The Continuum Suitability Index

Technical Report

Author: Dominik Affolter, arinas environment AG

Contact: Arinas Environment AG
Walter Abderhalden
w.abderhalden@arinas.ch

Swiss National Park
Ruedi Haller
rhaller@nationalpark.ch

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1 Background: The Econnect Project

A good introduction of the project is given on the econnect-hompage: "The main objective is the protection of biodiversity in the Alps through an integrated and multidisciplinary approach aimed at encouraging the promotion of an ecological continuum across the Alpine region." [1]

To achieve this objective some specific actions were defined. The Continuum-Suitability-Index (CSI) was developed within the scope of the major action category Information Gathering. The specific actions are:[2]

- harmonise geographical data across participating countries
- analyse existing physical and legal barriers to the establishment of ecological corridors
- define migration corridors between high value biodiversity areas in the Alps and links to other ecoregion

The CSI acts as spatial analysing instrument for the physical barriers and already existing ecological corridors.

Besides information gathering on the alpine ecological connectivity, ground actions and raising the public awareness concerning this issue, are the main project activities.

The Econnect Project is realised in seven pilot regions where the CSI was worked out for the Rhaethian Triangle. The region is situated in the Austrian-Italian-Swiss borderland and consists of several administrative and geographic subregions: The Swiss Engiadina Bassa located in the canton Grison (GR), the Austrian Tirol (TI), the Südtirol located in the Autonom Province Bozen (APB), the Province of Trento (TR) and Lombardia (LO) all part of Italy.

2 Ecological Network: Terms and Approaches

As mentioned before the establishment of an ecological continuum in the Alps is the main goal of the Econnect Project. Actually the term Ecological Continuum was not defined before the Econnect Project. For the CSI the terminology around the topic connectivity has to be clarified.

Connectivity can be considered from the functional as well as from the structural point of view. Whereas the functional side looks at the needs of specific species, the structural side describes the physical condition of the landscape in general.

Recent studies on connectivity mostly focused on habitat corridors. A corridor is often defined as a linear habitat patch within the landscape that facilitates species to move between larger habitat patches.

[1] European Union (2010)
[2] European Union (2010)

Besides the structural and the functional sights the landscape can also be looked at different scales. In this project the range can reach from a pan-alpine to a local view.

Further approaches in the context of connectivity are the Matrix and Landscape Permeability:

Matrix

"Throughout the literature reviewed here, definitions of the 'matrix' were generally vague. Most commonly, the matrix is defined as 'non-habitat' and/or the portion of the landscape in which habitat patches and corridors are 'embedded'. This very black and white interpretation fails to capture the myriad land cover types and functional continuum that constitute the matrix. Precisely, the matrix is a component of the landscape, altered from its original state by human land use, which may vary in cover from human-dominated to semi-natural and in which corridors and habitat patches are embedded. In other words, the matrix may be anything from urban development to agricultural land to grassland or forest. Matrix lands have the potential to function as habitat as well as the capacity to be barriers to movement. Just as with connectivity, the role played by the matrix will depend both on its composition and on the unique behavioral response of the species under consideration."[3]

Landscape Permeability

"In contrast to landscape connectivity – which characterizes the capacity of individual species to move between areas of habitat via corridors and linkage zones – permeability refers to the degree to which regional landscapes, encompassing a variety of natural, semi-natural and developed land cover types, are conducive to wildlife movement and sustain ecological processes. Multi-scale, multi-stakeholder, sustainable land management strategies that not only target conservation areas like reserves and corridors, but also target the matrix, including areas of human development, are essential to achieving landscape permeability." [4]

In the forerunning Continuum Project [5] the evaluation of different approaches was one of the main goals. Based on expert opinions four approaches were assessed there:

- The Ecoregion approach of the WWF takes the whole alpine range as one ecoregion. Its aims are focused on specific species, and the linkage of protected areas. Where the protected areas were considered as biodiversity hot spots and take centre of this approach.

[3] Meiklejohn, K., Ament, R., Tabor, G (2009)
[4] Meiklejohn, K., Ament, R., Tabor, G (2009)
[5] Scheurer, T., Bose, L., Künzle, I. (2008)

- Cross-border ecological network of protected areas by ALPARC concentrates on structural characteristics of the alpine space and like the WWF-approach on the linkage of protected areas. Especially transboundary protected areas are the centre and starting point of this approach.
- The Pan-European Ecological Network PEEN acts on the large scale of the whole European continent. It is an overview of the natural and semi-natural landscape elements which are understood as core areas. For the functioning of the Network in terms of the PEEN these areas have to be connected by corridors between them and protected by buffers around them.
- The Swiss Ecological Network REN scale is more local. But the overall goals are the same as those of the PEEN. Similar elements are used for the network-structure. REN considers the functional as well as the structural aspect.

3 Problem Definition

The CSI serves the purpose to show where, in terms of an exact position, the requirements for the ecological continuum already exist and in which areas there is need for improvement. It is the base of discussion for concrete measures for the implementation of the Ecological Continuum.

Therefore the index has to answers to a wide thematic range, which reaches from biological, landscape ecological and geographical up to socio-economical questions.

At the same time this question has to be answered at most precise spatial dimension as possible because the decisions and implementation will be done on a very local level.

For the data processing all data available is taken. The data availability as well as the data quality varies from region to region. Because of that the index is structured changeable and a quality indicator is calculated for each indicator and for each region. With the quality indicator the worth of the CSI analysis result can be shown. This is necessary to ensure the decisions made upon the CSI statements.

Finally this decision support system is presented as a web-application The CSI-Webservice this allows a broad access for all interested parties.

4 Overview of the Chosen Approach

For the thematic differentiation the index is structured in several indicators. They were elaborated within the frame of an experts working group[6].

For each indicator a raster surface was created. A raster surface represents the continuous character of the problem in the best way.

[6] Plassman, G. (2009)

For comparability reasons the indicator values range between zero and one hundred. Where zero means totally unsuitable, the value one hundred indicates a very high suitability for the ecological continuum.

Each indicator is a based on suitability analysis with one or more criteria. The target of the analysis is always the ecological connectivity which is considered from the topic of the indicator.

In the most cases the Multi Criteria Evaluation was applied for the composition of the indicators. This method will be described in chapter 5 Suitability Analysis: Methods and Approaches. The structure of the indicators will be described in the chapter 8 The Indicators: Concepts and Classification.

Following a semantic description of the CSI in the words defined in chapter 2 Ecological Network: Terms and Approaches

The CSI is a combined analysis of structural landscape connectivity and landscape permeability. The landscape is considered as a Matrix where each part or patch promotes more or less the ecological connectivity. Ecological connectivity comprises wildlife movement as well as ecological processes.

5 Suitability Analysis: Methods and Approaches

There are two types of suitability analysis the Multi Criteria Evaluation (MCE) and the Multi Objective Evaluation (MOE).

The Multi Criteria Evaluation was applied for the composition of the CSI indicators, as there is only one objective: to preserve and improve the ecological connectivity.

The standard proceeding for the MCE [7] contains the following steps:

- problem definition
- criteria selection
- criteria operationalisation
- criteria integration
- overlay of the criteria
- verification and evaluation

For the overlay of the criteria there are different methods:

- Boolean overlay: For each criterion there are only the values true and false resp. one and zero. The criteria can be combinated with Boolean operators e.g. AND, OR, NOT etc..
- Weighted overlay: The criteria can have any numeric value. They were combinated with mathematic operators.

The weights for the weighted overlay can be assigned in different ways:

- ranking of the criteria: weight = n - r + 1

[7] Lüscher, P. (2003)

r = rank, n = number of criteria

- rating of the criteria:
    - point allocation → assignment of a total of point
    - ratio estimation → assignment of any value out of codomain

Depending on the application field one of these methods were chosen, for the classification within the data processing for the indicators.

6 Spatial Analysis Methods

6.1 Raster Analysis

“Raster-based GIS is a way of storing geographic information into a matrix that is divided into a grid of equally sized cells. Grid cells are also called pixels, and are most typically square shaped. Each cell represents an area on the Earth's surface, for example a cell could represent one-square meter, or ten square meters, etc. In raster GIS, attribute information is stored with each cell. Each cell is assigned a value, which corresponds to what it contains on the ground.

For example, the figure below shows a grid of land use, where land use types are represented by grid cells with values of 1, 2, or 3. The numbers 1, 2, 3 are stored with each cell and correspond, in this case, to a land use type.”[8]

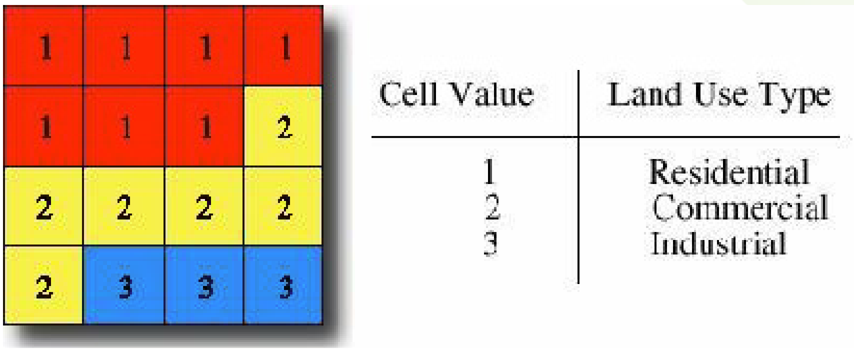

figure 1: grid of land use[9]

“Cell size is defined by the user, and corresponds to the length of one side of one grid cell. Cell size determines cell area, or the area on the Earth's surface that each cell represents. Cell area is equal to cell size squared.

The cell size determines the grid's resolution, or the finest level of detail that can be depicted on the map. For example, if a cell size of 10 meters is chosen, then the finest level of detail for that map will be 10 meters in width and height, and 100 square meters in area. Features smaller than the cell size can be shown, but they will be represented larger than actual size. For example, a road that is approximately 5 meters wide (actual width) can be represented on a 10 meter grid, but its width will appear as 10 meters. Also, smaller cell sizes correspond to higher resolutions.”

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[8] Carr, M. H., et al. (2002)
[9] Carr, M. H., et al. (2002)

The smaller the cell size the greater the number of total cells. “The greater the number of total cells, the longer the time it takes the computer to process an analytical function, overlay, or mathematical computation. Small cell sizes should be chosen only when the area of extent is relatively small and has small features and details that need representation”. [10]

6.2 Suitability Surface and Cost Path

The suitability surface is an application of raster analysis where the value of each cell shows the degree of fulfilment of a given objective.

The values can also be taken as a spatial resistance. So a low value for a cell means a high effort must be done to overcome it. In this case it can also be called spatial resistance surface or cost surface.

“A cost surface is a dataset that ranks areas depending on the "cost" to move through that area. Cost can be defined or thought of as impedance. Areas that are more likely to provide connectivity for wildlife and ecological processes have no or low impedance and areas that are barriers to connectivity have high impedance. In terms of linkages, cost can be correlated to the quality of land cover or habitat. Areas with natural land cover or high quality habitat will have a low cost. Urban or residential areas, which do not offer habitat or resources, will have a high cost. After specifying source and destination locations, the least cost path function will identify the path traversing the lowest cost areas. For example, the least cost path would traverse the highest quality land cover and habitat, in an attempt to avoid urban areas.”[11]

7 The Data Inventory and The Feasibility Study

Before the indicators were built up an overview of the available data had to be made. A data invetory was put together. Based on that and the describtion of the indicators a feasibility study was carried out. One criterion of this study was the question if the defined problem can be presented sufficient with the available data. The other question was if the indicator can be built up in a adaptable way, so that it can be realised with varying data sets.

The most of the indicators could be implemented. An overview of the indicators and the results of the feasibiltiy study is given in table 1. The complet list of the data used for the indicators is added in appendix A.

[10] Carr, M. H., et al. (2002)
[11] Carr, M. H., et al. (2002)

Indicator	Description	Feasibility
Ecological measures	Planned or realized measures	✓
Fragmentation	Degree of fragmentation by human infrastructure	✓
Landscape heterogeneity	Capacity of stepstones for species migration	✓
Environmental protection	Protected areas, based on legal status	✓
Population	General human pressure, local people and tourists	✓
Infrastructure	Impact of diverse infrastructure	✓
Land use	Coherence of activities with landscape type	✓
Land use planning	Future developments	✓
Altitude and topography	Absolute altitude, energy and slope	✓
Urbanisation	Pendular movements	○
Economical activity	Weight of economic activities by sectors	○
Public opinion and policy	Political and public will	✗
Pollution	Level of disturbances, human impacts	✗
Artificial light	Brightness per area	✗
✓	feasible	
○	partly feasible	
✗	not feasible	

table 1: Results of the feasibility study

For the indicators Public opinion and policy and Artificial light there is no data available in a appropriate resolution.

On the pollution topic there is a lot of data but not in that general way that would be required for the indicator.

The impact of the urbanisation and the economical activity can not be visualised spatialy so that it can not be part of a spatial analysis like the CSI calculation.

8 The Indicators: Concepts and Classification

The concepts for the indicator structures are the result of a literature research. The focus of the research was on similar projects and simple approaches for the implementation in GIS that can be adapted easily.

All the indicator concepts are structured in the same way:

- They are based on the **definition** which describes the problem that has to be expressed by the indicator.
- Whithin the **realisation** it has to be decided which data is used for the indicator and in which way it is processed.
- Finally the results have to be interpreted and **classified** for the indicator value.

8.1 Population

Definition

The explanation of this indicator reads as follows: "To define the general human pressure in an area by activities and including tourist activities and settlements."[12]

Realisation

The following data sets were used for this indicators (detailed describtion of data sets in appendix A):

- population per municipality
- overnights per municpality
- land use/land cover: residential areas, urban areas, buildings, sealed surfaces
- communal urban planning: constructional zones, residential areas

For the CSI analysis the resolution of the population and the tourist data is to crude. The data was brought to the scale of single houses or residential areas by the method spatial disaggregation [13]. Based on the site density this method distributes the population data over the residential areas. The result of the analysis is the value population per hectare for all residential areas within the evaluation. A detailed description of the spatial disaggregation process can be found in the description of the data processes in chapter 9.1 Population.

Precondition for the spatial dissaggregation is the classification of the buildings, respectively the residential areas, according to the site density of their surrounding.

There were already classified residential areas in some base data.

In other cases the information about the site density was derived by the following process:

- The sealed surfaces were converted from polygons to a raster data set with a resolution of two metres. The raster data set consists of the values one for sealed surfaces and zero for unsealed surfaces.

[12] Plassman, G. (2009)
[13] Steinnocher, K., et al. (2005)

- The binary raster data set was aggregated to a cell size of 100 m. The cell values of the first raster were summarized during the process.
- Out of the summarized values a percentage was calculated which represents the site density for an area.
- The percentage values were classified according the values in table 2: Classification of residential areas.
- The buildings were assigned to one of the four site density classes. Previously non residential buildings were separated on the basis of the urban planning zones.

The factor k was calculated. It is individual for each municipality depending on the ratio of residential areas per site denstiy category. It describes the relation between the site density and the population density.

$$k = \frac{\text{population \& tourists}}{\sum_i A_i * \text{site\_density}_i}$$

population & tourists: total of inhabitants and tourist overnights per municipality
A_i: area of the site density class i in hectares

The tourist activities are represented by the annual overnights per municipality. These data was refined by the same distribution like the population data. Therefore it was added to the population value in the following way.

$$population \,\&\, tourist\ activities = population + \frac{ovn * ImpFct}{365}$$

ovn: total overnights per municipality per year

ImpFct : factor of impact of a tourist overnight relative to a local inhabitant

The population density per hectare is calculated based on the factor k and the site density.

$$\text{pop.dens.per hectare} = k * \text{site\_density}_i$$

The influence of human activities is not only limited to the residential areas, so the per-hectare-values were forecasted by a Kernel Density Estimation within a radius of 1500 metres around the residential areas.

Classification

The classification was done by an expert survey. In the survey the following points were made clear:

- ratio of sealed surface per hectare for the site density classes:

site density class	ration in %
sparsely rural	9
dense rural	24
sparsely urban	40
dense urban	62

table 2: Classification of residential areas

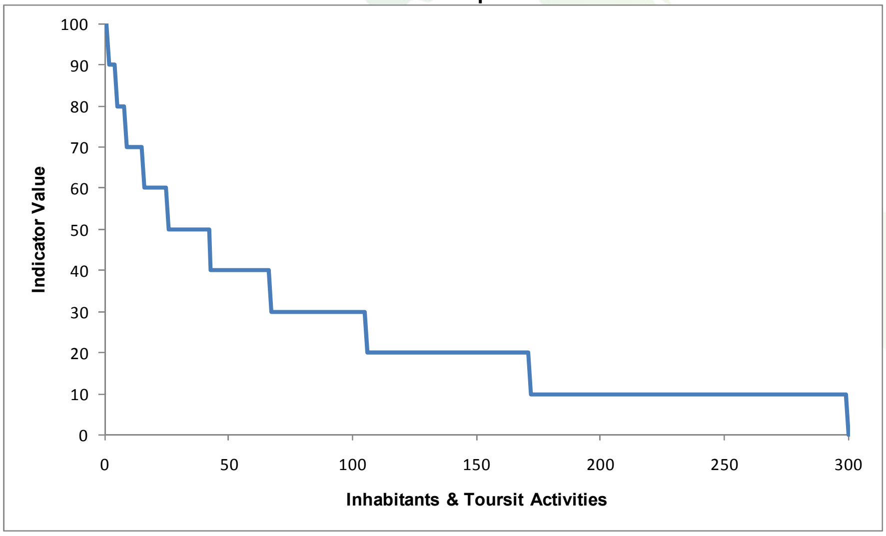
- the factor of impact of a tourist overnight relative to a local inhabitant:

ImpFct = 2, this means one tourist corresponds to 2 local inhabitant.
The higher impact of tourists was explained by the higher recreational activity.

- the classification of the population values:

Inhabitants & tourist activities per hectare	Indicator value
0	100
2	90
5	80
9	70
16	60
26	50
43	40
67	30
106	20
172	10
300	0

table 3: Classification Population Indicator



Graph 1: Classification Population Indicator

8.2 Land Use

Definition

The explanation of this indicator reads as follows: “To evaluate the coherence of activities with the type of landscape according to principles of sustainability.”[14]

Realisation

So in brief the various land use and land cover data sets had to be assessed according their impact on their natural environment.

The Indicator was composed of the following basic data sets (detailed describtion in appendix A).

- land survey: ground cover

[14] Plassman, G. (2009)

- communal planning: basic use
- land use, land cover

Where there were multiple data sets the data sets were prioritized according their spatial resolution and their actuality.

Classification

For the classification three reference scales were considered:

The cost surface classification of the Southeastern Ecological Framework
In this Project a cost surface was created to identify landscape linkages between hubs (large priority ecological areas).
This classification first divide the land use types into native and non-native landscape units. The non-native units were subclassified into three categories based on "their relative ecological value and their potential for restoration to native habitat"[15].
The categorized land uses as well as the native landscape units were scored from no data to 200'000. Where no data means that the cell is completely unsuitable. "The values in the cost surface represent the resistance to going through an individual cell. As an example, a least-cost path would go through 99 cells valued as 1 instead of going through a single cell valued as 100"[16].
The table in appendix B shows the scoring of the Land Use types.

Mean Species Abundance relative to land cover/land-use of Cross-roads of Planet Earth's Life-Project[17]
Based on ca. 120 published data sets, land use types were categorised according their species diversity. Each category a Mean Species Abundance (MSA) value was assigned to. The categories reach from undisturbed to irigated and built up areas.The table in appendix B[18] summarises and describes the different categories.

Habitat Protection and Spatial planning[19]

In this study the land use classes of the Swiss GEOSTAT dataset were classified according their potential of biotic regulation on a five level scale.

By this three references the classification scheme in appendix G was elaborated.

At this place, in stead of the scheme the well-known CORINE Land Cover nomenclatur is taken as a classification example.

[15] Carr, M. H., et al. (1999)
[16] Carr, M. H., et al. (2002)
[17] ten Brink, B., et al. (2006)
[18] ten Brink, B., et al. (2006)
[19] Kias, U. (1990)

	Land Cover Class	Classification (0 – 100)
1.1.1.	Continuous urban fabric	0
1.1.2.	Discontinuous urban fabric	0
1.2.1.	Industrial or commercial units	0
1.2.2.	Road and rail networks and associated land	40
1.2.3.	Port areas	5
1.2.4.	Airports	5
1.3.1.	Mineral extraction sites	0
1.3.2.	Dump sites	0
1.3.3.	Construction sites	0
1.4.1.	Green urban areas	40
1.4.2.	Sport and leisure facilities	0
2.1.1.	Non-irrigated arable land	10
2.1.2.	Permanently irrigated land	5
2.1.3.	Rice fields	10
2.2.1.	Vineyards	10
2.2.2.	Fruit trees and berry plantations	20
2.2.3.	Olive groves	20
2.3.1.	Pastures	50
2.4.1.	Annual crops associated with permanent crops	10
2.4.2.	Complex cultivation patterns	10
2.4.3.	Land principally occupied by agriculture, with significant areas of natural vegetation	50
2.4.4.	Agro-forestry areas	70
3.1.1.	Broad-leaved forest	60
3.1.2.	Coniferous forest	60
3.1.3.	Mixed forest	60
3.2.1.	Natural grasslands	70
3.2.2.	Moors and heathland	100
3.2.3.	Sclerophyllous vegetation	60
3.2.4.	Transitional woodland-shrub	60
3.3.1.	Beaches, dunes, sands	60
3.3.2.	Bare rocks	100
3.3.3.	Sparsely vegetated areas	100
3.3.4.	Burnt areas	100
3.3.5.	Glaciers and perpetual snow	100
4.1.1.	Inland marshes	100
4.1.2.	Peat bogs	100
4.2.1.	Salt marshes	100
4.2.2.	Salines	100
4.2.3.	Intertidal flats	100
5.1.1.	Water courses	60
5.1.2.	Water bodies	60
5.2.1.	Coastal lagoons	100
5.2.2.	Estuaries	100
5.2.3.	Sea and ocean	100

table 4: Corine Land Cover Nomenclatur classified

8.3 Fragmentation

Definition

The explanation of this indicator reads as follows: “To define the degree of fragmentation of natural or semi natural spaces by human infrastructure.”[20]

Realisation

For measuring the fragmentation the key figure effective Mesh Size m_{eff} was applied. It is defined over the degree of coherence C which shows the probability that two random points in an area remain in the same subarea after dividing the primary area.

The points can be taken as an individual and the dividing elements as human infrastructure. The degree of coherence becomes the meaning of the meeting probability of animals in each part of the natural living space.

The effective mesh size is the cell size of a regular grid with the calculated degree of coherence for each cell.[21]

$$C = \sum_{i=1}^{n} \left(\frac{A_i}{A_g}\right)^2 \qquad m_{eff} = \frac{1}{A_g}\sum_{i=1}^{n} A_i^2$$

A_g: total area
A_i: subarea i
n: number of subareas

Whithin CSI analysis the subareas areas or the meshes are the remaining unfragmented areas, after dividing the Pilot region by the barrier geometry.

The definition of the barriers was adopted from the Degree of Landscape Fragmentation in Switzerland[22]. According to the definition of the indicator the natural barriers were not taken into account of the analysis. Natural Barriers in terms of landforms are considered in the indicator Altitude and Topography described in the next chapter.

Finally the basic barriers were composed of the following elements (detailed describtion of data sets in appendix A):

- road system
- railway system
- pressure lines
- dams
- settlement areas (incl. industrial & commercial)
- facilities (airports, railway areas)

[20] Plassman, G. (2009)
[21] Jaeger, J.A. (2000)
[22] Bertiller, R., Schwick, C., Jaeger, J. (2007)

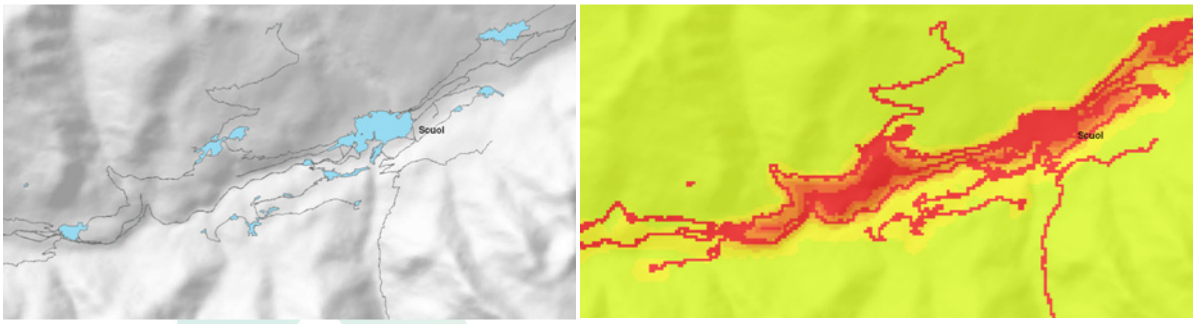


figure 2: basic barriers and classified analysis result

To consider the different fragmentation effect of the several barriers, a second barrier geometry was built. It consists of the following elements:

- primary roads
- secondary roads
- railway system
- settlement areas (incl. industrial & commercial)
- facilities (airports, railway areas)

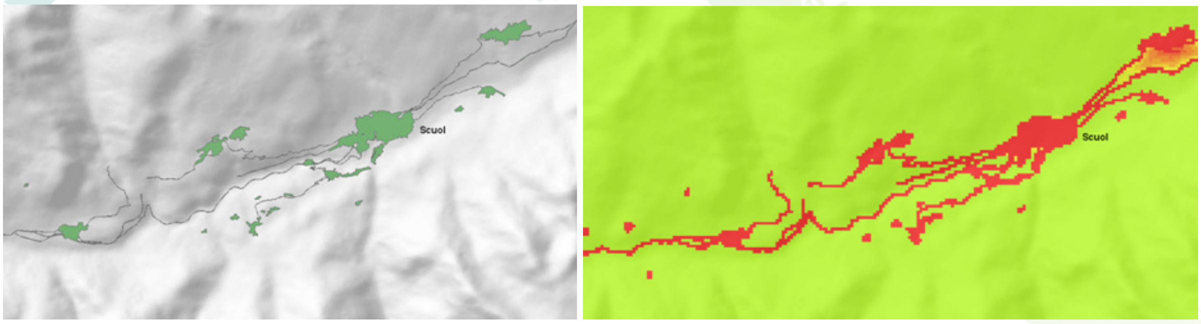


figure 3: major barriers and classified analysis result

The identical analysis was carried out with this barriers.

All the barriers were valued zero within the classification.

The classified results of the analysis were combined by a weighted summation, where the following weights were used:

Barriers used for the analysis	Weight
basic barriers	1/3
major barriers	2/3

table 5: Weights of Barrier Geometries

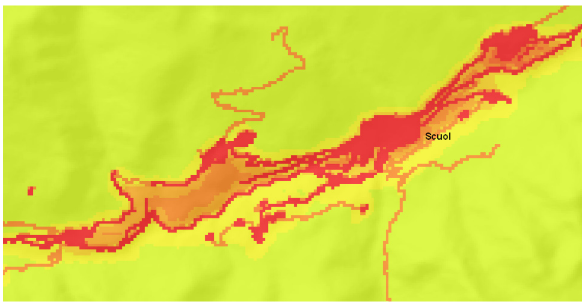


figure 4: Result of the weighted summation

Classification

Due to missing references for the classification of this indicator, the break values for the classification were worked out of the results of the Swiss reference study on landscape fragmentation. There the mesh size was calculated for all the cantons and for several bio geographic regions. As an additional orientation the mesh sizes of some European countries were considered. The values are shown in Appendix F.

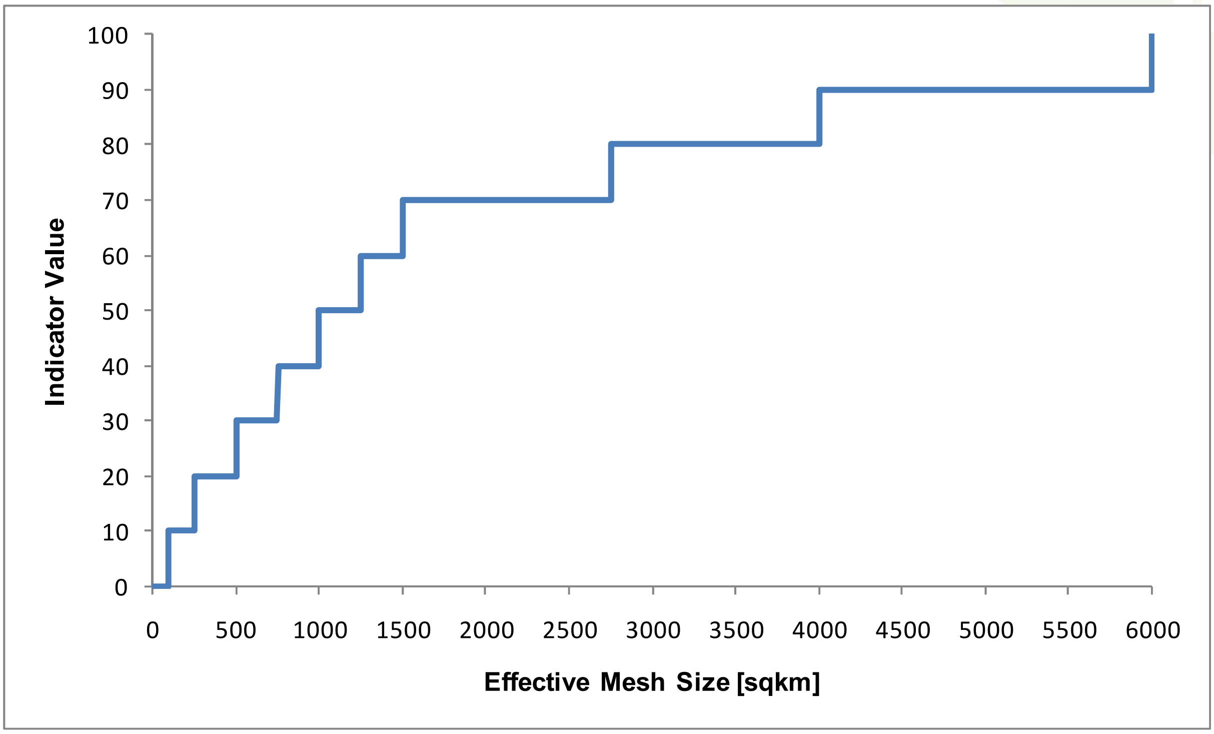
With the help of descriptive statistics the main break values were set shown in table 6. The amount of classes in between was chosen according the distribution of the calculated meff values. It was supposed that the progress between the main break values is linear. This led to the classification in table 7.

Break Values	Amount of preceding classes
500	3
1500	4
4000	2
10000	2

table 6: classification parameters Fragmentation Indicator

Mesh Size	Indicator Value (0-100)
0	0
100	10
250	20
500	30
750	40
1000	50
1250	60
1500	70
2750	80
4000	90
6000	100

table 7: Classification Fragmentation Indicator



Graph 2: Classification Fragmentation Indicator

8.4 Altitude and Topography

Definition

The explanation of this indicator reads as follows: “To express the potential to establish ecological network in lower altitudes (conflicts of use).”[23]

Realisation

As in the alpine region the topography is surely one of the determining living factor for all kind of species it was additionally analysed in this indicator.

For the classification three key figures were chosen:

- Meters Above Sea Level (MASL), the absolute altitude of a location
- “Topographic Position Index (TPI) is the difference between the elevation at a cell and the average elevation in a neighbourhood sorrounding that cell. Positive values indicate that cell is higher than its neighbours while negative values indicate the cell is lower. TPI values provide a simple and powerful means to classify the landscape into morphological classes.”[24]
- Slope, the ratio of the altitude change to the horizontal distance between two locations

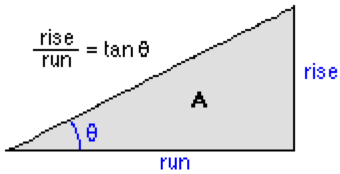
All the key figures were derived from the digital elevation models of the several regions (detailed describtion of data sets in appendix A).

$$TPI = H - \frac{\sum_{i=1}^{n} H_{Ni}}{n}$$

$$H = elevation\ at\ processed\ cell$$

$$H_{Ni} = elevation\ in\ neighberhood\ cell$$

$$Slope\ = \theta\ = \tan\frac{run}{rise}$$



Each cell was classified according its altitude where locations at low absolute altitude were assessed higher than locations at high altitude.

As in “Korridore für Wildtiere in der Schweiz”[25] described the overregional wildlife dispersal axes in the alpine space proceed along ridges, passes and valleys. Locations within this landforms were assessed higher than cells positioned otherwise.

The landform were classified on behalf of TPI and slope as followed:

Slope position classification (Weiss, 2001)	TPI and slope criteria
Valley	TPI ≤ -1 SD
Flat surface	TPI>-1SD and TPI< 1SD Slope <6°
Mid slope	TPI>-1SD and TPI< 1SD Slope >=6°
Hilltop	TPI>=1SD

SD: standard deviation

table 8: Description of slope position classes[26]

[23] Plassman, G. (2009)
[24] Tagil, S. & Jennes, J. (2008)
[25] Holzgang O., et al. (2001)
[26] Weiss, A. (2001)

Classification

The final Indicator Classification is composed as followed:

$$Classification\ Altitude * 0.5 + Classification\ Landform * 0.5$$

This weighting was elaborated by expert opinions.

Altitude and Landform was classified according the following schemes

- Landform

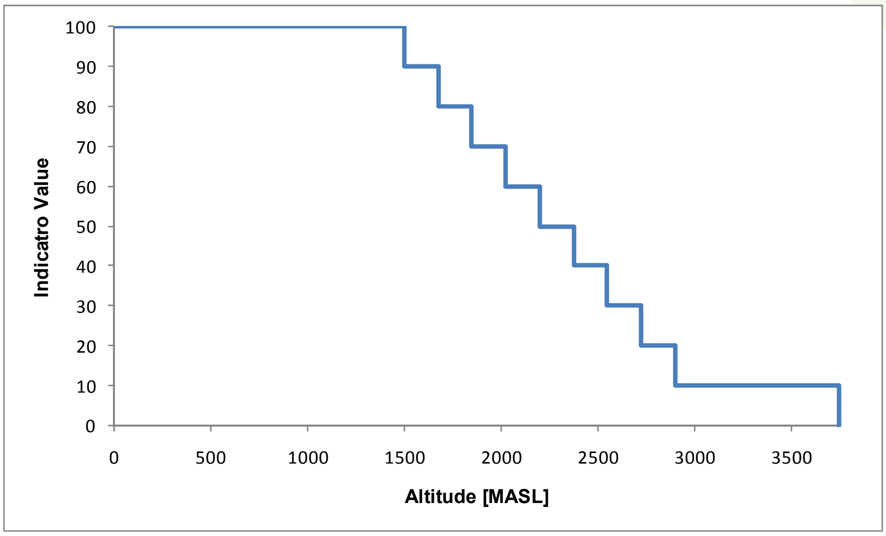
Landform	Classification
Valley	100
Flat Surface	100
Mid Slope	0
Hilltop	100

table 9: Classification Landforms

- Altitude

Altitude	Classification
- 1500	100
1500-1675	90
1675-1850	80
1850-2025	70
2025-2200	60
2200-2375	50
2375-2550	40
2550-2725	30
2725-2900	20
2900-3750	10
>3750	0

table 10: Classification Altitude



Graph 3: Classification Altitude

8.5 Infrastructure

Definition

The explanation of this indicator reads as follows: “To evaluate the impact of diverse infrastructure on ecological integrity.”[27]

Realisation

In this indicator structures that were not part of the analysis in the Fragmentation indicator (8.3 Fragmentation) were taken into account. These were linear buildings that fragment the landscape only in a discontinuous or a periodical way for example ski slopes or cable cars. Nonlinear structures were not part of this indicator.

The indicator was composed of the following infrastructure buildings (detailed describtion of data sets in appendix A):

- power lines
- ski slopes
- ski lifts
- cable cars
- avalanche barriers
- embankments

The indicator is based on the classified distance to the infrastructure buildings. The distances to the infrastructure objects in the maximum impact radius from each point of a 10 m raster was calculated. The distances were summarized per point. The indicator raster was derived from this point raster.

Classification

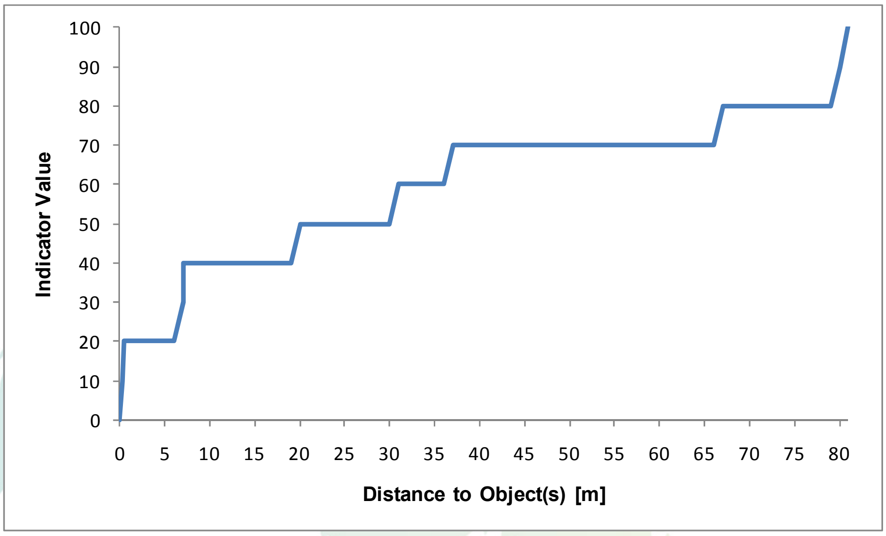
Each cell was classified by the summarized distances to the infrastructure elements. The radius as well as the classification of the final indicator value was specified based on experts opinions (questionary in appendix C).

- Maximum impact Radius: 80 m
- Indicator classification:

Distance to Objects [m]	Classification (0-100)
0	0
0.4	10
0.5	20
7	30
20	50
31	60
37	70
67	80
80	90
81	100

table 11: Classification Infrastructure Indicator

[27] Plassman, G. (2009)



Graph 4: Classification Infrastructure Indicator

8.6 Landscape heterogeneity

Definition

The explanation of this indicator reads as follows: “To define capacity of step stones for migration of species in an area”[28]

Realisation

For this indicator the land use data sets oft the several regions were used (detailed describtion of data sets in appendix A).

As they were described as the best predictors of dispersal success [29]the following two key figures were calculated for the characterisation of the landscape heterogeneity:

- Landscape Shape Index (LSI): Ratio of sum of edge lengths to minimum total length of edge of a constant reference area. LSI has the minimum value of one if the examined area consists of one single landscape patch and increases with the number of different patches.

$$LSI = \frac{\sum edges}{edge_{min}} \qquad \Sigma edges = sum\ of\ edges\ in\ metres \quad edge_{min} = edge\ of\ constant\ reference\ area\ in\ metres$$

- Patch Cohesion Index (COHESION): “Measures the physical connectedness of the corresponding patch type.” “Patch cohesion increases as the patch type becomes more clumped or aggregated in its distribution; hence, more physically connected.”[30]

[28] Plassman, G. (2009)
[29] Schumaker, N. (1996)
[30] Gustafson, E. J. (1998)

$$COHESION = \left[1 - \frac{\sum_{j=1}^{n} p_{ij}}{\sum_{j=1}^{n} p_{ij}\sqrt{a_{ij}}}\right]\left[1 - \frac{1}{\sqrt{A}}\right]^{-1} \cdot (100)$$

p_{ij} = perimeter of patch ij
a_{ij} = area of patch ij
$A = total\ area$

LSI and COHESION were applied as a moving window operation.

Applied in this way the meaning of LSI coresponds with Edge Density (ED) which is the relation between total length (m) of edge in landscape and total landscape area (m2) per hectare.

$$ED = \frac{E}{A} \times 10'000$$

E = total length (m) of edge in landscape
A = total landscape area (m^2)

In both cases the sum of edges is divided by a constant value. For LSI it is the perimeter of the moving window for ED it is the area of the moving window. This difference lead to different values which are more suitable for the classification. Therefore ED was applied instead of LSI in this indicator.

COHESION and ED develop opposite, therefore they were realized in two seperate indicators.

The calculation is based on the following landscape elements:

- common natural landcover types
- different wood types
- biotope mappings
- hedges, shrubs
- water bodies
- wetlands
- extensive and low intesive agriculture landcover types

All seminatural and natural landscape elements were categorized in different classes where as all agricultural elements were summarized to one class. All artificial elements were classified as background value and were not considered in the calculation.

Classification

The classification of the ED values as well as the COHESION values is based on reference areas.

For the ED some areas known for its high quantity of structure elements were chosen. For the COHESION parts of landscape with large homogenous areas were chosen as reference.

These were areas within the tirolan, the southtirolian and the engiandinian region.

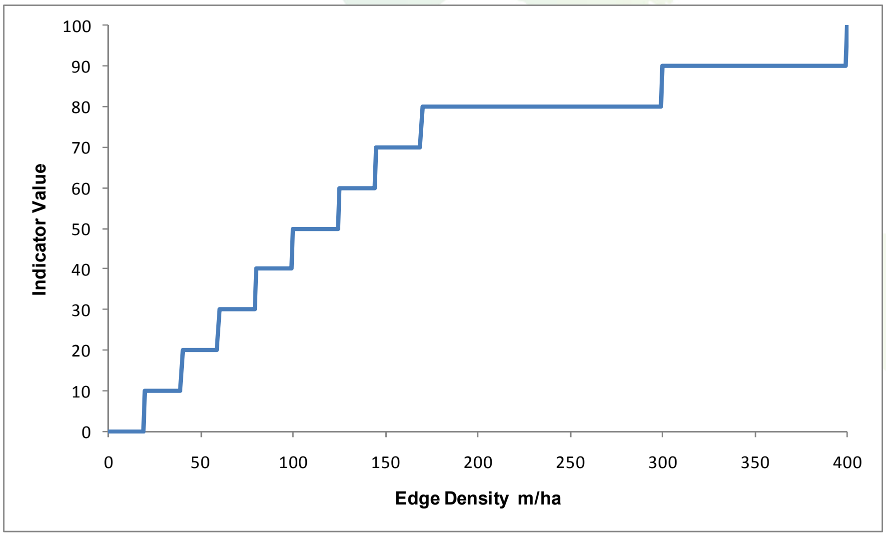
The following break values were set based on the reference area values.

ED	Indicator Value (0-100)
0	0
20	10
40	20
60	30
80	40
100	50
125	60
145	70
170	80
300	90
400	100

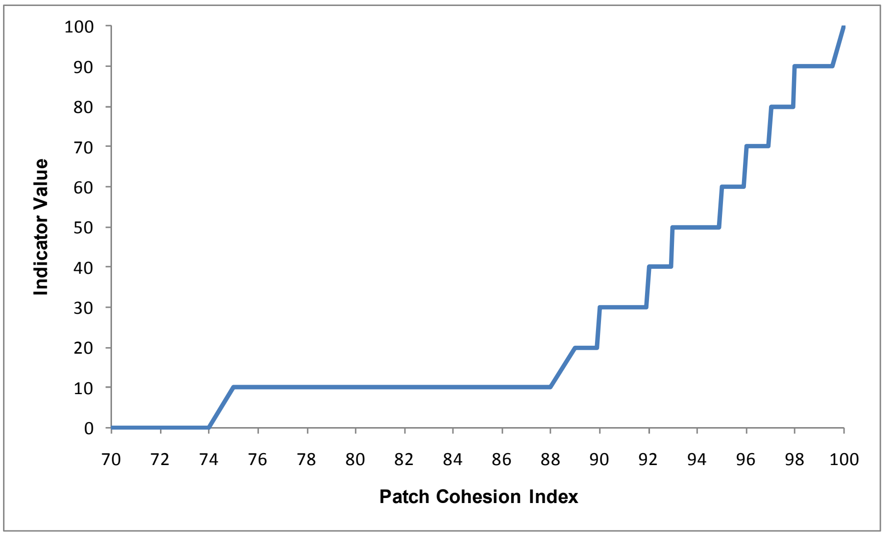
table 12: Classification Landscape heterogeneity – Edge Density

COHESION	Indicator Value (0-100)
0	0
75	10
89	20
90	30
92	40
93	50
95	60
96	70
97	80
98	90
100	100

table 13: Classification Landscape Heterogeneity – COHESION



Graph 5: Classification Edge Density



Graph 6: Classification Patch Cohesion Index

8.7 International Protected Areas

Definition

The explanation of this indicator reads as follows: "To define if in the concerned area already a positive attitude and measures towards ecological integrity exist."

Realisation

The indicator consists of this protected areas which tends to a global scale (detailed describtion of data sets in appendix A):

- Natura 2000 sites
- national & regional natural parks
- biosphere reservation
- Natural Monuments
- UNESCO Natural sites

They were classified according to the type of protection respectively the IUCN category.

Classification

The classification was based on expert opinions (questionary in appendix C). Where the question was: Which type of protection benefits most the continuum?

Protected Area Type	Classification (0-100)
Natura 2000	80
Biosphere reservation	60
protected River Area	80
IUCN Cat. I, II	90
IUCN Cat. III, V	60
IUCN Cat. IV, VI	70

table 14: Classification Environmental Protection Indicator

8.8 Land use planning

Definition

The explanation of this indicator reads as follows: "Evaluate future developments which could have consequences for ecological connectivity"

Realisation

In this indicator negative as well as positive consequences of land use planning were evaluated.

It is based on elements of the communal land use plans, on measures which are not primary intended for natural conservation and on protected areas that tends to a more local scale which are not of that comprehensive character like the areas in the indicator 8.7 International Protected Areas (detailed describtion of data sets in appendix A):

Negative Developments

- Residential expansion zone
- Industrial expansion zone

- Construction zone, construction readiness in 5 years
- Construction zone, construction readiness in 5 to 15 years
- Planned roads
- Planned railways

Positive Developments

- Communal land use planning: Restricted areas, Danger zones
- Biotopes
- Nature and landscape conservation areas
- Wildlife rest & reserve areas
- Environmental restoration
- Special protected Areas

Classification

These measures were classified by its type on expert opinions (questionary in appendix C). Where the question was: Which type of measure benefits most the continuum?

Type	Classification (0-100)
Ban Zone	60
Biotope	60
Nature & Landscape Conservation areas	80
Wildlife Rest Areas	60
Wildlife Reserves	60
Rest Areas	60
Special protected Areas	80
Environmental Restoration	70
Danger Area	50
No Developments	20
Negative Developments	0

table 15: Classification Land Use Planning Indicator

8.9 Ecological Measures

The explanation of this indicator reads as follows: “To define if in the concerned area already a positive attitude and measures towards ecological integrity exist.”

Realisation

The measures in this indicator are on very local level often located on only a few parcels or smaller spatial entities. They are mostly based on contracts with private people.

For the classification the measures were divided into the following thematic types:

Type	Explication Examples
Biotope Conservation	conservation of, caring measures for waters, wetlands, dry grasslands and pastures
Species Conservation	establishment of rest areas conservation of habitats on buildings assistance measures for chosen species
Structures	conservation, care of structures recreation of structures
Agriculture	extensifications species development programmes (e.g. arable sanctuary)
Forestry	establishment of woodland reserves conservation, care of particular woodland types
Technical Measures	e.g. green bridges, passages for small animals
Environmental Education Public Relations	realisation of ecological measures with school classes, firms, families etc. Workshops, Articles

Classification

These measures were classified by its type on expert opinions (questionary in appendix C). Where the question was: Which type of measure benefits most the continuum?

Type	Classification (0-100)
Biotope Conservation	70
Species Conservation	80
Structures	70
Agriculture	80
Forestry	90
Technical Measures	60
Environmental Education Public Relations	70

THIS PROJECT IS CO-FUNDED BY THE EUROPEAN REGIONAL DEVELOPMENT FUND

9 Dataprocessing

9.1 Population

Tirol

For the tirolian part of the pilot region Rhaetian Triangle there were no classified residential areas available. The information about the site density was derived by the process describe in chapter 8.1 Population.

Autonom Province Bozen, Southtirol

The population indicator in this part of the pilot region is based on the objects of the following four classified residential areas of the land use data set Realkarte 2001:

Densely urban built-up area, sparsely urban built-up area, densely rural built-up area, single houses and scattered settlement

As in the official describtion of the classes of land use there is no specification of the degree of sealed surface of the several classes the values in table 2: Classification of residential areas were assigned.

Lombardia

The population indicator in the Lombardian part of the pilot region is based on the objects of the following four classified residential areas of the land use data set DUSAF, Current Land Use:

dense residential areas, medium to dense residential areas, discontinuous residential area, less dense residential area, scattered residential area

The classes dense residential and the medium to dense residential areas were summarized to one category. The following degree of sealed surface were asigned to the categories according the official data documentation.

Category	ratio of sealed surface
dense residential areas & medium to dense residential areas	80 % - 100 %
discontinuous residential area	50 % - 80 %
less dense residential area	30 % - 50 %
scattered residential area	10 % - 30 %

table 16: Residential area categories Lombardia

Province of Trento

The population indicator in the Trentinian part of the pilot region is based on the objects of the following three classified residential areas of the land use data set USGR22, Current Land Use:

Continous urban, discontinous urban, single houses

According the official data documentation the following degree of sealed surface were asigned to the categories:

Category	ratio of sealed surface
Continous urban	80 % - 100 %
discontinous urban	50 % - 80 %
single houses	- 10 %

table 17: Residential area categories Trento

Lower Engadin

For the swiss part of the pilot region the population data are already available per hectare. Combined with the tourist data these values were directly used for the indicator.

Region	Base Data
Berchtesgaden	uncl. built up areas
Salzburg	uncl. built up areas, buildings, residential zones (urban planning)
Kaernten	uncl. built up areas, buildings
Niederösterreich	uncl. built up areas, buildings
Steiermark	uncl. built up areas, buildings
Alpi Marittime	uncl. built up areas, buildings
Mercantour	cl. built up areas

table 18: base data of the Population Indicator

Spatial dissagregation

The process consisted of the following steps. The flow chart is added in appendix D the following numbers refer to the numbers on the chart.

1 spatial join: intersect
This intersection assignes the residential areas to the municipal areas.

2 select residential areas by category
For each residential category a new data set is built.

3 dissolve by municipalities
The areas for each site density category are summarized per municipality.

4 join field
The summarized areas per category and the population and tourists data are attached to one data set.

5 calculation of k with the ArcGIS Field Calculator

The factor k is individual for each municipality depending on the ratio of the residential categories. It describes the relation between the site density and the population density.

$$k = \frac{\text{population}}{\sum_i A_i * \text{site\_density}_i}$$

population: total of inhabitants per municipality
A_i: percentage of area of the site density class i in hectares

6 join field
The factor k was assigned to the residental area categories by municipalities.

7 calculation of population density per hectare with the ArcGIS Field Calculator
By the factor k for each municipality the population density per hectar is calculated for the several categories.

$$\text{pop.dens. per hectare} = k * \text{site\_density}_i$$

8 merge polygons
The polygons with the assigned population density values are joined together.

9 conversion polygon to raster

9.2 Fragmentation

The effective mesh size was calculated with the Function Meff Surface of the Meff-Tool for ArcGIS[31].

The tool needs as inputs the bounding Geometry of the investigated area and the patches these are the unfragmented spaces within the perimeter.

For the Inputs the following preparing steps were necessary:

- Selecting the barrier geometry out of the Land Use or Land Cover data sets
- Buffering the linear elements of the barrier geometry, the following buffer sizes were used:

Element Type	Buffer size
Highway	20 m
Primary Road	10 m
Railway	10 m
Secondary Road	8 m
local road	5 m
dams	10 m

table 19: Buffer sizes Fragmentation Indicator

- Union of all the barrier geometry elements
- Cutting the bounding geometry with the barriers to get the patches

For the meff surface analysis the following parameters were chosen:

- Total Area: equal area of subregions
- Analysis Method: (5)...by one sided relation[32]
- Sample Grid Geometry
  Distance (D) : 500 m , Circle Radius (R) : 355 m
  The Radius was chosen in the way that it leads to an area-wide analysis (figure 5: Fragmentation: area-wide analysis).

$$R = \sqrt{2 * \left(\frac{D}{2}\right)^2}$$

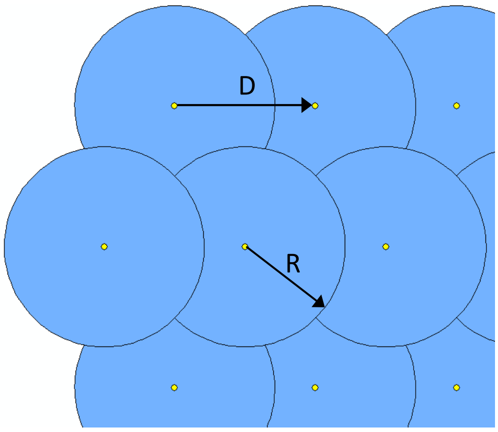


figure 5: Fragmentation: area-wide analysis

- Surface Raster: Cell Size = 100

[31] Lang, C., Schwarz, H.-G., Esswein, H. (2008)
[32] Schwarz, H.-G., Esswein, H. (2006)

9.3 Infrastructure

For the infrastructure indicator for each cell of a raster the distances to the surrounding infrastructure objects had to be calculated. The final indicator is the classification of the sum of reciprocal distances for each cell respectively point.

The data processing was done by the following steps:

- Creating a 10 m sample point grid within the influence range of the infrastructure objects ca. 500 m.
- Buffering the linear elements of the infrastructure objects, the following buffer sizes were used:

Element Type	Buffer size
aerial cable, phone cable, low-voltage line	10 m
high-voltage line	14 m
ski lifts	10 m
cable cars	14 m

table 20: Buffer sizes Infrastructure Indicator

- Calculating distances from each point to each infrastructure object within a radius of 80 m
- Setting calculated 0 values to 0.001 m
- Calculating the reciprocal values of the distances, and summarizing it per point
- Conversion point to raster with the summarized worths as raster value

9.4 Landscape Heterogeneity

The two landscape indices ED and COHESION were calculated with the Fragstats Tool for ArcGIS[33]. The input for the Fragstats Tool is a landscape raster, whereas the several landscape elements are represented as different raster values.

Therefore the different polygon datasets with the landscape elements had to be merged to one single polygon layer. This layer was converted to the input landscape raster.

Due to the memory limits the Fragstats tool allows only a limited cell size. The following cell sizes were used.

Region	Cell Size	Region	Cell Size	Region	Cell Size
GR	20	BGD/SBG	20	ISE	20
TI (RT)	20	APB (HT)	10	MEC	20
LO	25	KAE (HT)	15	APM	20
TR	25	TI (HT)	10	NOE	10
APB (RT)	25	SBG (HT)	5	STMK	10

table 21: Cell sizes for the Landscape herogeneity indicator

The following run parameters were set in the Fragstats tool for the calculation:

- Input Data Type: Arc Grid
- Analysis Type: Moving Window, Square, Radius: Cell Size x 10
- Patch Neighbours: 8 Cell Rule

[33] University of Massachusetts (2010)

10 Problems and solutions

10.1 Holes between different data sets

Due to different capturing methods and different definitions of boundaries, there are holes between subregions data sets (figure 6). To overcome this problem a nearest neighbour interpolation was done in these areas. The base of the interpolation was the classified indicator raster.

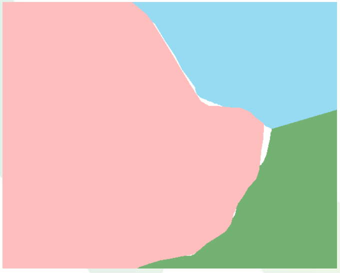


figure 6: holes between different data sets

10.2 Boundary effects by the moving window analysis

For the Indicator Landscape Heterogeneity a moving window analysis was carried out. This analysis processes every cell of an input raster by performing a calculation with itself and its neighbouring cells covered by the analysis window. Only these cells were processed where the analysis window is completly filled out with data cells. This rule makes the boundary effects in the analysis results. The affected range is about the size of the analysis window.

The regions inside the perimeter between the subregions were interpolated like the holes between different data sets. The regions at the outside of the Pilot Regions were left as no data value.

A better solution would be to use a larger extract of the input data. In the most cases the data was limited to the pilot regions boundaries, so this solution could not be applied at the moment.

10.3 Artefacts in digital elevation model

In digital elevation model artefacts can arise through interpolation or assembling during the creation process. These artefacts were reduced through a low pass filtering of the DEM. The filtering was done with the filter tool of ArcGIS, it was applied three times.

10.4 Fragmentation through analysis border

The results of the fragmentation analysis are influenced through the Pilot Regions borders. The borders do not exists physically and fragment the remaining areas in a wrong way. To solve this problem the barrier geometry must be extend in such a way that the wrong fragmented areas are represented in its entire extent.

11 Data quality index

The data quality index describes the correspondence with the conditions of the indicator values. It is an assessment of value of the results respectively the statements of the CSI analysis.

Only together with this value the CSI can be interpreted correctly and serves as basis of discussion since the conclusions and decisions can be ensured by this value.

11.1 Requirements

Initially the requirements whose fullfilment is described in this index had to be defined. This was already done partially in chapter 3 Problem Definition.

There the importance of the spatial precision was made clear, because of the local character of the decisions.

In addition the ecological system which is analysed is a spatial continuous phenomenon so the data should be available in the same continous way for a realistic model. Due to that the availability in terms of completeness is documented in the index.

The contact to reality is beside other factors mainly influenced by the up-to-dateness of the data. This is the third quality requirement that is expressed in the quality index.

Further important quality elements like consistency or correctness are expected to be controlled in advance and remained constant during the analysis process.

11.2 The Model

As already mentioned before the quality is represented by the following four quality characteristics:

- geometric resolution
- thematic resolution
- completeness
- actuality

The quality value (QV) expresses the fulfilment of the quality characteristics in a percent declaration.

The quality values were multiplied if there was a combination of different datasets within one indicator.

For the calculation for each quality characteristics the following parameters had to be defined:

- evaluated quantity: X
- minimum value (QV = 0 %): min
- maximum value (QV = 100 %): max

Because of the large differences for the thematic level these parameters had to be defined per Indicator for the thematic resolution.

The complete calculation is added in Appendix E.

11.3 The Parameterization

- Geometric resolution

  X: accuracy & resolution of original data, resolution of resulting raster
  min.: 105 m, minimum project target = 100 m
  max.: 0.1 m, maximum accuracy of common GIS Datasets

- Thematic Resolution

Indicator	X	min	max	remarks
TOP	resolution/accuracy elevation in metres	20 m	0.05 m	min/max: experience value, latest stat of the art
COH/LSI	number of different landscape patches	2	60	min: minimum for realisation, max: latest state of the art for land cover data sets
ENV	number of protected area classes	1	4	min: minimum for realisation, max: from the classification modell
FRA	number of elements of the barrier geometry	1	7	min: minimum for realisation, max: from the classification modell
INF	number of infrastructure objects	1	6	min: minimum for realisation, max: from the classification modell
LAN	number of land use classes	1	100	min: minimum for realisation, max: latest state of the art for land cover data sets
LAP	number of developments	1	15	min: minimum for realisation, max: latest state of the art for land cover data sets
POP	reference for the population data (hectare, municipality, etc.)	-	-	classification by reference type

- Completeness

  X: degree of coverage of the datasets
  min: 0 %, no data
  max: 100 %, complete coverage

- Actuality

  X: age of the data
  min: 1997, 12 years max. update cycle for periodical updated official data
  max: 2009

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