to identify core areas and bridges, which are the most important areas to protect to maintain wolf connectivity over the Alps. However, there was a significant difference if we considered 0.5 or 0.8 thresholds. If the threshold was set at 0.5, we documented a big connected area over the Alps (Figure 4a and 5a). If the threshold was set at 0.8, we documented a more fragmented area, especially in the Western-Central Alps (Figure 4b and 5b). In order to prioritize the most important core areas, we considered the analysis with a threshold of 0.8, which is the most conservative approach that identified the source areas for the connectivity analysis. The ECONNECT pilot regions which contain the higher percentages of core and bridge areas are: the Northern Limestone Region, the Rhaethian Triangle, and the Hohe Tauern Region which are all located in the Eastern Alps. The Mercantour/Alpi Marittime Region contains the higher percentages of core and bridge areas in the Western Alps. Therefore, they represent a key source area for the current recolonization process which originates from the Apennines (FABBRI et al. 2007). An additional key source area to protect should be identified in the Pennine and Lepontine Alps. In these pilot regions it could be useful to improve green bridges over highways and railways, where the majority of alpine wolves have been found killed (AVANZINELLI et al. 2007); as well as to enforce anti-poaching teams in order to decrease the high levels of illegal killing, which are the major sources of mortality for wolves in core areas.

The Connectivity analysis was based on the potential wolf source areas identified by the MSPA analysis. Wolves can easily cross roads and highways, as documented by many studies (e.g. BOYD & PLETSCHER 1999, CIUCCI et al. 2009); therefore, a single road is not usually identified as a barrier for wolf dispersal. However, in Italy wolves are often killed by car accidents (LOVARI et al. 2007), especially if they settle a territory in a region with a high road density (e.g. AVANZINELLI et al. 2007). Therefore, road density is a major limitation to pack settlement more than to wolf dispersal. We documented that not just road density is a variable negatively related to wolf presence, but also human settlements, low forest cover and high rock elevation presence (MARUCCO 2009). Hence, we considered a combination of these factors as the resistance raster to conduct the analysis on wolf connectivity. Connectivity results need also to be interpreted within the strict regulations of wolf sociality and dispersal movement patters, very different than for the other solitary large carnivores. Our analysis incorporated these elements to effectively account for the major barriers for wolf connectivity, which were identified as from anthropogenic and landscape origin. In particular, the reported results (Figure 6) showed the lowest levels of connectivity between source areas in the Pennine and Lepontine Alps, between Switzerland and Italy.

Another factor that can also affect connectivity is management fragmentation, which is a type of fragmentation often overlooked (LINNELL et al. 2007). The high level of management fragmentation present over the Alps, due to the international alpine landscape divided within several countries, is an important issue related to wolf conservation and connectivity. From this landscape analysis, the Pennine and Lepontine Alps, especially of Switzerland, are a critical part in the overall wolf alpine connectivity, where no consistent source areas for wolf packs were identified. This need to be added to the fact that currently Switzerland is the only country in the Alps with a program of legal wolf removals of solitary and dispersal wolves, despite the very low density of the predator in the country and no packs settled yet (WEBER 2008). So far this area seems to be both a landscape and management barrier for wolf expansion over the Eastern Alps. A shared management program within the different alpine countries is a key step to maintain wolf connectivity and conservation over the Alps, as advocated by the Guidelines for Population Level Management Plans for Large Carnivores in Europe approved by the European Commission in 2007 (LINNELL et al. 2007).

Finally, wolf connectivity over the Alps needs to be analysed in a wider context, taking into consideration that the alpine wolf population was naturally generated 20 years ago through natural dispersal from the south-western Apennines (FABBRI et al. 2007). The connection with the Apennine population is constituted by an ecological corridor represented by the Ligurian Apennines Mountains, which is fundamental to be maintained in order to guarantee enough genetic diversity in the wolf alpine population (FABBRI et al. 2007). Moreover, an interesting slight connection has been documented with the Dinaric population from Slovenia, and the Carpatian wolf population (Rauer & Groff, pers.comm.). Spatial analysis of potential connectivity within these areas and the Alps, and characterisation of the barriers by their origin, size, shape and degree of permeability with an assessment of possibilities to diminish them, would be extremely important to allow a future wolf metapopulation over the different mountain chains in Western-Central Europe.

1.9 References

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