PLUREL

Land Use Relationships in Rural-Urban Regions

Module 2

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Modelling Approach for Response Functions on Agricultural Production, Ecological Regulation and Recreation Function

D2.3.9 and D2.3.10

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SIXTH FRAMEWORK PROGRAMME

Contents

Abstract

In the past, urban areas have grown significantly in Europe and still continue to grow. This process has a strong direct and indirect impact on e.g. agriculture and the ecology of a region. Direct impacts are e.g. reduction of agricultural area and indirect impacts relate to changes in the landscape, e.g. the degree of fragmentation, which negatively impacts on biodiversity and recreation. The aim of the study at hand is to quantify the relationship between artificial surface (urban area) and different indicators for agricultural production, habitats and ecological regulation as well as for recreation. Thus the strength of the impact of urban growth on these indicators can be estimated for the present and the future.

The chosen methodology embraces on a regression analysis between artificial surface and each indicator, using values for the NUTSX regions in the year 2000 for the whole of Europe. For more than 35 variables, regression models (response functions) were developed. The most robust regressions are part of the European Urbanisation Impact Model (EUI Model).

The results show that the regressions are enhanced by integration of regional typologies (coastal regions, central regions, southern regions, etc.), so eight response functions can legitimately be used. As urban areas mainly grow at the expense of agricultural land, the impact of urbanisation on agriculture is mainly negative. The same is deduced for the complexes of ecological regulation and biodiversity as well as for recreation. Still some indicators correlate in a positive way with urbanisation – e.g. the Standard Gross Margin – representing the productivity of farms. This is probably due to highly economically valuable crops from horticulture.

Classification of results/outputs

For the purpose of integrating the results of this deliverable into the PLUREL Explorer dissemination platform as fact sheets and associated documentation please classify the results in relation to spatial scale; DPSIR framework; land use issues; output indicators and knowledge type.

Spatial scale for results: Regional, national, European	European
DPSIR framework: Driver, Pressure, State, Impact, Response	Pressure – State - Impact
Land use issues covered: Housing, Traffic, Agriculture, Natural area, Water, Tourism/recreation	Agriculture, Natural area (Landscape, Biodiversity, Habitats), Water, Tourism/recreation
Scenario sensitivity: Are the products/outputs sensitive to Module 1 scenarios?	YES
Output indicators: Socio-economic & environmental external constraints; Land Use structure; RUR Metabolism; ECO-system integrity; Ecosystem Services; Socio-economic assessment Criteria; Decisions	ECO-system integrity; Ecosystem Services
Knowledge type: Narrative storylines; Response functions; GIS-based maps; Tables or charts; Handbooks	Response functions; GIS-based maps; Tables or charts;

How many fact sheets will be derived from this deliverable:	**3**

Introduction

In the recent decades Europe has experienced a rapid process of urbanisation (EEA 2006). Extension of the transportation infrastructure network and the massive distribution of individual car use represent major urbanisation factors (Dielemann and Wegener 2004; Newman and Kenworthy 1998; Schrijnen 2000). Diminishing commuting time distances, decreasing transportation cost and the overall increase of accessibility within regions contributed to the expansion of the functional urban regions, resulting in urban transformations. The conversion of open, non-built-up area into low density settlement area, well-known as "urban sprawl" represents the most recognised type of urban growth basically along urban edges and beyond (EEA 2006; Thomas et al. 2008). Especially those sub-urban and counter-urban developments are most influencing in rural areas (Buciega et al. 2009; Russell 2006).

European regions have experienced considerable urban development, causing large scale impacts and transitions in landscapes. Particularly high quality farmland close to urban agglomerations has been converted for settlement purpose or limited in agricultural operations. Ecological regulation and buffering functions of landscape and its soils are degraded, whereas also the quality of life aspects, like recreation is affected. As these processes take mainly place in peri-urban areas, the research focus is on those regions.

RF embrace mathematical expressions of causal relationship between urbanisation as driving force and changing states of landscape functions within peri-urban regions. RF are based on the hypothesis, that urban growth affect landscape's capacity to provide different kinds of functions, such as agricultural production, regulation function and biodiversity as well as recreational functions.

Derived from European regional database, RF consists of a regression analysis of indicators (variables and indices related to landscape and land use) in dependence of urbanisation (Fig.1). Indicator values allow insights into the current state of the landscapes in European regions and their capacity to fulfil the abovementioned functions. The RF as a result from the modelling process provides the opportunity to calculate future values for each indicator. They are used for ex ante assessments based on the scenario storylines for years 2015 and 2025.

The study is produced in PLURELs WP2.3. The WP aims at development and application of response functions and the deliverable at hand aims to describe this development for certain issues. Thus the response functions for agricultural production, habitats and ecological regulation as well as for recreation are presented. The results of WP2.1 (the RUR Sub-delineation, D2.1.4) are included in the response functions. Further on the results of WP 1.4 (RUG model results for artificial surface changes for the four PLUREL scenarios, D1.4.3) are implemented with the regression models and thus deliver values for the indicators on agriculture, ecology and recreation for the four scenarios for the available time steps (2015, 2025). The respective deliverable providing maps on the scenario situations for selected indicators is D2.3.14/2.3.15. The resulting assessment by the EUI Model is fed into the iIAT-EU from WP5.3 (D5.3.1), one of the end-products of PLUREL. In this context, also the results of WP2.2 (typology on governance and spatial planning, D2.2.1) can be used as a filter for the results of the response functions.

The response functions not only contribute to end-products iIAT-EU, but also to the XPlorer with three factsheets and to the Policy Brochure, where certain development trends of agriculture, etc. are analysed.

The report is structured as follows:

The Abstract and Introduction section is followed by the description of the analytical framework. It provides a deeper insight into the driving forces of urbanisation, an overview over landscape and other indicators important to describe the relationship between urbanisation and agricultural production, etc. as well as the necessity to regionalise the model with the help of regional typologies. Then, the three different landscape functions for which the response functions of this deliverable are developed are described with regard to their peri-urban relevance. The next section embraces the data mining and generation as well as the methodology for the response functions – which are based on a regression analysis. Afterwards the results are presented and interpreted. In the following section the model is discussed, and strength and weaknesses are pointed out. The last sections encompass the utilised literature. In the annex, variables which can serve as indicators are listed, further literature on their relation to urbanisation, maps for the different analysed variables and regional typologies are displayed, the iterative indicator selection is visualised and the regression functions with graphs for the different indicators are shown.

Analytical Framework

Response Functions (RF) describe the relationship between the driving force urbanisation and the resulting changes of landscape and environment and enable the evaluation of the effects of these changes. The analytical framework for the modelling work of the RF consists of two main elements:

The analysis framework resorts to the *Driver-Pressure-State-Impact-Response* (DPSIR) approach developed by the European Environmental Agency (EEA 1999), with its wording adapted to the needs of PLUREL. It is based on the assumption of causal relationships between **trends and driving forces** (drivers/pressures) on the one hand and **changes** of the status quo (state) and their related **effects** (impacts) on the other hand. The response is the reaction of the political decision making.

To describe the *changes of landscape and environment*, the RF make use of landscape functions. Enhancing the understanding of categories, such as production, services and functions in landscape, several analytical frameworks have been developed contributing to the impact assessment and land use decision making processes (Bastian and Röder 1996; Costanza 1998; de Groot 1992; Pérez-Soba et al. 2008). In general they embark on conceptualisations of natural processes and functions in landscapes and on their interaction with society with regards to sustainable development. The different frameworks have in common that functions and services are grouped around economic production, environmental regulation and social recreational and cultural dimensions of sustainability.

This approach is based on the *notion of landscape functions*, an approach evaluating landscapes as they developed historically and represented in their actual land cover according to their ability to provide *societal required and demanded functions*. There are numerous attempts to structure these groups of functions. There is some agreement on the classification of functions, representing the perspectives of sustainable development. According (i) *Economic Production Functions (Agriculture)*, (ii) *Ecologic Regulation and Habitat Functions* as well as (iii) *Social and Recreation Functions* of landscapes are distinguished.

Driving Force - Urbanisation

As described in the introductory section, urban land use change represents a major pressure for sustainable development, landscapes and environment.

In the RF, urbanisation represents the independent variable, which influences environmental and landscape variables.

The degree of urbanisation is measured as area share of artificial surface on the total area of a region.

Variables of Landscape Structure, Land Cover & Land use intensity

Landscape - Structure

Based on ideas for *landscape ecology*, the structure and configuration of a landscape influences its capability to provide landscape functions.

Landscape structure is assessed through *landscape analysis* of spatial information on land cover. Different properties of landscapes, such as cohesion, fragmentation, diversity and evenness are analysed using geographical information systems (GIS). Depending on their interpretation, variables of landscape structure can be used to analyse the landscape situation and its functions, especially regarding ecological integrity.

Landscape Diversity: In landscape research diversity serves as a collective term for different perspectives on ecosystems. The landscape ecologic view aims at the spatial assessment of the outer, horizontal diversity of ecosystems and its mosaics. The structural diversity (composition and configuration) of land use and vegetation stock plays a crucial role for the value of habitats. Landscape diversity has also an impact on recreational quality of a landscape, due to its importance for the evaluation of landscape scenery. Within the framework of impact analysis of urbanisation processes, diversity represents an important issue since landscape diversity is affected by expanding urban areas and infrastructure (Antrop and Van Eetvelde 2000).

Landscape Continuity/Connectivity: Defines the ability of the landscape to facilitate flows of energy, matter, individuals or genes (Bierwagen 2007).

To analyse landscape structure several geometry based *landscape indices* have been developed and can be processed with the GIS-based tool "FRAGSTATS" (McGarigal et al 1994). These indices depend on the scale of the input data and are all applicable on European level with CLC. The limitation of CLC data is that it only regards the dominating land-use types. A report of the European Commission gives an overview of the variety of indices of landscape structure (EC 2001). As the first one the index of *Patch Density (PD)* represents a simple structured expression about the number of patches in a certain area (e.g. number per 100 ha). Further area related indicators are *Edge density (ED)* measuring the length of edges (perimeter of patches) and the number of different land use classes. More complex indicators are the *Shannon's Diversity Index (SHDI), Shannon Evenness Index (SHEI), Simpson's Diversity Index (SIDI) and Simpson's Evenness Index (SIEI)* as well as *Interspersion and Juxtaposition Index (IJI)*. Shannon's Diversity index integrates a compositional as well as a structural component by analysing land use types (LT) and the areal distribution. It increases with the number of LT as well as with the evenness of the LT distribution. SHEI, SIDI, and SIEI are similar indices. The IJI takes the spatial configuration and neighbourhood of the patch types into consideration. The more patch types of an area are equally adjacent to each other and are so directly neighbouring, the higher the IJI.

Fragmentation: Transportation infrastructure transforms the physical conditions on and adjacent to it, creating edge effects with consequences that extend beyond the time of the road's construction. Along with linear structures also area settlement structures account for fragmentation effects (Siedentop 1999). At least physical characteristics of the environment are altered by roads: soil density, temperature, soil water content, light, dust, surface-water flow, pattern of runoff, and sedimentation. In general ecological and recreational impacts can be distinguished being negatively influenced by fragmentation, due to anthropogenic disturbance, wind and light intensity, noise, pollution of salt, heavy metals, dioxins (Trombulak and Frissell 2000; Seiler 2001; Spellerberg 1998). Moreover Seiler (2001) distinguish five categories of ecological effects through infrastructure: habitat loss, disturbance, corridor, mortality and barrier effects. Fragmentation represents one of the major causes of species loss in Middle-Europe (Jaeger et al 2001). But also the influence on recreational issues through detraction of landscape image, barrier effects and disturbance of nature-based recreational activities are seen as important (Schrijnen 2000, Dosch 2002, Antrop 2004).

Landscape – Land Cover

The next group embraces variables, which concern the topic of land cover. The occurrence of certain land covers in a region is the basis for some landscape functions and is directly affected by the conversion into urban area. The assessment of land use/cover always depends on the spatial level of analysis. The RF approach is characterised by the idea of considering land use changes on a regional/landscape level (Pauleit et al. 2005). Land cover is basically distinguished into *agricultural area, pastures, forest and semi-natural areas, wetlands* as well as *urban green and leisure area*. Agricultural area and pastures are indicators for the economic production function; whereas forest and semi-natural areas and wetlands indicate the habitat function. Most of them can also be the place for recreation, but first of all the urban green and leisure areas can provide this function.

Land use - Farm Structure

Urbanisation effects agricultural production in different ways beyond conversion of land for settlement and infrastructure purposes. It even more influences the *structure of agricultural production*, which is discussed later in the context of the agricultural production function of landscape.

Structure of farming relates to *farm sizes*, *socio-economic characterisation of farms and farm holders*, such as diversification, yields and revenues, extensivation, organic farming, land abandonment, etc.

In the first place all variables belonging to this category tell something about the economic production function of a region. Still many variables have a broader meaning. The number of part-time farmers, for example, can be an indicator for a more recreation-oriented way of farming.

Land use – Environmental Quality

The last group of variables included into the response function modelling process focuses on those, addressing the state of environment and quality of life. Those variables are *Emission values, surface water quality, Important Bird Areas and the number of endangered species, values for the Green Background Index* as well as measures for the *shared edges of urban space and green or urban green area.*

Annex I provides an overview of the variables (and explanations) used for the modelling process and the maps of Annex III show the regional values for each variable.

Regional Characteristics

Between Northern Scandinavia and Portugal, the shores of Ireland and the Rumanian Walachia, between Inner London and the Spanish Extremadura, regions in the European Union are characterised by a large bio-physical and socio-economic variability and different appearance of landscapes (Meeus 1995). The EU embraces regions of deep rurality, urbanised regions as well as metropolitan regions (Steinnocher et al. 2008; European Commission 1999). This diversity inherently brings about different response pattern of urbanisation and land use change onto landscape and ecosystem services. Already, different approaches to integrate the regional differentiation have been developed (Wascher 2005; Renetzeder et al. 2008). Here we attempted to operationalise the regional variability by making use of different typologies, which address the degree of urbanity as well as the spatial location within Europe (defined by the belonging to macro-regions) as well as border and coastal situations.

Typologies used: (i) the RUR typology: Regions predominantly characterised as urban, peri-urban or rural region (derived from a spatially explicit delineation approach); (ii) Coast location; (iii) Border Location; (iv) Belonging to a European Macro-regions (EU INTERREG regions like Baltic Sea, Alpine, etc.); (v) Belonging to Centrality Pentagon EU 27. All those typologies are shown in Annex IV.

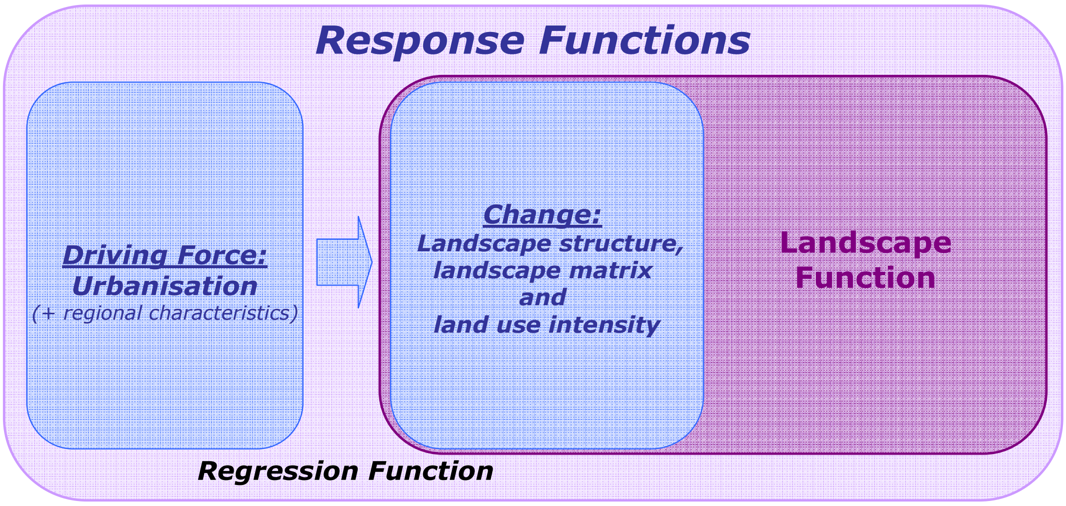

Fig. 1 – Response Function Modelling Scheme

Landscape Functions in Peri-urban Areas

Economic production function, ecological regulation function and social recreation function portrayed and discussed concerning their role in peri-urban areas. Particularly their responsiveness to landscape changes is outlined, providing the interpretation basis of RF.

Annex II provides a literature overview of empirical research on the relationship between landscape properties (structure, land cover, environmental quality) and landscape functions.

Economic Production Function

Historically, cities and urban areas depend on the surrounding *food production*, where arable production played an important role. With improvements in infrastructure, time distances and transportation costs decreased and continue to decrease. The necessity to provide the food supply for the urban area locally is not given anymore. In contrast the improved accessibility triggered the growth of the functional urban region, area with common real estate and work force market, which are spreading from the urban centres to the rural hinterland. Increasingly even former rural areas become subject to urbanisation processes. Driven by output related subsidies, the European rural countryside of the second half of the 20th century has been characterised by intensive fordist agriculture use, even in peri-urban areas.

Limited to its *food and fibre production* value, farmland was reduced to a reserve of space for the urbanisation demand. Consequently in the non-built-up peri-urban area agricultural production experiences urban pressure through valuable farmland loss (EEA 2006). Urbanisation related land conversion basically takes place on agricultural area.

Adjacency to urban land use, such as housing, additionally generates *conflicts* e.g. through pollution, noise and odur (Bouraoui 2005; Agger 2001). Moreover limitations, such as operational restrictions through disruption of farm land by infrastructure network and small farm sizes (Gallent 2006; Péron and Geoffriau 2007), high land prices (Cavailhes and Wavresky 2003; Cathelinaud 1979) as well as legal constraints are at work in peri-urban areas and limiting operations and profitability (FAO 2007).

Despite and due to these limitations agriculture plays an important role for spatial development in the peri-urban fringe (von Münchhausen 2008). The ability for *innovative and flexible adaption* of production methods is particularly pronounced (Bryant 1984; Clouth 1998). This is especially the case for horticulture and fruit and vegetable production (Lohrberg 2001; Péron and Geoffriau 2007). Urban agglomerations provide advantages due to the proximity to the demand location.

The meaning of the *peri-urban location* of the agricultural production defined by its distance to the central city already described in classical model by Von Thünen enjoys a renaissance due to the increase in demand of urban dwellers for goods and services provided by the rural areas nearby (Heimlich and Anderson 2001). Based on French peri-urban case studies Fleury (2002) as well as Bernard and colleagues (2006) highlight the reinforced social relations between farmers and urban dwellers in peri-urban agriculture. Another aspect for peri-urban agriculture arises from concerns for food security. In the face of again growing global demand and prices for food, increasing energy and transportation costs as well as the growing urban demand for regionally produced agricultural products, the role of agriculture in peri-urban areas remain meaningful as a alternative approach (Norberg-Hodge et al. 2002; Holloway et al. 2007).

Nevertheless, today traditional functions of agriculture are replaced by new *non- or post-productive functions*, such as provision of amenities or hobby- and retirement-farming (Brandt and Vreje 2004; Van Huylenbroeck et al. 2005; Dewaelheyns and Gulinck 2008). From the landscape perspective the emergence of a post-fordist consumption and productive landscape pattern is discussed (Bergstrom 2005; Cazaux et al. 2007; Potter and Tilzey 2005). Exemplary for other urban regions, in his analysis of the peri-urban transitions in Belgium; Cazaux (2007) states that „the rural outskirts are no longer the monopoly of the agricultural business, which is correspondingly faced by multilateral exigencies of new neighbours and recreational visitors."

Ecologic Regulation and Habitat Function

With *ecological regulation and habitat* another major function is influenced by urban pressure. There are complex links between agriculture and natural environment. High levels of human activity, population density, soil sealing and emission volumes affect the ecologically valuable habitats, such as woodland (Arnberger 2006; Ode and Fry 2006; Jacsman 1998) and particular species (McKinney 2002; Blair 2004) in the peri-urban non-built-up area. At the same time through moderate urban density and heterogeneity of the landscape in sub-urban or peri-urban areas comparably high species densities are measured (McKinney 2002). Therefore urban ecologist (Donnelly and Marzluff 2006a; Miller and Hobbs 2002) highlight the importance of conservation efforts in these areas.

Green, unsealed open spaces provide valuable functions for the settlement areas. It is important for the regional *provision with drinking water* (Magnucki et al. 2004; Haase and Nuissl 2007), *soil protection* (Doichinova et al. 2006), *flood control* (Watts and Hawke 2003) and *moderation of urban climate* (Heidt and Neef 2008; Jenerette 2007) and is responsible for an important share of climate oriented *carbon sequestration* (Pataki et al. 2006; Nowak and Crane 2002). Derived from the metabolism and resilience debate, the local self-sustaining and provision of biotic and abiotic resources and toleration of alteration of framework conditions (Alberti and Marzluff 2004) gains increase attention.

Surface sealing: high relevance for hydrology and biodiversity. Environmental Effects of soil sealing: loss of soil functions, run-off, decreased evaporation, infiltration, groundwater recharge; increased above-surface temperature, less capability to cope with climate changes, metrological events. Vegetation takes up water and releases it again through evaporation. Sealed soil does not provide a substrate for plant life and does not fulfil the biodiversity related soil functions in general. On the other hand impervious surfaces prevent pollutants from entering soil (Scalenghe and Marsan 2009; Turner and et al. 2002).

Hydrological balance and soil functions: Soil functions are limited in urban areas, only few parts remaining natural as housing green, private gardens, street green, parks, churchyards, sports and playgrounds. Only those areas serve the recreation and groundwater recharge in city areas. Soils of urban green areas are generally artificially altered (groundwater dropping, disturbance of soil horizons, compression, eutrophication, contamination, soil sealing). Thus they are hardly able to fulfil their ecologic functions (Alberti 2005; Glugla and Fürtig 1997; Watts and Hawke 2003; Haase and Nuissl 2007).

Micro-climate regulation and air filtering: Temperature differences between city centre and hinterland, due to lowered wind speed and reduced solar radiation by vegetation shading buildings and evaporation from trees (Bolund and Hunhammar 1999). Vegetation contributes to air filtering and reduces air pollution, increase with more leaf area, trees more than bushes and grass (Givoni 1998).

Urban heat island: A phenomenon, known as "urban heat island," can raise air temperature in a city. It accelerates chemical reactions that produce high ozone concentrations and increasing air pollution. Natural ecosystems reduce these effects. Urban heat islands have a particular role in the context of global climate change as local effects are aggravated. Still the smog and haze can also lead to the reduction of solar radiation (Brazel et al. 2007).

Urbanisation represents pressure on *biodiversity* through alteration and destruction of habitats. Increasing fragmentation, transformation of habitats (natural replaced by human influenced/disturbed habitats); Change of species composition (parallel global homogenization and urban diversification of species in the urban/peri-urban sphere). High levels of human activity, population density, soil sealing and emission volumes affect the ecologically valuable habitats, such as woodland (Arnberger 2006; Ode and Fry 2006; Jacsman 1998) and particular species (McKinney 2002; Blair 2004) in the peri-urban area.

Nevertheless urban and peri-urban areas provide *specific habitat qualities* (heterogeneous land use structure, habitat niches, etc.) for numerous species, as mentioned before.

Social and Recreation Function

Another externality of peri-urban landscape is the *provision of natural amenities*. They are important for the quality of the living environment and improve the recreational capacity of an area and contribute to healthy, liveable and sustainable cities (Chiesura 2004).

Societal changes toward *leisure* and amenity orientation as well as the extended spatial reach of urban dwellers led to increasing recreational activity especially in proximity to settlement areas (Kretschmer et al. 2007). Open space is considered as most relevant for landscape bounded recreation and important for physical and psychological health. Thus urban areas have high importance for a region’s recreational potential.

The *preferences* for the availability and adjacency of amenities are analysed in numerous studies based on surveys and hedonic price models for woodland (Kaplan and Austin 2004; Mansfield et al. 2005; Gundersen and Frivold 2008; Tyrväinen et al. 2005), farmland (Beasley et al. 1986; Kan et al. 2008; Torquati et al. 2008) and other natural amenities (Cavailhes et al. 2009; Hartman et al. 2003; Ready and Abdalla 2005; Wu 2002). Especially aesthetic values of the rural environment are identified being motive to visit or move to the non-built-up peri-urban area (Bouraoui 2005; Knowd 2006).

Conflict situations between agricultural production and the provision of amenities occur first of all in areas of intensive agriculture. The absence of a complex, diverse landscape pattern or crop mix, intensive agriculture can hardly provide amenities (Cavailhes et al. 2009; Fleischer and Tsur 2009).

Methodology and Database

Data Mining

Data sources embraced data from EUROSTAT (2000/2003), EEA (2000) and other data sources, such as Bird Life International. Land use data was derived from Corine Land Cover (CLC 2000) and, for the dynamic modelling, also from CLC1990.

Landscape Analysis

A landscape analysis has been conducted using the software package of ArcGIS 9.2 and FRAGSTATS – Calculation of indices for landscape structure on the basis of Corine Land Cover year 2000. Moreover some calculations were conducted using Microsoft Excel and Access.

Regression Analysis static approach (2000)

- Objective: Analysis of the relationship between urbanisation and environmental / landscape variable values.
- Hypothesis: (i) The degree of urbanisation within a region accounts for at least a part of the state of environment and (ii) Due to the pan-European approach the statistical relationship can be considered as generic relationship and accordingly used to model future states of environment and landscape.
- Spatial focus: NUTSX regions (combination of NUTS2 and 3, for more equally sized regions)
- General approach: focussing on one particular point in time - 2000 (status quo approach for non-land cover related variables).
- OLS Regression Analysis performed in software package SPSS 12.
- Independent variable: Share of artificial surface/Share of settlement area.
- Dependent variable: ~40 environmental variables.

Regression Analysis Dynamic Approach (Land cover change 1990-2000)

Relationship land-cover related variables (agricultural area, forest area, green urban and leisure area) to urbanisation (artificial area/settlement area) analysed through regression analysis of annual changes.

Enhancement of Model Quality

- Objective: Introduction of regional characteristics using regional classifications and typologies can improve the model quality (R^2).
- Hypothesis: The relatively stable regional framework (socio-economic and bio-physical conditions) accounts for an important share of the value distribution of environmental and landscape variables.
- Operationalisation of regional typologies as dummy variables within the regression modelling.

Selection of regions predominately characterised by peri-urban area

Objective: the effects of urbanisation take place particularly in urbanised regions. Thus the statistical relationship between independent variables (share of artificial surface) and dependent variables (for agriculture, environment and recreation) is strongest in urban and especially in peri-urban areas.

Database: Typology of Rural Urban Regions (RUR) based on the spatial subdelineation provided by project partner AIT. The six RUR categories (urban high and urban low density; peri-urban high and peri-urban low density; rural high and rural low density) were combined to three classes (urban, peri-urban, rural). The categories "glacier, rock, water" as well as "no data" were excluded. The area share of each class on each NUTSX region was calculated. All NUTSX regions with share values equalling or above the median class value were assigned to the respective class. Thus some NUTSX regions can belong to one or more or no class.

Selection of cases: NUTSX regions which are predominantly peri-urban (50% of all cases, based on the median).

Iterative selection of suitable variables as indicators

The choice of indicators is based on literature knowledge and iteratively selected according to data availability and consistency (see Annex V):

1. List derived from literature
2. Availability check
3. Statistical significance check
4. Model quality check

Results

Regression functions for more than 35 variables were calculated for all NUTSX regions. Only 2 showed a significant R^2 in the beginning (first R^2 value in Graphic of Annex V). The R^2 got better, when focussing only on the peri-urban NUTSX regions based on the RUR typology (second R^2 value in Graphic of Annex V). By integrating regional typologies, the R^2 was enhanced in >45% of the cases (last R^2 value in Graphic of Annex V). The integration of the urban and rural types form the RUR typology enhances almost 30% of the R^2. Further typologies, representing the geographical location within a European macro-region (e.g. Baltic Sea, Alpine, Mediterranean), border or coastal region, additionally enhanced the R^2 of the variables, so 23% of the variable reveal reliable regression models. For the typologies see Annex IV.

In general, for the analysis of urbanisation effects on the analysed landscape functions, the high share of rural NUTS X regions compared to the more urbanised ones negatively affects the equal sample distribution. By the integration of the RUR typology, this inequality can be levelled to some extent, as the enhanced R^2 shows (Annex V).

Annex VI shows the graphs for the regression functions based on the initial variable values, so without any corrections like taking the logarithm or including typologies. This is due to the impossibility of displaying the typologies in the graph. It has to be kept in mind as many of the graphs do not look accurate. Furthermore in Annex VI the regression functions themselves are given as well as the different R^2. The first R^2 addresses the regression function for the peri-urban NUTSX regions. The second R^2 shows the enhancement of the function by integrating the urban and rural types into the function (typology group A) and the third R^2 shows the changes when also including other typologies into the calculation (typology group B).

The Effective Mesh Size is the indicator with the strongest direct relation to artificial surface. For all other indicators the location in Europe has a stronger influence on the indicators development, as the enhanced R^2 values by integrating regional typologies show.

Economic Production Function

The RF for the average annual change of *Agricultural Area* shows a decrease the stronger the artificial surface increases in a region. This supports the general expectation that cities grow mainly at the expense of agricultural area. The equation also shows that the reduction of Agricultural Area gets lower, the more rural (RUR3) and the more in the South and in the Baltic area the region is situated.

In contrast, the RF for the *Standard Gross Margin* rises the more the region is urbanised. Many cities are built up next to highly fertile soils, which can explain this linear function. Also intensive specialized production (e.g. horticulture) is typical closer to urban areas. The regional differentiation of the equation reveals a tendency of increase of Standard Gross Margin the more the region is situated at the coast or in Western Europe.

The number of farm holders decreases the more the artificial surface increases – thus does the number of *part- time farmers*. The equation shows a positive influence only from the "Archimedes" regions, which are Greece and Southern Italy.

It can be seen that the RF all have different R^2 values and are differently enhanced by the typologies. The most reliable R^2 values are assigned to the *Agricultural Area* change indicator.

Ecologic Regulation and Habitat Function

Landscape Shape Index (LSI) describes the perimeter-to-area ratio of a landscape. Its value declines with increasing urbanisation, indicating fewer edge situations in the landscape, which represent important habitat elements for many species. Besides from the rurality of a region, the indicator values are influenced by the regions centrality in Europe, its closeness to borders and to the Mediterranean coast, as indicated in the equation.

The *Interspersion and Juxtaposition Index (IJI)* gives insights in the intermixing of different land cover patches of a landscape. The RF for *IJI* reveals that urban growth contributes to evenness of patch dispersion. Even distribution is supposed to enhance biodiversity as it supports species which occupy different habitats. The equation shows that the IJI is higher, the more central the region is located.

Effective Mesh Size (MESH) measures landscape continuity indicating probability of individuals to meet in landscape fragmented by traffic network. The RF shows a decline of mesh sizes with growth of urban area in a region. MESH is promoted in coastal regions, except from Greece and Southern Italy. This might be due to the high share of little islands, Greece consists of.

Probability of ecological valuable habitats in a region is addressed by the *Green Background Index (GBI)*. Its values decrease the more urbanised a landscape becomes. Also some rural regions show low values due to intensive anthropogenic land use. Whereas Atlantic and Alpine regions have favourable conditions for the GBI, the Eastern part does not.

The number of *endangered bird species* increases with growing urban area of a region. This is partly supported by research results showing the high biodiversity of cities. At the same time only certain species are able to adapt to anthropogenic disturbances, leading to species homogenisation in urban areas. The equation itself has low R^2, even when including typologies. Only the North Sea has a further positive influence on the No of endangered birds. This shows that there are still some important variables/typologies missing in this regression function.

Emission of heavy metal and other pollutants represent an important environmental topic. The RF reveals significantly rising emissions, with increasing share of urban area in a region, indicating a concentration of emission sources in the agglomerations. Again the R^2 values for this equation are rather low. The equation shows that in coastal regions, more Heavy Metals are emitted, besides from the Baltic Sea Area.

The typologies generally enhance the R^2. It can be seen that the RF all have different R^2 values and are differently enhanced by the typologies. The most reliable R^2 values are assigned to *MESH* and *LSI*.

Social Recreation Function

The *LSI* describes the perimeter-to-area ratio of a landscape. The RF decreases towards the more urbanised areas. That means that the perimeter is higher in rural areas. Those borders are often paths used for recreational purposes. Besides from the rurality of a region, the indicator values are influenced by the regions centrality in Europe, its closeness to borders and to the Mediterranean coast, as indicated in the equation.

MESH is a measure for the continuity of a landscape. The higher the effective mesh size, the lower the fragmentation by traffic network. The graph for the RF shows that the fragmentation increases the more artificial surface a region consists of. Thus forming barriers and disturbing recreation activities. MESH is promoted in coastal regions, except from Greece and Southern Italy. This might be due to the high share of little islands, Greece consists of.

The probability of ecological valuable habitats in a region is measured by the *GBI*. Its values decrease the more urbanised a landscape becomes. Still also some more rural regions show low values due to intensive anthropogenic land use. Whereas Atlantic and Alpine regions have favourable conditions for the GBI, the Eastern part does not.

The typologies generally enhance the R^2. It can be seen that the RF all have different R^2 values and are differently enhanced by the typologies. The most reliable R^2 values are assigned to *MESH* and *LSI*.

Discussion

Inductive reasoning

Due to large scale data gaps in historical data a trend projection derived from a time-line analysis was not possible in the given situation, except for the indicator of agricultural land use change.

The chosen approach is instead based on an inductive reasoning approach, assuming that a relationship analysed over a large entity of units (270 predominantly peri-urban NUTSX regions) for one certain time (year 2000) is meaningful also in the specific case for future situations (2015, 2025) of all NUTSX. We transfer the peri-urban RF to all regions as they are the present urbanisation centres and they suit best for the analysis of urban development.

The broader approach – to consider all NUTSX regions, no matter to which RUR region they predominantly belong to, as described in the method section, lead to only two RF with a considerable R^2. This implies that the method was far too general, trying to combine converse processes in one equation. Therefore it was reasonable to focus on the peri-urban regions, the main issue of the project, only.

Model Regionalisation

To some extent the modelling approach tends to level modelled indicator values of regions more strongly as they are observed. The integration of regional information as additional explanatory variable therefore significantly enhanced the model, as the R^2 demonstrate.

The integration of the two other RUR types (urban and rural) as dummy variables leads to higher R^2 values, showing that the described relationship between amount of urban area and indicators is also depending on the type of urbanisation.

The RUR typology as used in this approach does not cover all NUTS X regions due to the median value approach. Certain regions are never above this value and are thus not classified. This is especially pushed in regions with high amounts of areas belonging to the missing categories "no data" and "rock, glacier, water".

Strength

The chosen modelling scheme represents an opportunity to approach the highly complex and dynamic process of urbanisation and the (inter-) related landscape transitions.

To the good of keeping the modelling task manageable and the results suitable for interpretation and brief information, the approach intentionally simplified the actual interrelationships to allow coarse assessment of future impacts on landscapes.

The regression analysis itself reveals interesting insights in the driving force – changes -relationship between urbanisation and landscape.

Limitations

Large time line and spatial gaps exist on statistical data concerning completeness among units and spatial level. This seems to be a general problem, when working at the pan-European level (Vihinen, H. et al. 2006).

The geographical land use data of CLC is characterised by a coarse spatial resolution, limiting interpretation of landscape analysis results.

Administrative units have been chosen as units of analysis. So problems with differences of spatial extent and outlying variable values emerge: Few regions are characterised by extreme values either concerning the degree of urbanisation or the indicating variable.

Numerous important variables to describe the state of landscape and environment have proven non-sensitive to urbanisation on the regional level by showing only very low R^2 values (see Annex V).

The available pan-European typologies are not able to cover all the regions in the EU in an equal way. Thus some regions have a stronger impact in the regression analysis than others.

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Annex I – List of Variables

No.	Variable Name	Variable Description
Landscape - Structure		
1	Patch Density (PD)	Patch density (PD) expresses number of patches on a per unit area basis that facilitates comparisons among landscapes of varying size. It is a measure of landscape configuration, describing the spatial character of a landscape. Without information about the area and spatial distribution of patches.
2	Edge Density (ED)	Edge density (ED) reports edge length on a per unit area basis that facilitates comparison among landscapes of varying size. It is a measure of density of patch edges in the landscape.
3	Landscape Shape Index (LSI)	Landscape shape index (LSI) provides information on class aggregation/disaggregation or clumpiness of a landscape. It calculates the ratio of sum of edge lengths to total area for a landscape measured against a circle standard.
4	Shannon's Diversity Index (SHDI)	Shannon's diversity index (SHDI) represents a measure of diversity in community ecology, applied here to landscapes. It increases with class number and equally distributed area sizes of patches.
5	Simpson's Diversity Index (SIDI)	Simpson's diversity index (SIDI) is a diversity measure from community ecology applied to landscape diversity. The value of SIDI represents the probability that any 2 pixels selected at random would be different patch types.
6	Shannon Eve-ness Index (SHEI)	Shannon evenness index (SHEI) is a measure of landscape configuration, indicating the evenness of distribution of patches within a landscape.
7	Simpson Even-ness Index (SIEI)	Simpson evenness index (SIEI) is a measure of landscape configuration, indicating the evenness of distribution of patches within a landscape.
8	Interspersion and Juxtaposition Index (IJI)	Interspersion and juxtaposition index (IJI) is an index for spatial configuration of a landscape, which is based on patch adjacencies. It isolates the interspersion or intermixing of patch types.
9	Effective Mesh Size Index (MESH)	The index MESH is based on the probability that in a certain area two individuals could meet without barriers. It is a measure of cumulative patch area distribution and is interpreted as the size of the patches when the landscape is subdivided into S patches, where S is the value of the splitting index. It indicates the size of effective meshes, integrates extent and structure of the fragmentation by transportation infrastructure.
10	Non-interrupted low-traffic area	Index for remaining continuous open spaces; Considering main infrastructure network (railway and main roads) and settlement area as fragmenting elements
Landscape – Land Cover		
11	Share of Agricultural Area in %	The share of agricultural area within a region gives information on the potentially utilizable area for agricultural purposes. It is calculated on the bases of Corine Land

		Cover classes 211-244
12	Share of Green and Leisure Area on Urban Area in %	Green urban and leisure area embraces all kinds of artifical surfaces, which are dedicated to urban recreational purposes, like parks, golf courses, camping grounds, etc. It is calculated on the bases of Corine Land Cover classes 141 & 142
13	Share of Forest Area and Semi-natural Area	The share of forest area and semi-natural area in region is calculated on the bases of Corine Land Cover classes 311-335.
14	Share of Pasture Area in %	The share of pasture area in region is calculated on the bases of Corine Land Cover class 231.
15	Share of Wetland Area in %	The share of wetland area in region is calculated on the bases of Corine Land Cover classes 411-423.
Land use - Farm Structure		
16	Share of Farms < 5ha	Measure of small-scale farm structure
17	Share of Farms > 50ha	Measure of large-scale farm structure
18	Share of Agricultural Area with Arable land in %	Measure of intensive agricultural production
19	Share of Agricultural Area with Grassland in %	Measure of extensive agricultural production
20	Share of Agricultural Area with Vegetable Production in %	Specialisation on high value crops
21	Share of Land Abandonment (not available)	Non-used agricultural area.
22	Share High Nature Value Farmland (not available)	Covers dykes, groves, species rich grassland, etc. Source: EU2010 Biodiversity Indicators
23	Share of part-time farmers in %	Holder's being a natural person: work time <25%
24	Share of farm-holders, who are a natural person in %	Measure of ownership situation. It give the share of holder, who own the farm
25	Share of farms <2 ESU in %	Measure of extensive agricultural production
26	Share of farms >100 ESU in %	Measure of intensive agricultural production
27	Average Standard Gross Margin (SGM)	The SGM provides a measure of a holding's business size, irrespective of its area and intensity of production. Measure of agricultural income generation.
28	Area under Organic Farming (not available)	Environmental-oriented agricultural production
Land use – Environmental Quality		
29	Freshwater	Amount of freshwater potential in a region

	Quantity (not available)	
30	Index of volume of all emissions into water and soil (direct and indirect) and air in kg/ha/year	Index of cumulated and hazard-potential-weighted (thresholds) emissions; Indicates the degree of pollution of air, water and soil. Database: EPER dataset 2008, reporting year 2001
31	Index of volume of all emissions into water and soil (direct and indirect) in kg/ha/year	Index of cumulated and hazard-potential-weighted (thresholds) emissions; Indicates the degree of pollution of air, water and soil. Database: EPER dataset 2008, reporting year 2001
32	Index of volume of heavy metals into water and soil (direct and indirect) and air in kg/ha/year	Index of cumulated and hazard-potential-weighted (thresholds) heavy metal emissions; Indicates the degree of pollution of air, water and soil. Database: EPER dataset 2008, reporting year 2001
33	Index of volume of heavy metals into water and soil (direct and indirect) in kg/ha/year	Index of cumulated and hazard-potential-weighted (thresholds) heavy metal emissions; Indicates the degree of pollution of water and soil. Database: EPER dataset 2008, reporting year 2001
34	Index of Surface Water Quality	Index of the bathing water quality indicates the environmental quality of a region
35	Nitrogen Balance (not available)	Measure of soil emission volumes from agriculture. Source: EU2010 Biodiversity Indicators
36	Area Share of Important Bird Areas in %	The selection of Important Bird Areas (IBA) is achieved through the application of quantitative ornithological criteria, grounded in up-to-date knowledge of the sizes and trends of bird populations. The criteria ensure that the sites selected as IBA have true significance for the international conservation of bird populations, and provide a common currency that all IBA adhere to, thus creating consistency among, and enabling comparability between, sites at national, continental and global levels. (Indicates the presence of ecologically important habitats for species; Basis for FFH area protection; Ecological integrity)
37	Number of endangered birds per 100 km²	Measure of ecological integrity; Importance for the preservation of endangered species, Source: BirdLife International
38	Red List Index for European Species (not available)	Measure of ecological integrity; Importance for the preservation of endangered species; Source: EU2010 Biodiversity Indicators
39	Soil Erosion Risk Index (not available)	Regional average risk class for soil erosion.
40	Green Background Index	Indicator of naturality; Regional richness regarding natural land-cover types; Provided by the EEA. Aggregated Index of CORILIS components for "green" classes (Pastures & mixed farmland, Forests and transitional woodland shrub, Natural grassland, Heathland, Sclerophylous vegetation, Open space with little or no vegetation and Water bodies)
41	Ratio of Green	Measure of accessibility of urban dweller to green urban

	Urban Edge Length to Urban Area	area. Calculated as shared edge of CLC111/112 with CLC141/142 divided by area CLC111/112
42	Ratio of All Green Edge to Urban Area	Measure of accessibility of urban dweller to green urban area. Calculated as shared edge of CLC111/112 with CLC 231/243 divided by area CLC111/112. The total urban edge refers to the total length of the edge between urban fabric and all other land use classes in the landscape. Analysis of the composition of the total urban edge is used to identify the land cover classes that are directly adjacent to urban fabric.

Annex II – Literature Review on Landscape Functions

Landscape – Structure

Regions	***Impact on landscape function***	***Change of parameter***	***Change of functionality***	***Source***
Ohio/California, USA	Biodiversity	Increase of landscape diversity	Increase of species richness	(Blair 2004)
Agrarian landscape, North-eastern Germany	Biodiversity	Increase of structure	Increase of density breeding bird	(Kretschmer and Hoffmann 1997)
South-eastern England, UK	Biodiversity	Landscape structure	Effect breeding success of Barn-owls	(Bond et al. 2005)
City of Seattle, Washington, USA	Biodiversity	Urban-rural-gradient	Effect on breeding bird diversity	(Donnelly and Marzluff 2006b)
Ohio/California, USA	Biodiversity	Increase of landscape diversity	Increase of species richness	(Blair 2004)
Estonia	Biodiversity	Increase of landscape diversity	Nesting success related to landscape parameters	(Oja et al. 2005)
City of Vancouver, BC, Canada	Biodiversity	Landscape complexity	Increase of bird likelihood	(Melles et al. 2003)
Sauerland, Northrhein-Westphalia Germany	Aesthetics	Edge density among other ("diversity value")	Increase of diversity value of the landscape	(Kiemstedt et al. 1975)
	Aesthetics	Landscape diversity	Correlation of landscape diversity and aesthetic preference	(Hall 2005)
	Aesthetics	Clearance of natural landscape elements	Reduction of aesthetical potential	(Corell 1993)
Model	Local recreation	Edge density among other ("diversity value") $V = \frac{(W+3*G+N*Ge+}{1000}$	Increase of diversity value of the landscape	(Kiemstedt 1967)

	Local recreation	Agricultural complexity	Increases visual complexity	(Butler et al. 1998)
	Local recreation	High shape complexity, low forest contiguity and a high landscape shape index (LSI)	Increase in accessibility of forests	(De Clercq et al. 2007)
City of Birmingham, UK	Biodiversity	Urban greenways, linear habitats	Dispersion of plants, invertebrates, dormice and water voles	(Angold et al. 2006)
North Carolina, USA	Biodiversity	Expansion of urban greenways <50m, 100m, >300m)	Increasing forest bird diversity	(Mason et al. 2007)
66 urban areas in the USA	Biodiversity	Change in landscape connectivity	Non-linear relationship between habitat and connectivity loss	(Bierwagen 2007)
	Biodiversity		Movement of animals across the landscape	(Dawson 1997)
Sweden	Biodiversity	Landscape connectivity as property of natural landscape	Increase of breeding bird communities	(Mortberg and Wallentinus 2000)
	Soil function & hydrology		Absorption of run-off	(Dawson 1997)
	Micro-climate		Moderation of micro-climate	(Dawson 1997)
Mountainous South-eastern Australia	Biodiversity	Increase of fragmentation	Varying respond of woodland birds	(Watson et al. 2005)
Western USA	Biodiversity	Increase of fragmentation	3 of 6 bird species correlate positive to fragmentation	(Leu et al. 2008)
Summit county, Colorado, USA	Biodiversity	Type of urbanisation	Clustered development with lower impact on wildlife species	(Theobald et al. 1997)
Rural Ontario, Canada	Biodiversity	Increase of road density	Positive effect on mouse population	(Rytwinski and Fahrig 2007)
Switzerland	Biodiversity	Increase of fragmentation	Provision of valuable habitats and migration corridors	(Giulio and Nobis 2008)

Helsinki	Biodiversity	Fragmentation	Woodland edges as habitats for carabids; trempling less negative	(Lehvävirta et al. 2006)
State of New York, USA	Biodiversity	Fragmentation	Bird community integrity was strongly related to roadlessness	(Glennon and Porter 2005)
Japan	Biodiversity	Fragmentation	Some bird depending on large continuous habitats due to probability to find breeding pairs	(Kurosawa and Askins 2003)
France	Biodiversity	Fragmentation	Homogenization of bird communities is strongly positively correlated to landscape disturbance and fragmentation	(Devictor et al. 2008)
The Netherland	Soil function & hydrology	Road network	Zinc load is increased in comparison to the background deposition	(Blok 2005)
City of Salo, Finland	Local recreation	Distance to urban areas	50% of the reasons not using urban parks was distance	(Tahvanainen et al. 2001)

Landscape – Land Cover

Regions	***Impact on landscape function***	***Change of parameter***	***Change of functionality***	***Source***
USA	Arable production	Increase of urban area	Decrease of agricultural area	(American Farmland Trust 2002)
USA	Arable production	Increase of urban areas	Reduced production high-value or specialty crops	(Heimlich and Anderson 2001)
Canada	Arable production	Increase of urban area	50% of the urbanised land converted from dependable agricultural land	(Hofman 2001)
France	Arable production	Urban-rural-gradient	High farmland prices in urban belt	(Cavailhes and Wavresky 2003)
USA	Biodiversity	Ex-urban development	native species have reduced survival and reproduction near homes, and native species richness often drops with increased exurban densities	(Hansen et al. 2005)
State Ohio/California, USA	Biodiversity	Increase of density of woodland	Increase of species richness	(Blair 2004)
City of Quebec, Canada / City of Rennes, France	Biodiversity	Urban-rural-gradient	Decrease of bird species density	(Clergeau et al. 1998)
City of Ottawa, Canada	Biodiversity	Urban-rural-gradient	Changing behaviour of water-birds	(Donaldson et al. 2007)
City of Leipzig, Germany	Biodiversity	Urban structure types	Impact on habitat suitability	(Mehnert et al. 2004)
City of Berlin	Biodiversity	Urban-rural-gradient	Change in food composition	(Kübler and Zeller 2005)
City of Berlin	Biodiversity	Urban-rural gradient	Positive correlation with bird species numbers	(Simon et al. 2007)
Region of Flanders, Belgium	Biodiversity	Urban-rural-gradient	Increase of species richness from rural areas over suburban to urban areas due	(Honnay et al. 2003)

			to alien plant species	
City and peri-urban area of Halle, Germany	Biodiversity	Urban-rural-gradient	Decrease of plant species richness	(Wania et al. 2006)
City of Soro, South Zealand, Denmark	Biodiversity	Urban-rural-gradient	Urban habitats with high beetle density for particular species	(Elek and Lovei 2007)
Swiss lowlands, Switzerland	Biodiversity	Urbanisation	Decrease of local flora species in peri-urban areas	(Stehlik et al. 2007)
Italy	Biodiversity	Urbanisation	50 % Italian avifauna in cities	(Dinetti et al. 1996)
State of New York, USA	Biodiversity	Urbanisation	Bird community integrity strongly to distinction between developed and undeveloped land types	(Glennon and Porter 2005)
City of Seattle, Washington, USA	Biodiversity	Urbanisation	Increasing share of urban LC leads to reduction of bird species	(Alberti and Marzluff 2004)
City of Seattle, Washington, USA	Biodiversity	Urbanisation	Low bird densities in urban areas compared to wildlands	(Donnelly and Marzluff 2006b)
City of Seattle, Washington, USA	Biodiversity	Urbanisation	Low bird densities in urban areas compared to wildlands	(Blewett and Marzluff 2005)
California & Nevada, USA	Biodiversity	Urbanisati0n	Human disturbance most important factor for richness surpassing habitat loss from development	(Schlesinger et al. 2008)
Southeast England, UK	Biodiversity	Urban density	Species richness and abundance decline with an increasing number of buildings.	(Evans et al. 2009)
Italy	Biodiversity	Increase of forest and urban area	Decrease of birds and mammal species	(Falcucci et al. 2007)
City of Berlin, Germany	Biodiversity	Urbanisation	Decline of domestic plants	(Kowarik 1992)
City of Berlin, Germany	Biodiversity	Urbanisation	Diffusion of non-domestic plants	(Kowarik 1992)

Arizona, USA	Biodiversity	Urbanisation	Relationships between butterflies and native vegetation to be less tightly coupled in exurban than in undeveloped landscapes	(Bock et al. 2007)
Mexico City, Mexico	Biodiversity	Urbanisation	Functional homogenization of bird communities	(Ortega-Alvarez and Gregor-Fors 2009)
5 cities, UK	Biodiversity, ecosystem performance	Urban density	Ecosystem performance declined with increasing urban density, but variability in the relationships	(Tratalos et al. 2007)
Canada	Soil Function	Urban area	Relationship between urban development and soil quality	
City of Leipzig, Germany	Soil Function	Urban area	Urban soils without regulation function	(Haase and Nuissl 2007)
Europe	Soil Function	Land use	Soil Erosion depending from biophysical parameters and land use	PESERA project
Germany	Soil Function	Urbanisation	Relationship between urban development and soil quality	Federal Bureau of Statistics Germany
State Baden-Wurttemberg, Germany	Soil Function	Urbanisation	Relationship between urban development and soil quality	(Lohrberg 2001)
City of Leipzig, Germany	Soil Function	Urbanisation	Negative influence on soil regulation function	(Magnucki et al. 2004)
City region Sofia, Bulgaria	Soil Function	Comparison urban and semi-urban area	Reduction of the buffering capability (clay, C-content) in topsoil of urban areas	(Doichinova et al. 2006)
State New York, USA	Soil Function	Urbanisation	High level of deicing salt pollution in semi-urban soils	(Cunningham et al. 2007)

City of Leipzig, Germany	Hydrology	Increase of settlement area	Negative influence on hydrologic balance	(Magnucki et al. 2004)
State Victoria, Australia	Hydrology	Increase of urban area	Recharge reduction and salination of groundwater	(Salama et al. 1999)
State Georgia, USA	Hydrology	Undeveloped → suburban land	Increase of stormwater lost from 4% to 15%	(Stephenson 1994)
City of Stockholm, Sweden	Hydrology	Soil sealing and high water extraction	Decrease of groundwater level	(Bolund and Hunhammar 1999)
City of Philadelphia, USA	Hydrology	Suburban development	Increases in solute transport as direct result of modern suburban development in the watershed	(Interlandi and Crockett 2003)
Coastal catchments in New Zealand	Hydrology	Urbanisation	Correlation between land use and hydrologic response (increased peak flow 300-900%, run-off)	(Watts and Hawke 2003)
Review	Hydrology	Soil Sealing	Disruption of hydrological systems	(Arnold, Jr. and Gibbons 1996)
Maryland, USA	Hydrology	Soil Sealing	Increase of peak discharges Reduced infiltration	(Barnes et al. 2001)
City of Phoenix, Arizona, USA	Micro-climate	Urbanisation	Increase of 3.1 degree Celsius in urban area	(Baker and et al 2002)
East England, UK	Biodiversity	Changing crop type in vegetable production	Crop type & organic farming influences ground beetle activity	(Eyre et al. 2009)
State Saxony, Germany	Hydrology	Arable land → pasture	Reduction of groundwater recharge capacity	(Bastian and Röder 1996)
Germany (Model MONERIS)	Hydrology	Agricultural production	Nutrient emissions (Nitrogen and Phosphorous) into ground and surface water	(Behrendt et al. 1999)
Germany	Hydrology	Agricultural production	water consumption	(Bach et al. 2003)
USA (re-	Hydrology	Agricultural	Surplus of Nitro-	(Carpenter

view)		production and urban land use	gen and Phosphorous	et al. 1998)
State of North Carolina, USA	Hydrology	Agricultural production	NO3-N and NH4-N increased along the drainage streams	(Dukes and Evans 2006)
Falenty, Poland	Hydrology	Agricultural production	Environmental Pollution. Manure heap was observable at a distance of over 35 m down the groundwater flow	(Rossa 2003)
State Hesse, Germany	Hydrology	Forest area: 42% → 13%; Agricultural area: 44% → 73%	Increase of run-off +8%	(Fohrer et al. 1999)
Israel	Aesthetics, natural amenities	Agricultural land	Provision of amenities by agricultural land use	(Kan et al. 2008)
Surrey, UK	Biodiversity	Leisure & open spaces	Greater variety of habitats on golf courses than intensively managed agricultural areas.	(Tanner et al. 2005)
City of Vancouver, BC, Canada	Biodiversity	Forest and park cover	Increase of bird likelihood	(Melles et al. 2003)
City of Orebro, Sweden	Biodiversity	Urban green spaces	no dead wood in city centre in contrast to the periphery	(Sandstrom et al. 2006)
State Hesse, Germany	Hydrology	Forest area: 42% → 13%; Agricultural area: 44% → 73%	Increase of run-off +8%	(Fohrer et al. 1999)
Region Andalucía, Spain	Aesthetics	Percentage of plant cover	Increase of visual quality	(Arriaza et al. 2004)
City of Halle, Germany	Local Recreation	Green open spaces		(Breuste and Breuste 1999)
Region Malmö-Lund, Sweden	Local Recreation	Forest	Accessibility and qualitative (area, tree cover, track network & designation) determine recreational attraction	(Ode and Fry 2006)

Vienna, Austria	Local Recreation	Forest	Different utilization pattern in urban & peri-urban forest	(Arnberger 2006)
State of North Carolina, USA	Housing	Forest and greenery	Greenness and forest cover add value to parcels; adjacency to institutional forests was not significant	(Mansfield et al. 2005)
City of New Brunswick, USA	Housing	Forest	Relationship between urban forest pattern and residential property value	(Hartman et al. 2003)
State of Michigan, USA	Housing	Forest	Availability of woodland important for housing decision	(Kaplan and Austin 2004)
Kane county, USA	Housing	Open spaces	Positive effect of proximate open spaces on housing prices	(Stewart and Krieger 1999)
City of Portland, Oregon, USA	Housing	Open spaces	Positive effect of open spaces and other natural amenities to housing prices	(Wu et al. 2004)

Land Use – Farm Structure

Regions	***Impact on landscape function***	***Change of parameter***	***Change of functionality***	***Source***
Denmark	Arable production	Increase in part-time farming	Full-time and part-time farms are involved in extensification of land use.	(Kristensen 1999)
Saratov, Russia	Arable production	Decreasing farm sizes (of large scale farms >1,000 ha)	Reduction of productivity	(Glebov et al. 2003)
Saratov, Russia	Livestock production	Decreasing farm sizes (of large scale farms >1,000 ha)	Reduction of productivity	(Glebov et al. 2003)
The Netherlands	Biodiversity	Organic vs. conventional farming	Most species did not differ in densities between organic & conventional farms	(Kragten and de Snoo 2008)
South-west England, UK	Biodiversity	Organic vs. conventional farming	Semi-natural habitats with similar plant abundance, richness or diversity in organic and conventional farms	(Gibson et al. 2007)
Roslangen, Sweden	Biodiversity	Organic vs. conventional farming	Bird, butterfly, herbaceous plant and bumblebees species abundance in organic famring	(Belfrage et al. 2005)
Saxony, Germany	Biodiversity	Intensivation of agriculture	Decrease of species	(Bastian and Röder 1996)
UK	Biodiversity	Intensivation of agriculture	Decrease of species	(Chamberlain et al. 2000)
East England, UK	Biodiversity	Changing crop type in vegetable production	Crop type & organic farming influences ground beetle activity	(Eyre et al. 2009)
Roslangen, Sweden	Biodiversity	Comparison between small (<52 ha) and large farms	200% increase in bird, butterfly and herbaceous plant species	(Belfrage et al. 2005)

		(>153 ha)	500% increase in bumblebees	
Kanton Zurich, Switzerland	Biodiversity	Comparison of grassland farms of different sizes and management practice	Management intensity explained 15% of variation in species composition at the plot level, farm size and animal density had no effect	(Weyermann et al. 2008)
The Netherlands	Soil function	Farm structure & management	Nitrogen and phosphate surplus stronger related to farm management than structure	(Ondersteijn et al. 2003)
Izmir province, Turkey	Aesthetics	Management type	Well-managed farms can enhance visual quality	(Kaplan et al. 2006)
	Local recreation	Farm size	Large scale farms without attraction for visitors, rather small farm sizes	(Butler et al. 1998)

Land Use – Environmental Quality

Regions	***Impact on landscape function***	***Change of parameter***	***Change of functionality***	***Source***
City of Halle/Saale & county of Saalkreis, Germany	Biodiversity	(Size) of protected areas	Higher number of butterflies, birds and lichens	(Knapp et al. 2008)
Province Flanders, Belgium	Biodiversity	Semi-natural areas in Urban/suburban park	Increase of biodiversity	(Cornelis et al. 2004)
Region Andalucía, Spain	Aesthetics	Amount of wilderness	Increase of visual quality	(Arriaza et al. 2004)
Germany (MODEL)	(Local) Recreation	Increase of naturalness	Increase of recreational potential	(Kiemstedt 1976)
Germany	(Local) Recreation	45% of all recreational sites in nature protection area	Recreational potential	Bundesamtes für Naturschutz (BfN) 1997
Izmir province, Turkey	Aesthetics	Degree of naturalness	Naturalness with positive effects of visual quality	(Kaplan et al. 2006)
(Model)	Housing	Natural amenities	Spatial heterogeneity of amenities related to the formation of development patterns	(Wu 2002)
South-eastern Australia	Housing	Natural amenities	Increasing relationship between amenities and in-migration	(Argent et al. 2007)

Annex III – Variable Values for European Regions

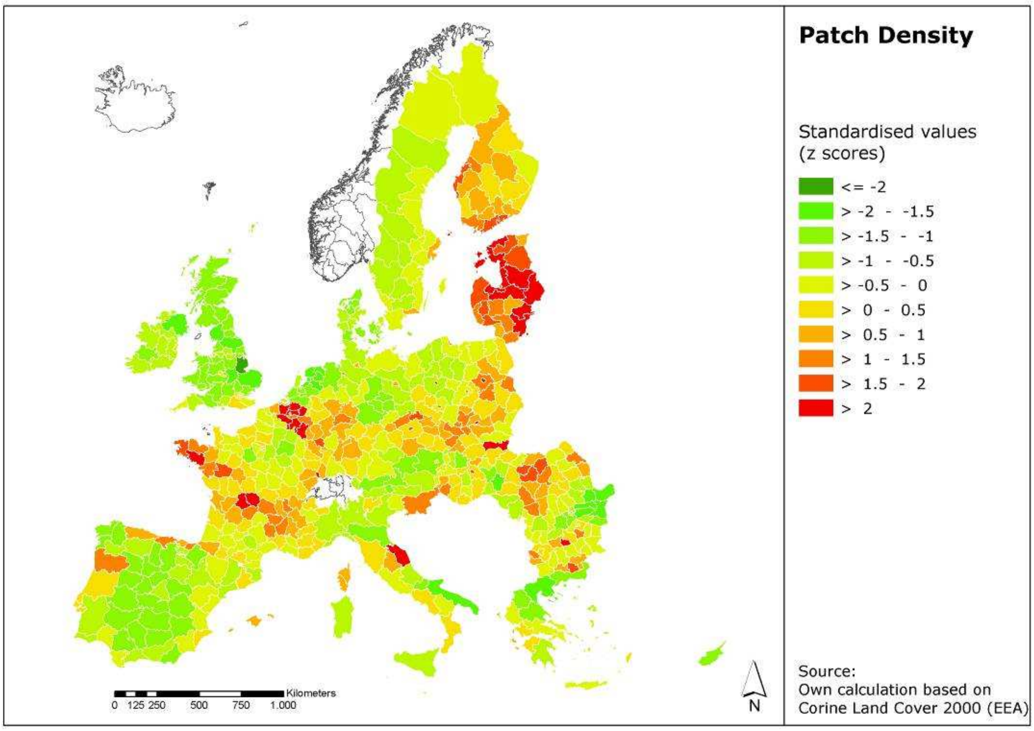


Fig. 3.1 – Patch Density (PD), based on CLC 2000

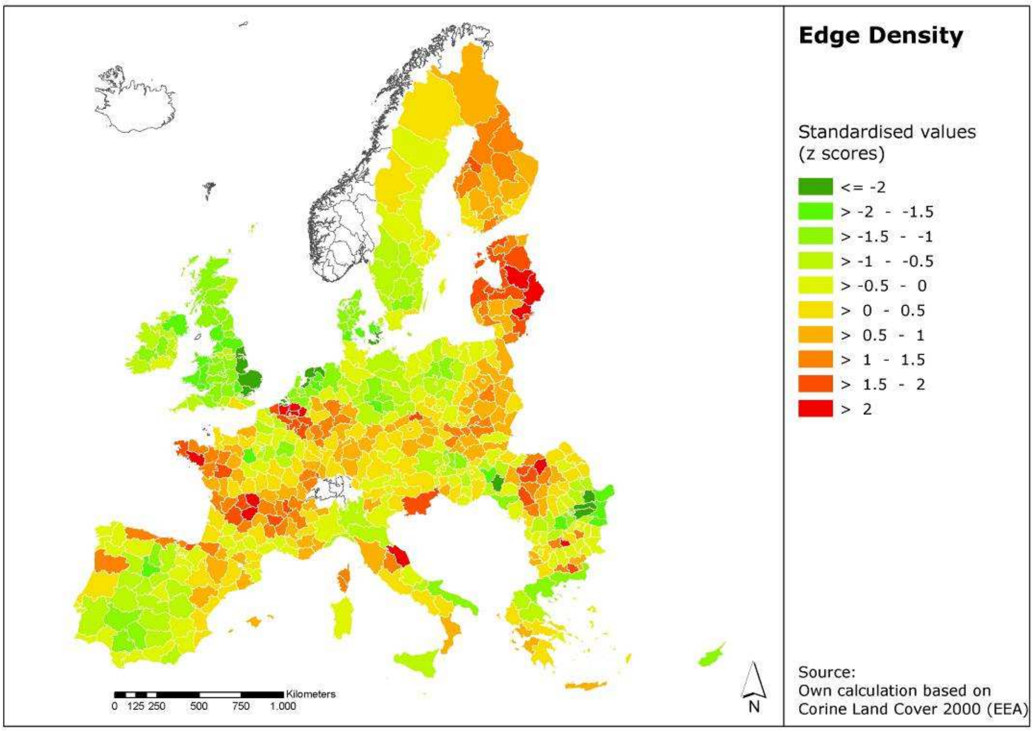


Fig. 3.2 – Edge Density (ED), based on CLC 2000

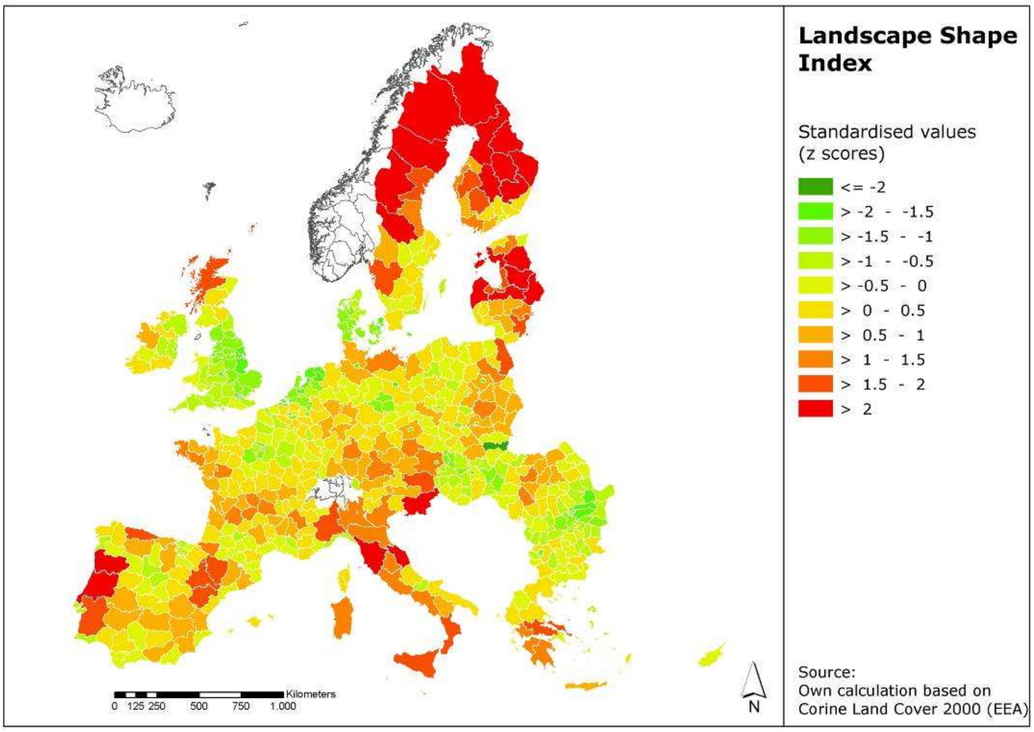


Fig. 3.3 – Landscape Shape Index (LSI), based on CLC 2000

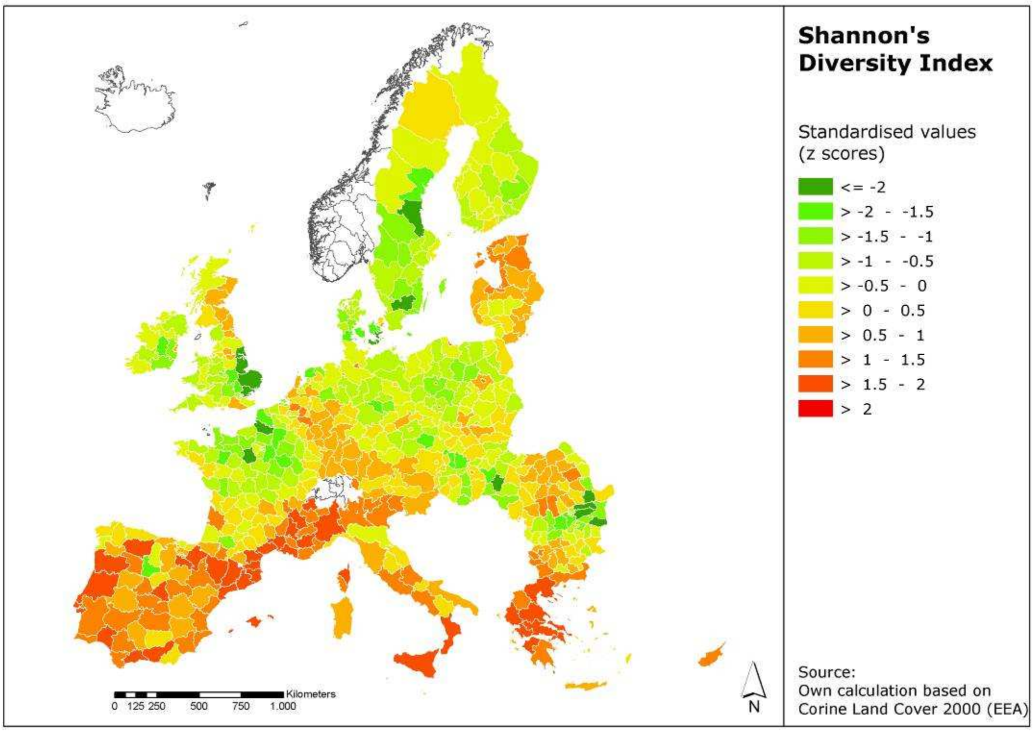


Fig. 3.4 – Shannon's Diversity Index (SHDI), based on CLC 2000

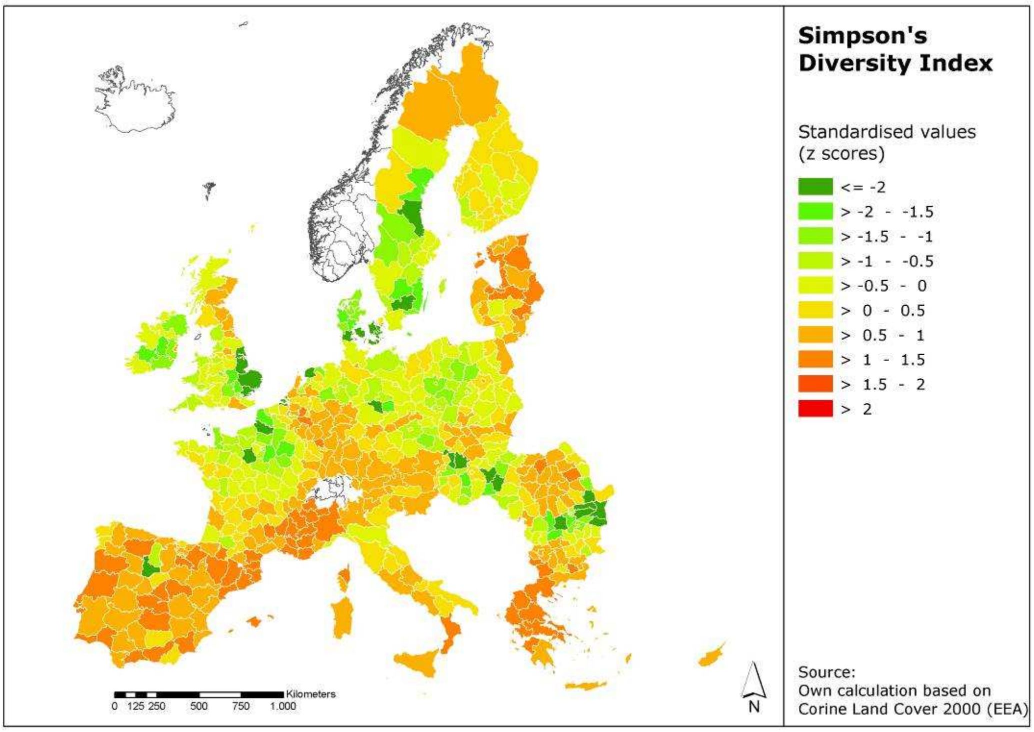


Fig. 3.5 – Simpson's Diversity Index (SHDI), based on CLC 2000

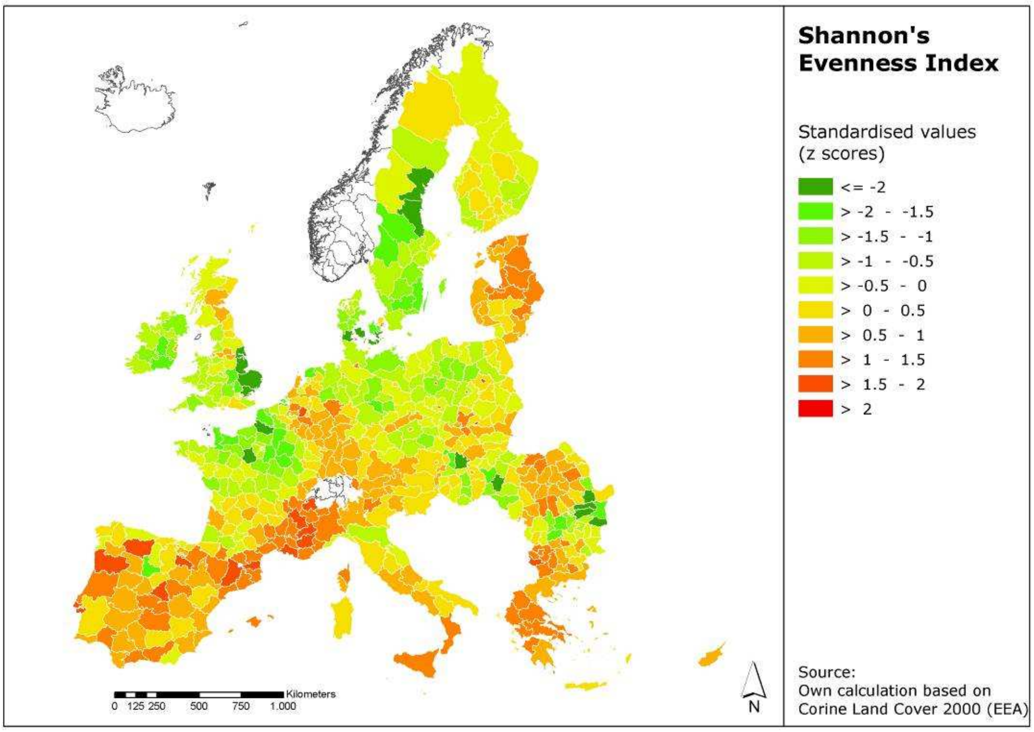


Fig. 3.6 – Shannon's Evenness Index (SHEI), based on CLC 2000

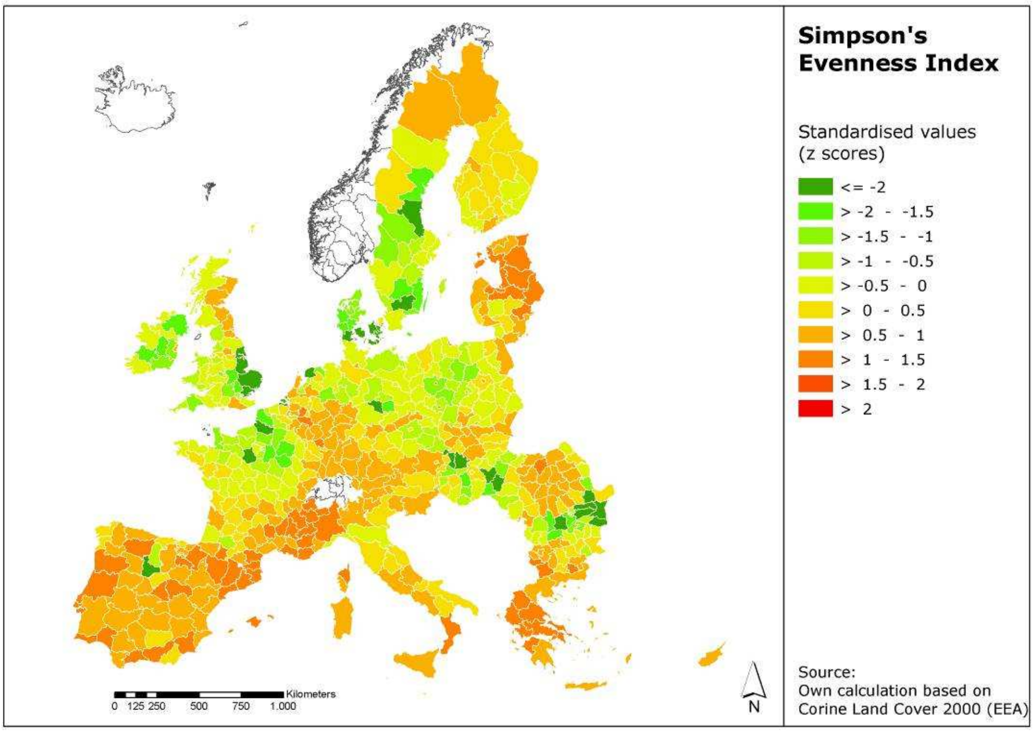


Fig. 3.7 – Simpson's Evenness Index (SIEI), based on CLC 2000

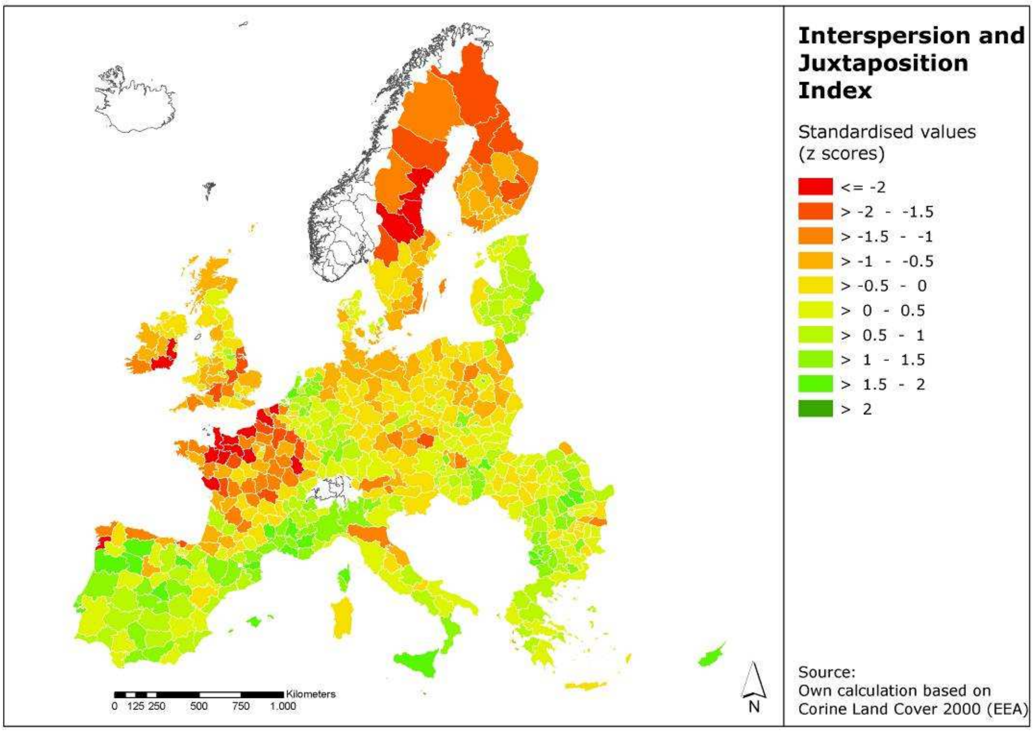


Fig. 3.8 – Interspersion and Juxtaposition Index (IJI), based on CLC 2000

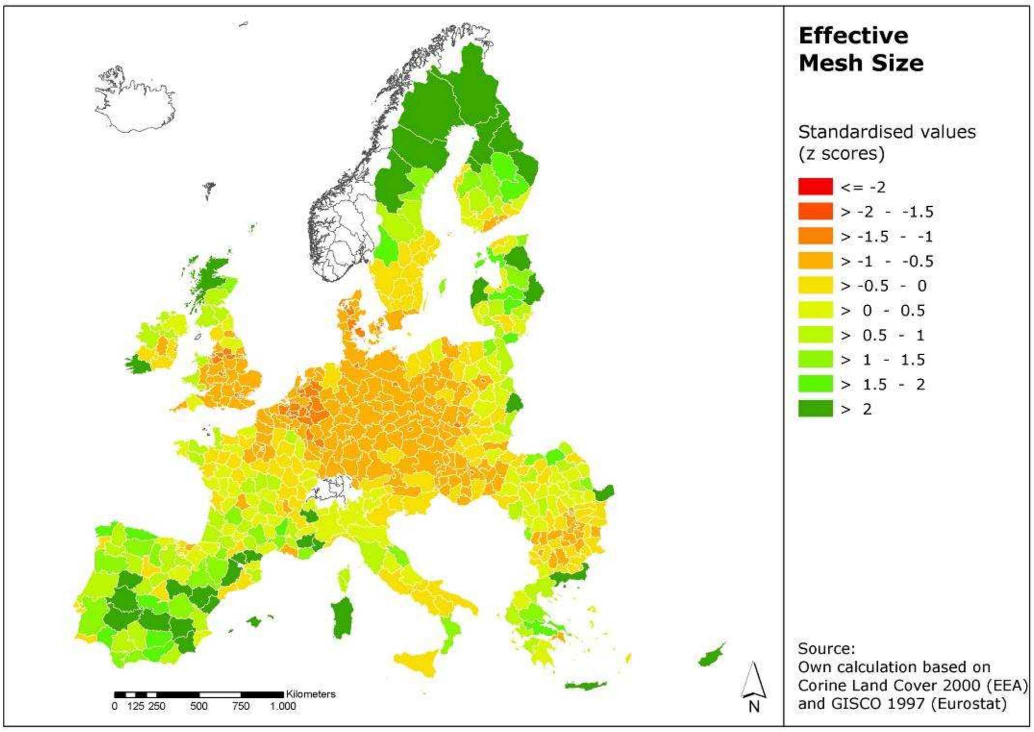


Fig. 3.9 – Effective Mesh Size (MESH), based on CLC 2000

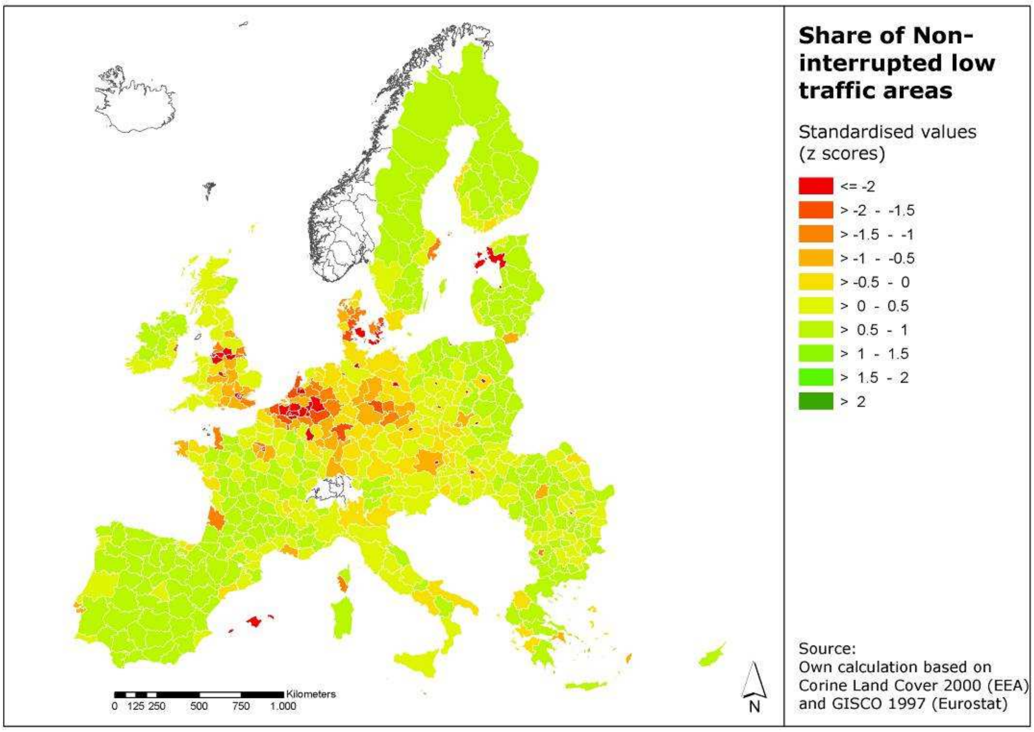


Fig. 3.10 – Share of Non-interrupted low traffic areas > 100 km² in %, 1997

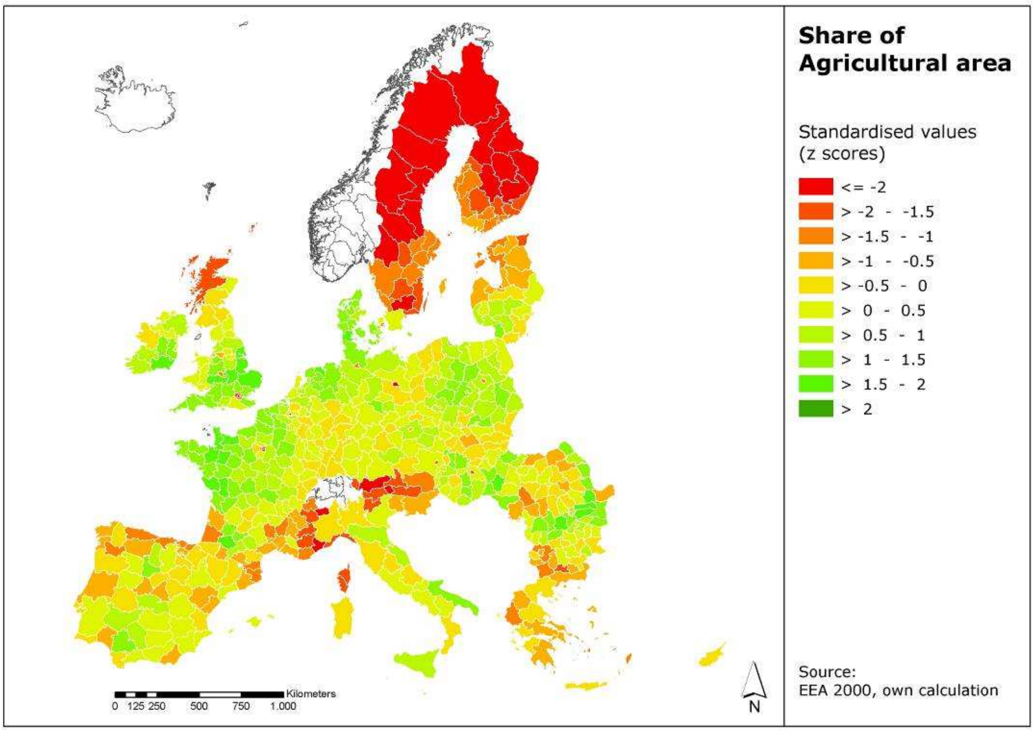


Fig. 3.11 – Share of Agricultural area on total area in %, based on CLC 2000

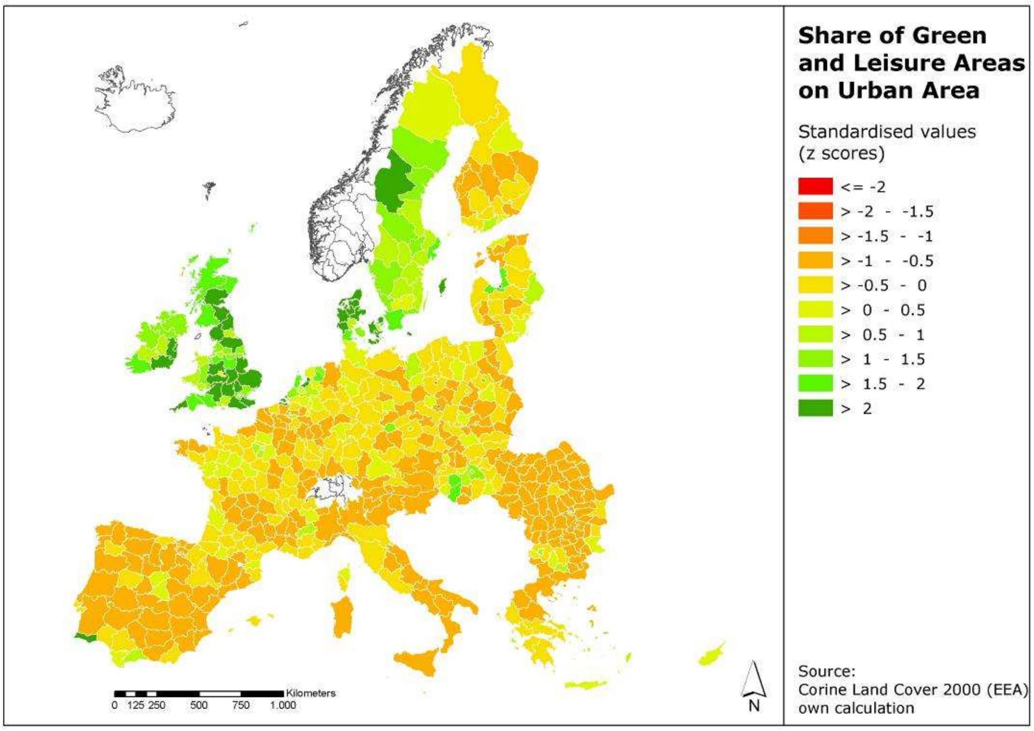


Fig. 3.12 – Share of Green and Leisure Area on urban area in %, based on CLC 2000

PLUREL

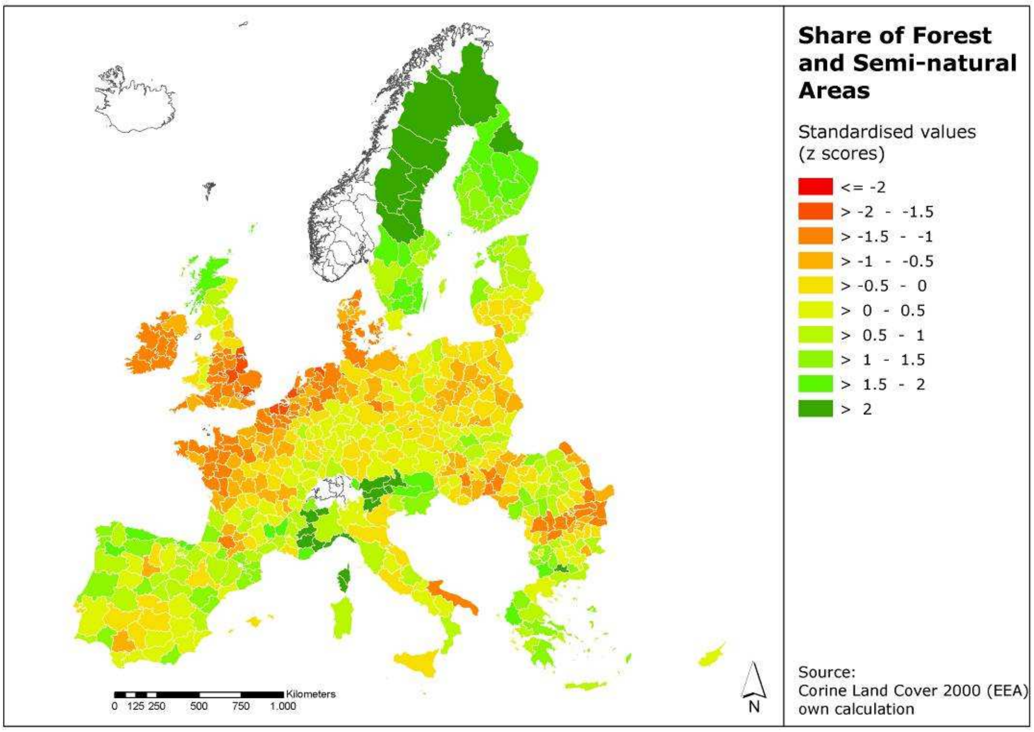


Fig. 3.13 – Share of Forest and Semi-natural Area on urban area in %, based on CLC 2000

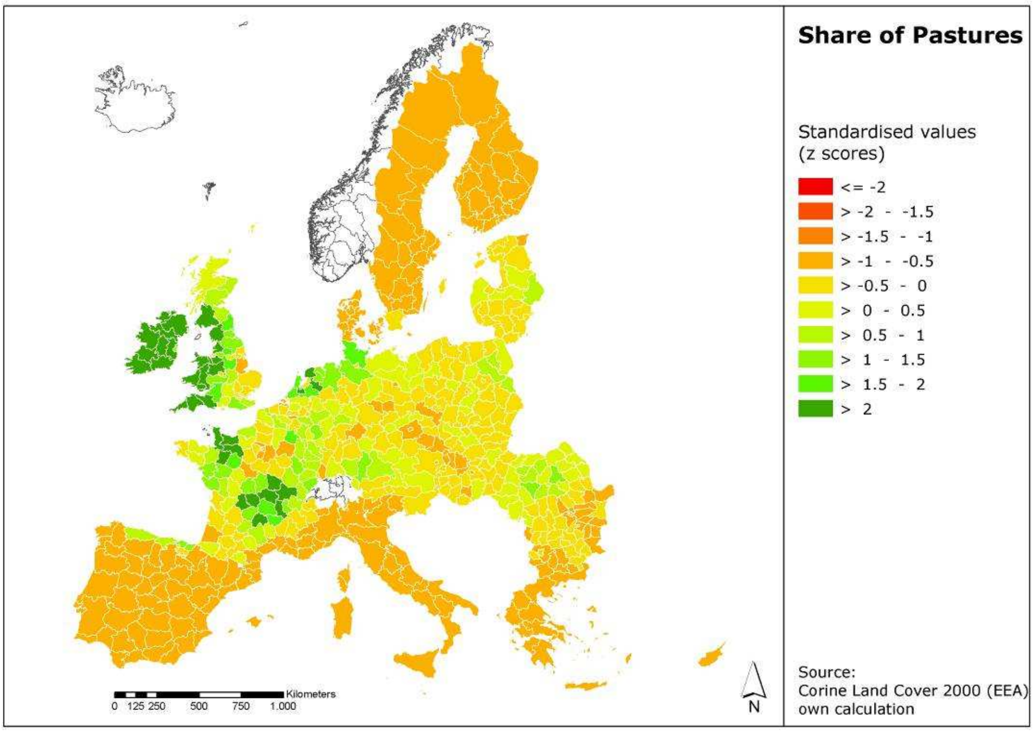


Fig. 3.14 – Share of Pasture Area on total area in %, based on CLC 2000

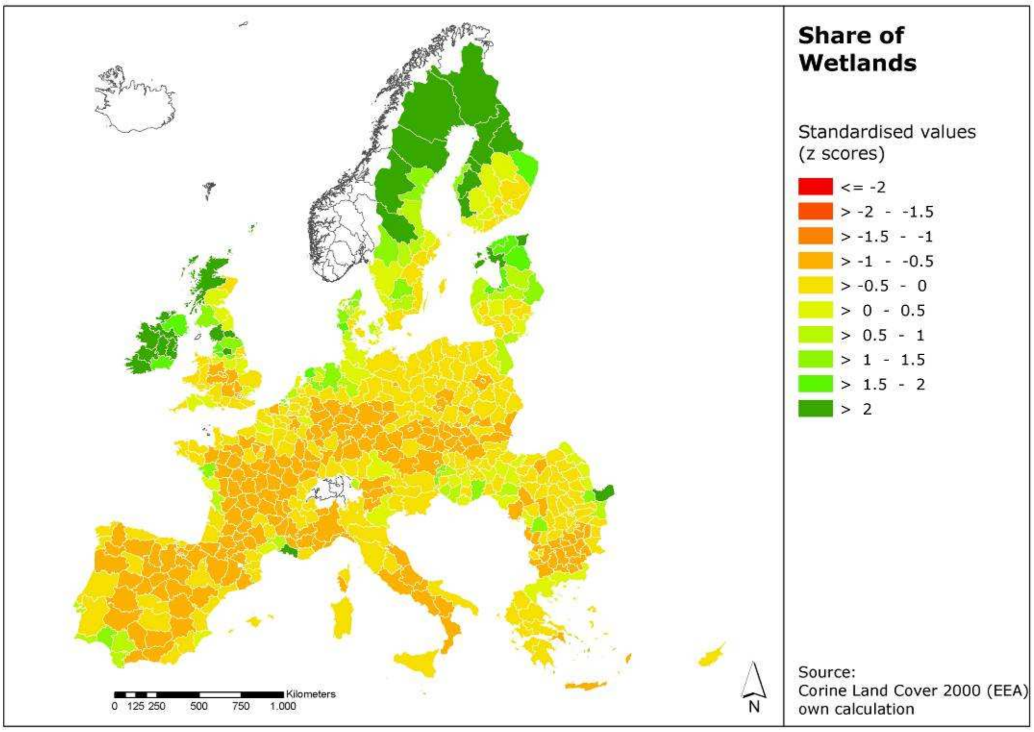


Fig. 3.15 – Share of Wetland Area on total area in %, based on CLC 2000

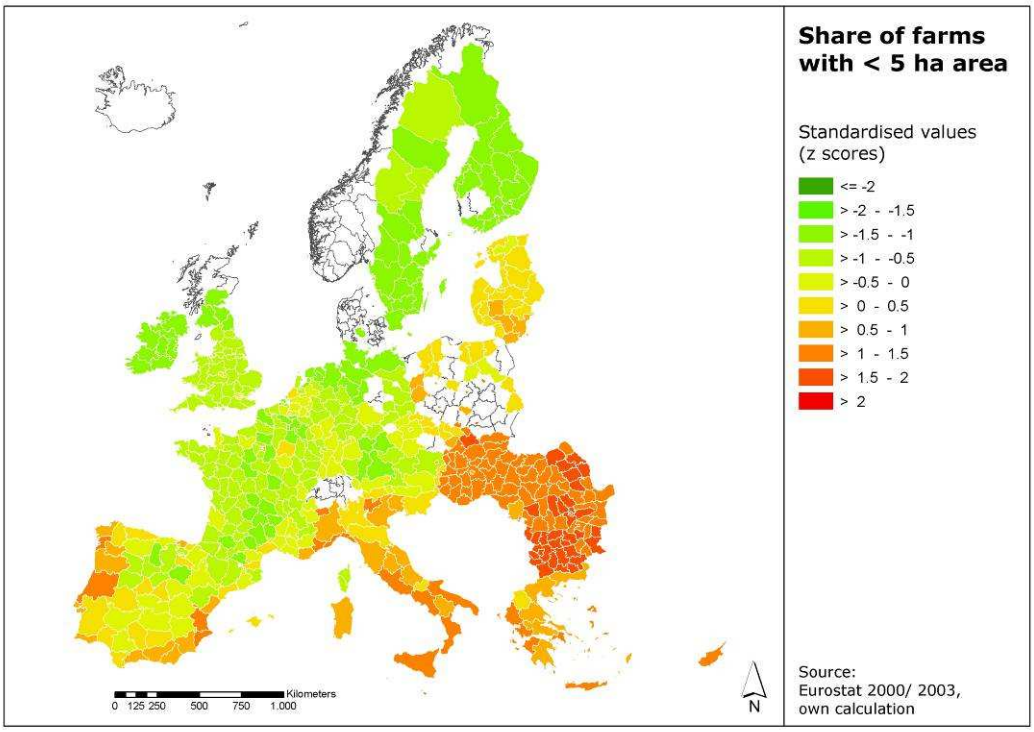


Fig. 3.16 – Share of farms with < 5 ha area in %

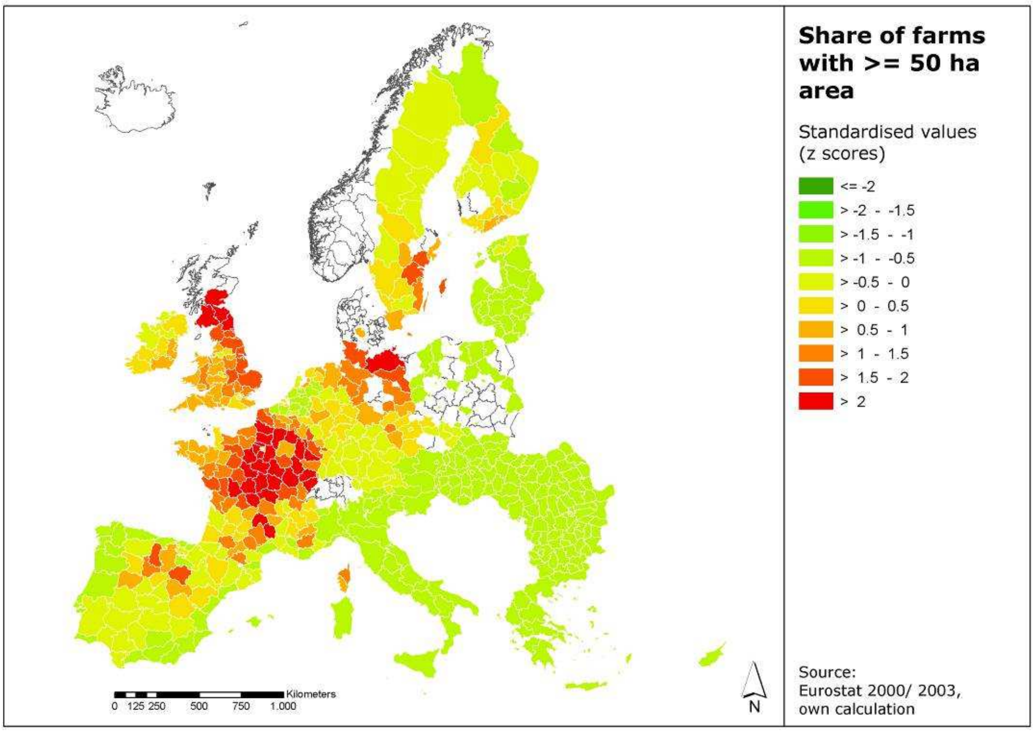


Fig. 3.17 – Share of farms with > 50 ha area in %

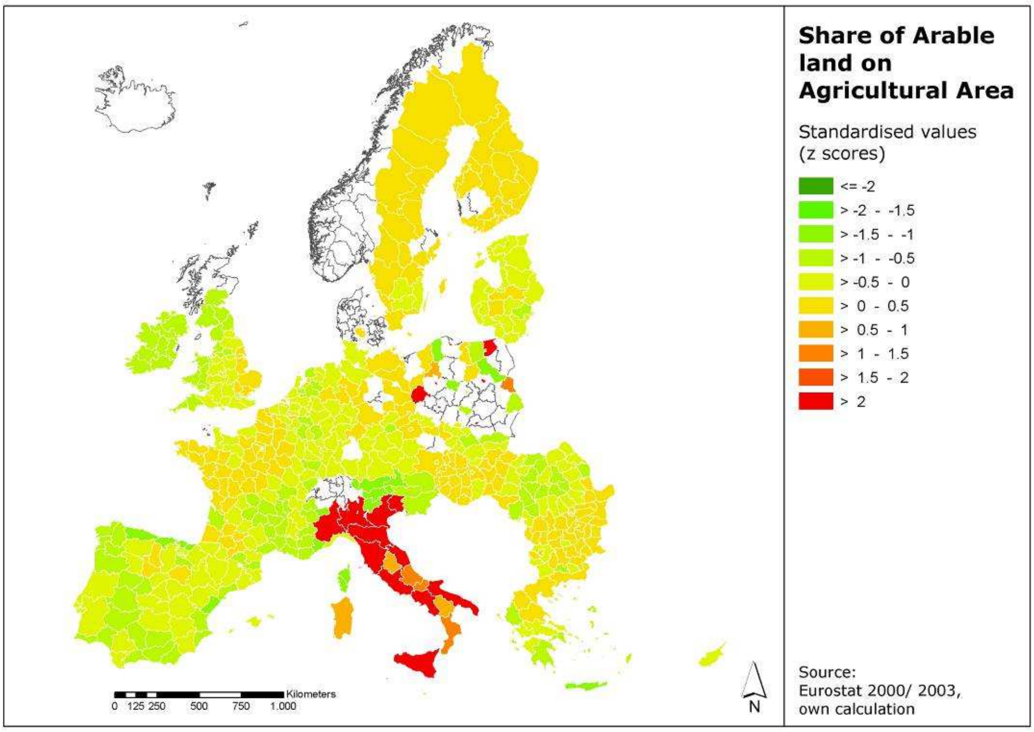


Fig. 3.18 – Share of Arable Land on Agricultural area in %

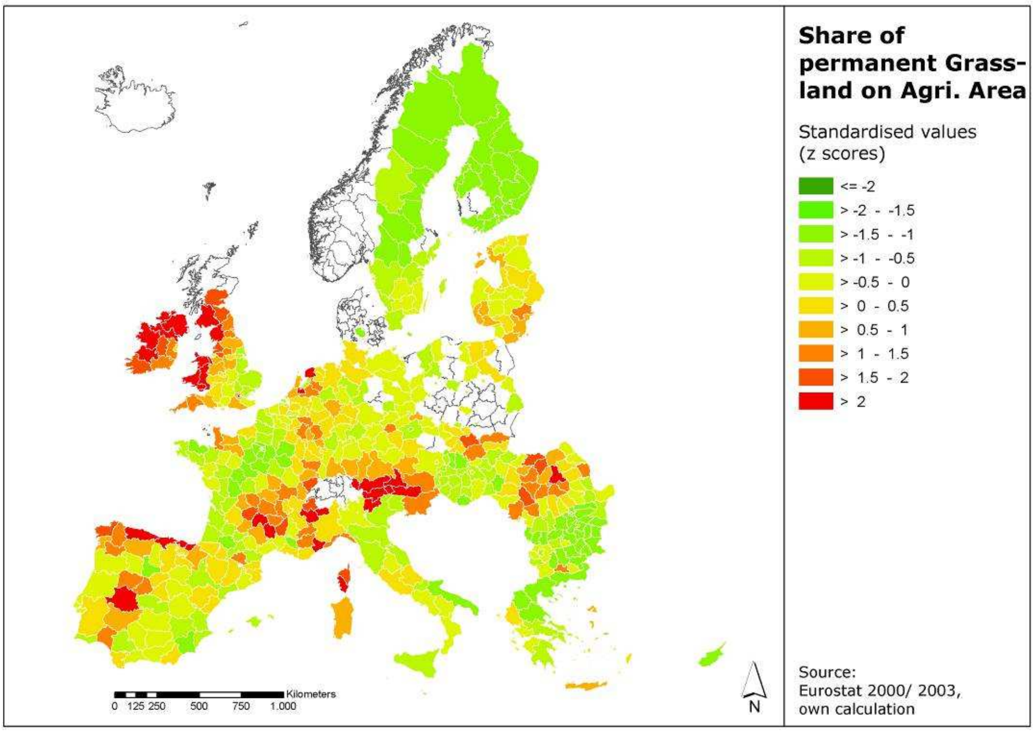


Fig. 3.19 – Share of permanent Grassland on Agricultural area in %

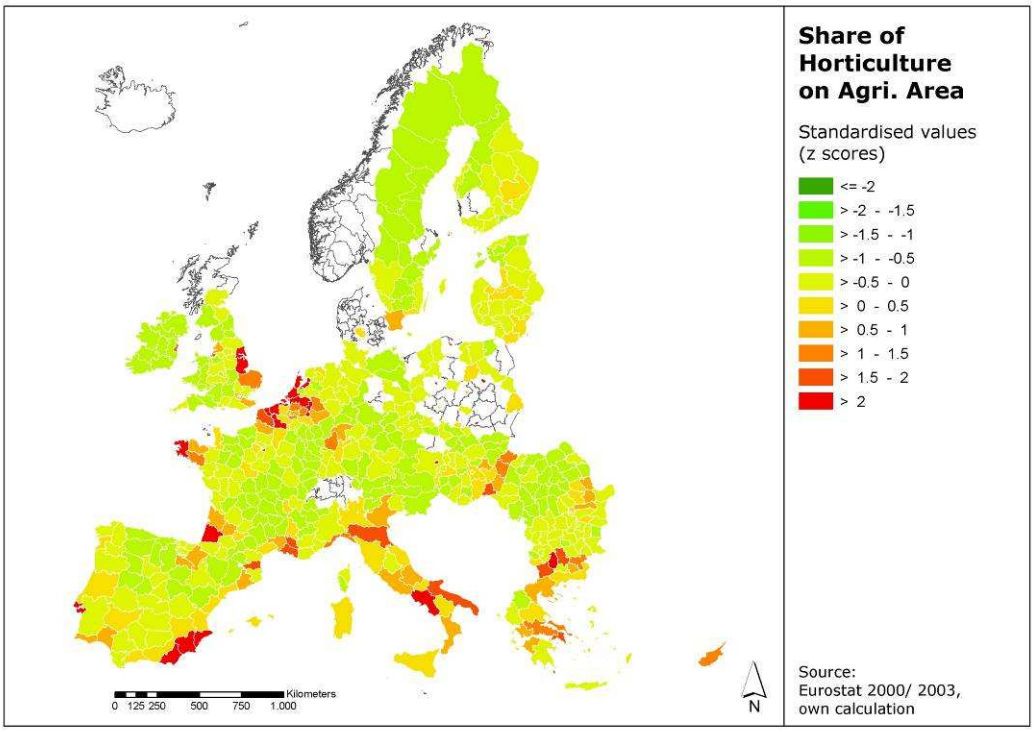


Fig. 3.20 – Share of Horticulture on Agricultural area in %

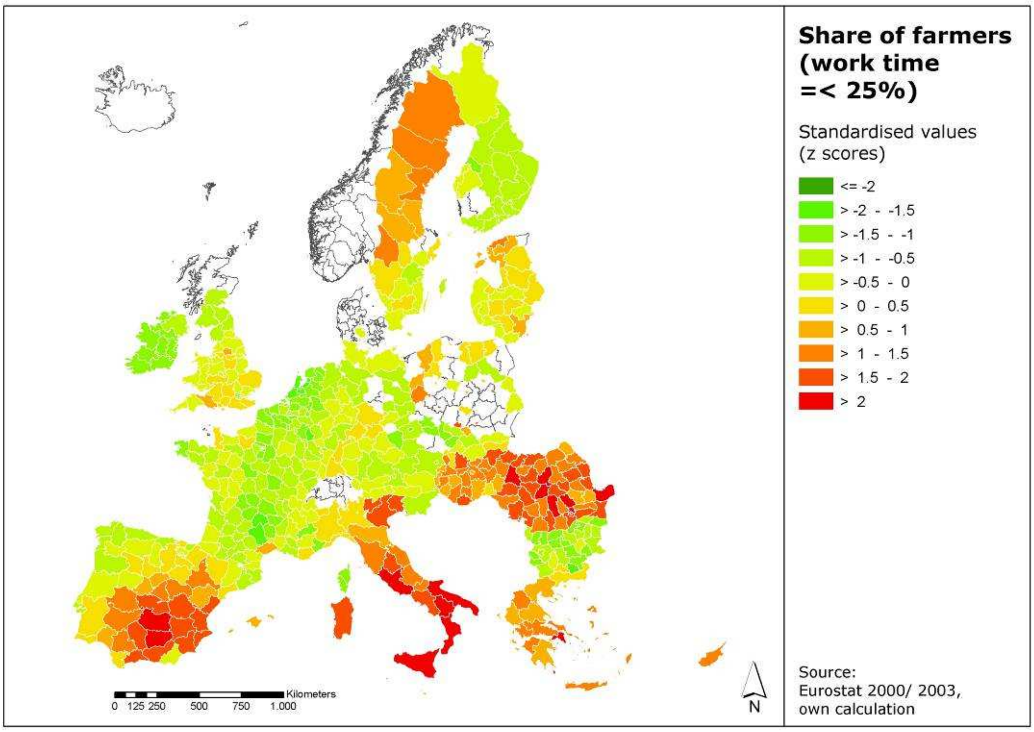


Fig. 3.21 – Share of farm holders with working time in agriculture < 25% in %

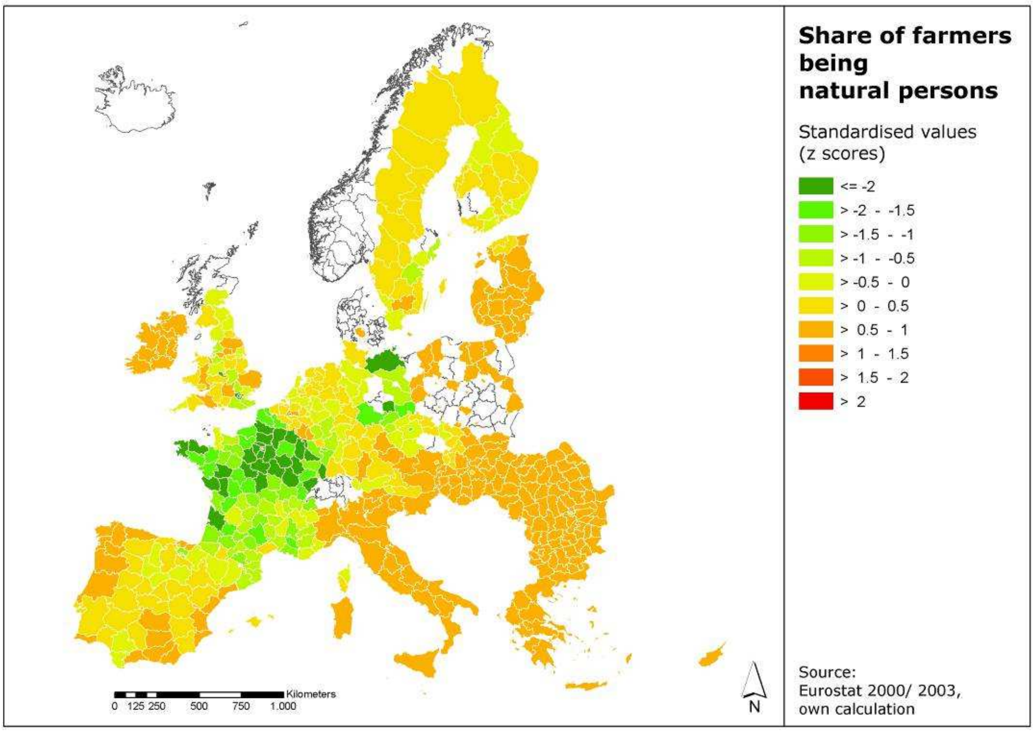


Fig. 3.22 – Share of farm holders who are a natural person in %

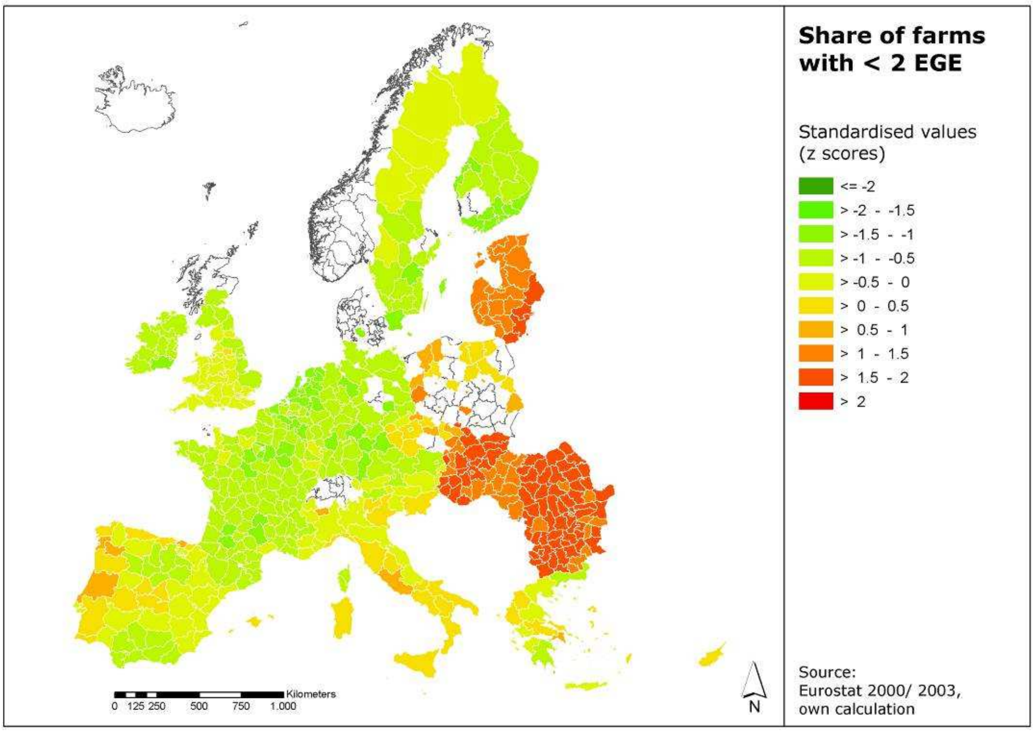


Fig. 3.23 – Share of farms with < 2 ESU in %

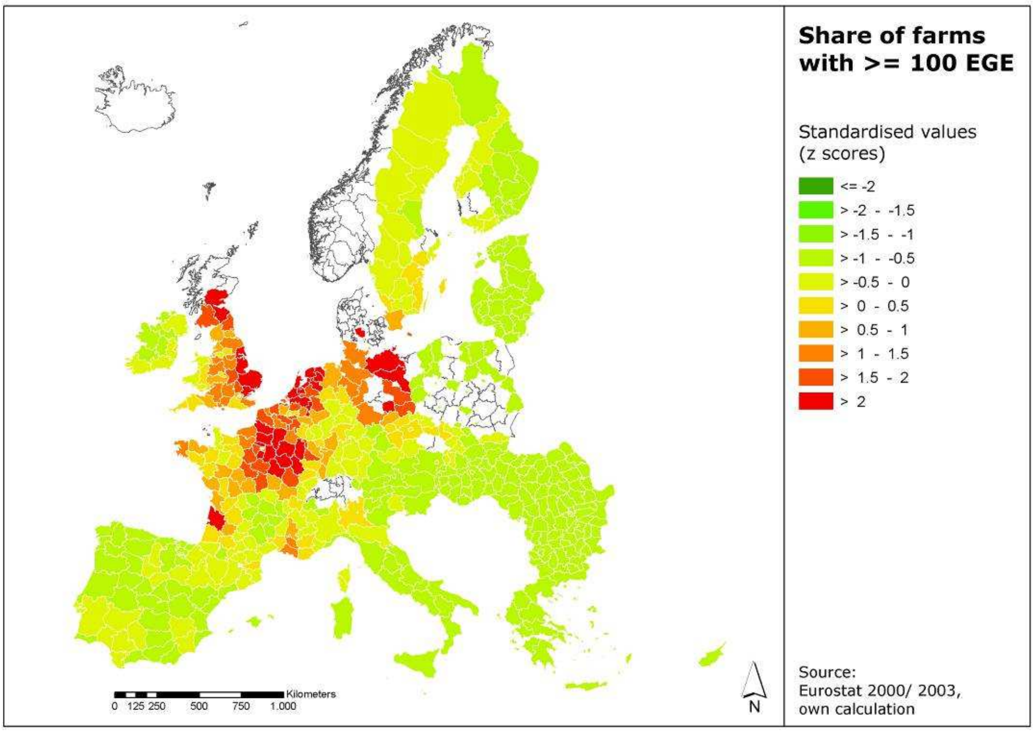


Fig. 3.24 – Share of farms with > 100 ESU in %

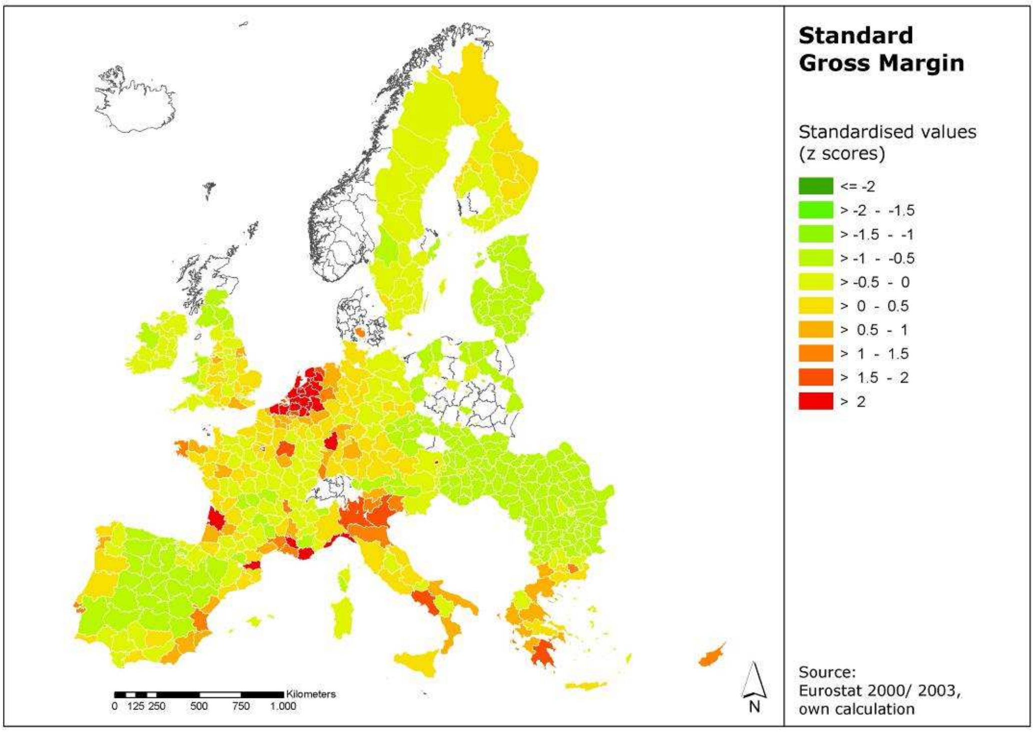


Fig. 3.25 – Average Standard Gross Margin per ha

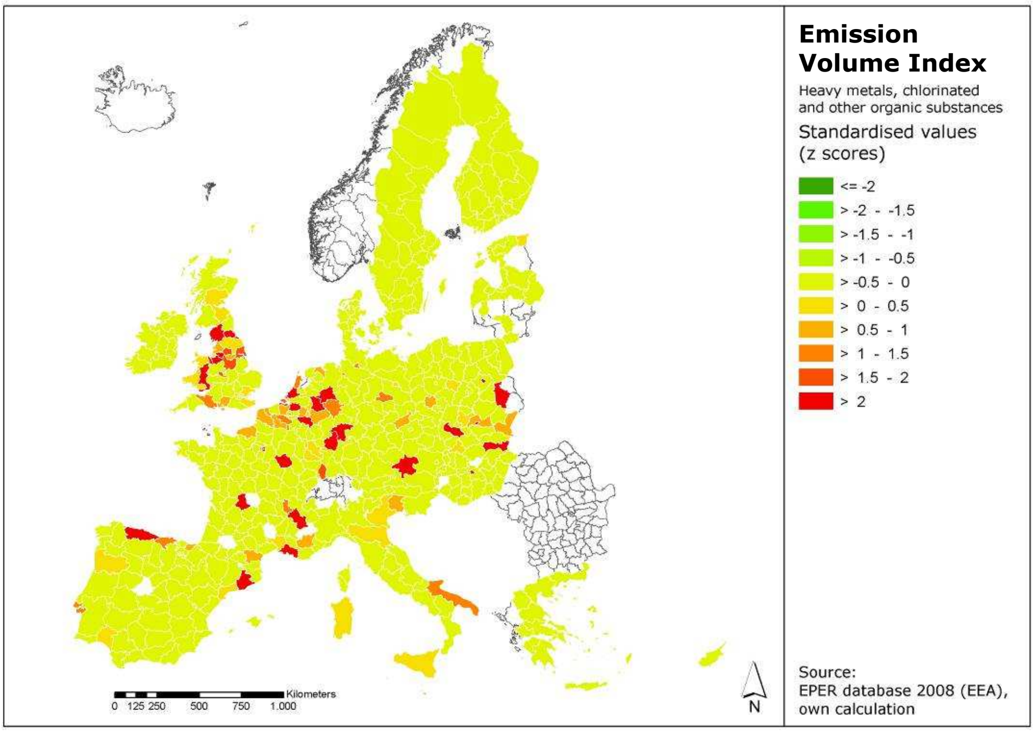


Fig. 3.26 – Emission Volume Index all pollutants

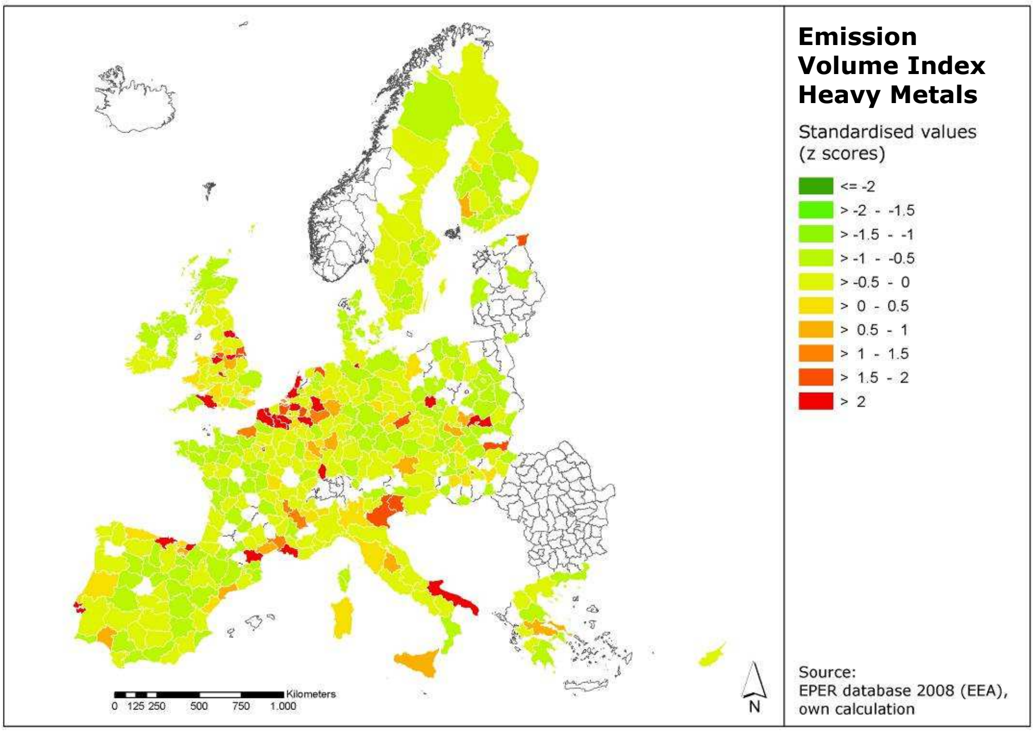


Fig. 3.27 – Emission Volume Index heavy metals

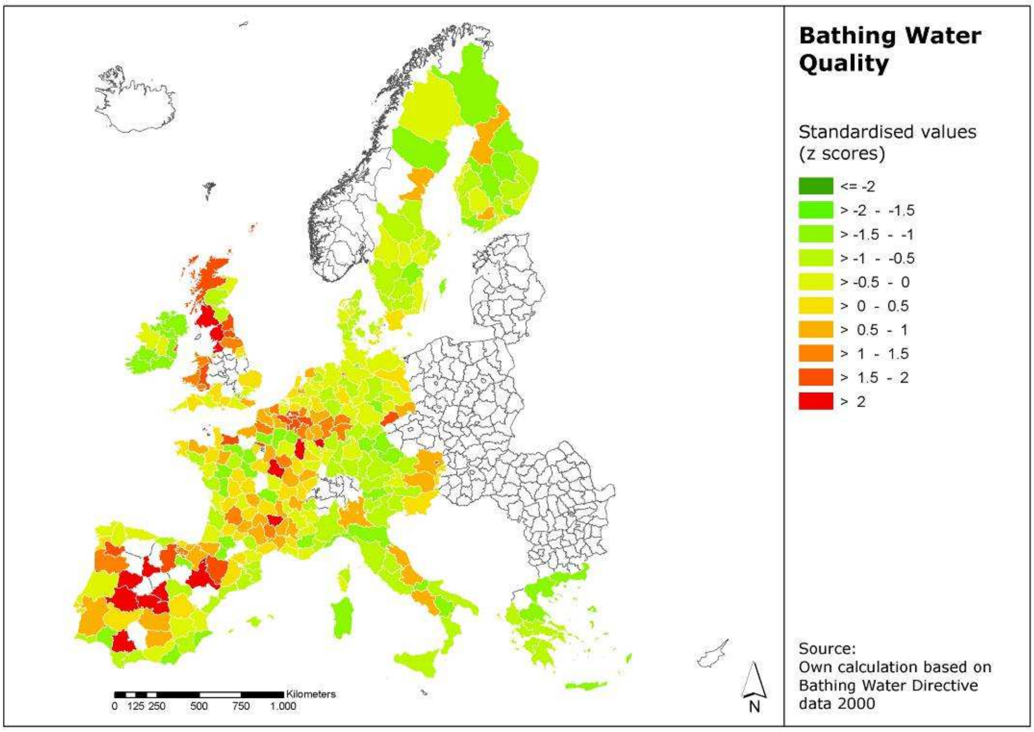


Fig. 3.28 – Aggregated Index Surface Water Quality

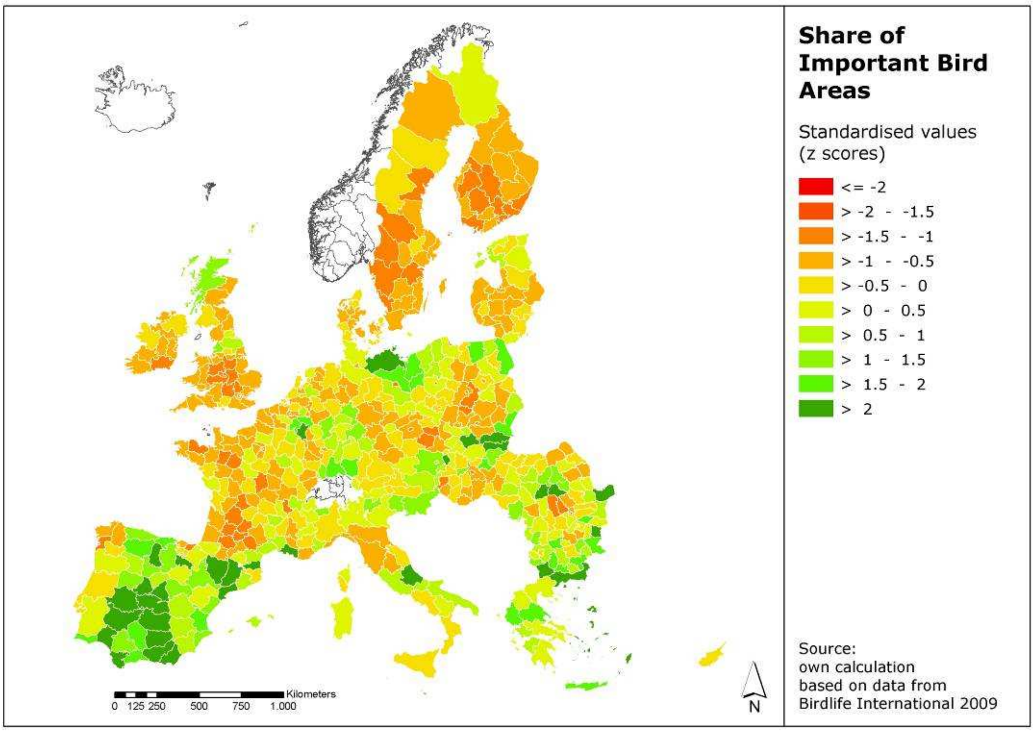


Fig. 3.29 – Share of Important Bird Areas in %

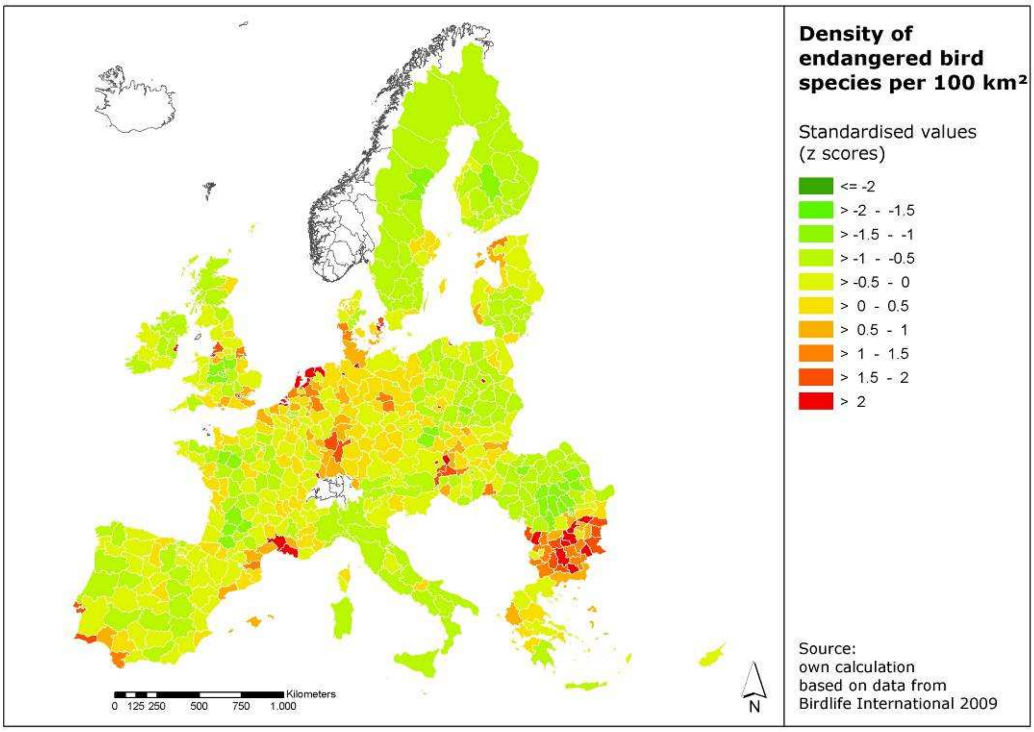


Fig. 3.30 – Density of Endangered Bird Species per 100 km²

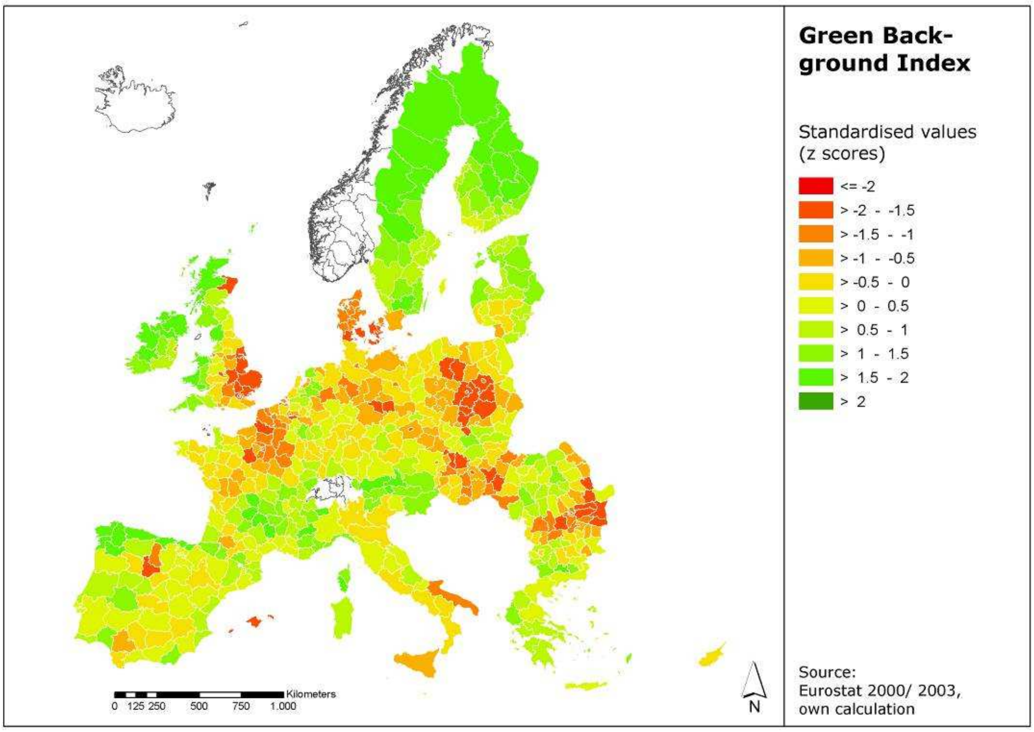


Fig. 3.31 – Green Background Index (GBI) 2000

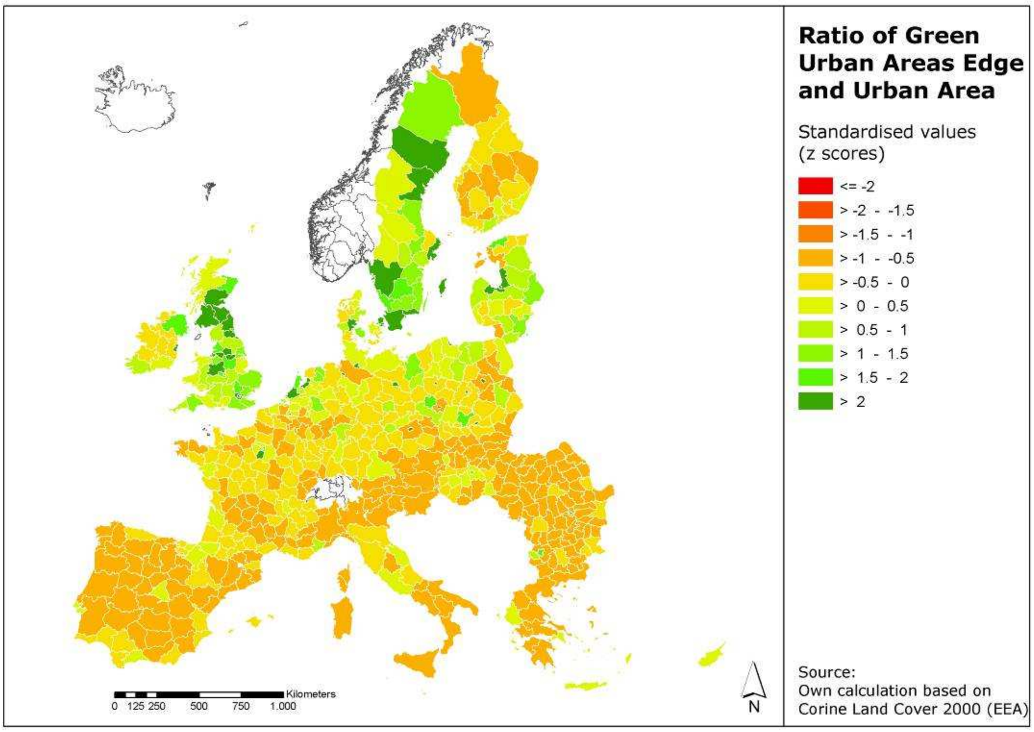


Fig. 3.32 – Ratio of Green Urban Area Edge / Urban Area

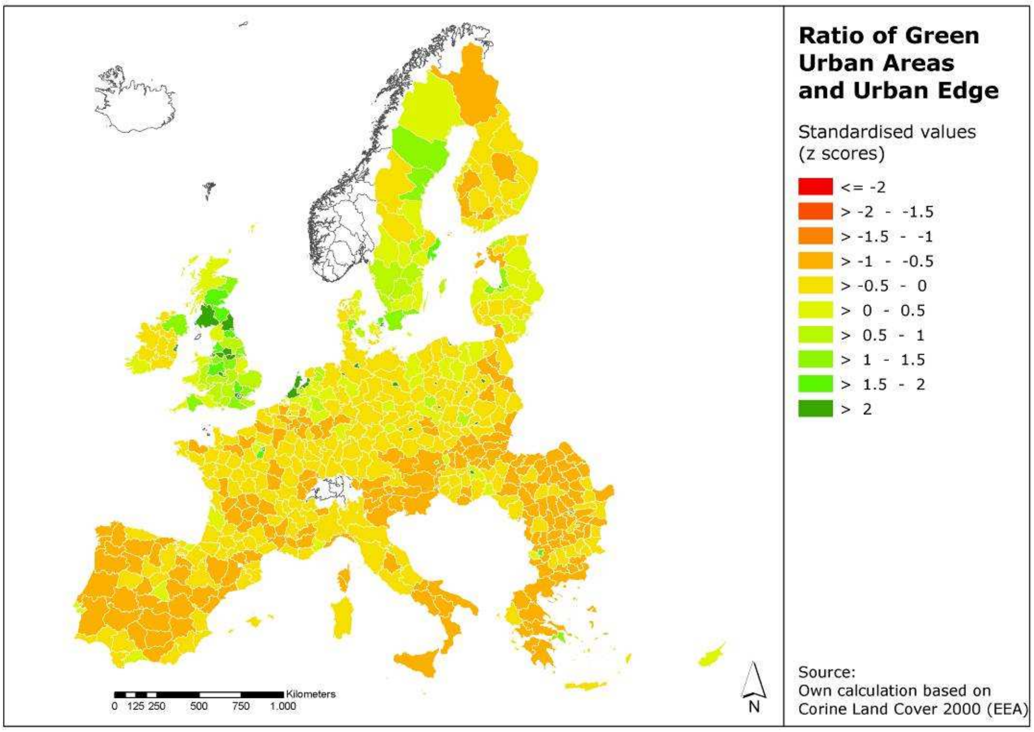


Fig. 3.33 – Ratio of Green Area Edge / Urban Area

Annex IV – Regional Typologies

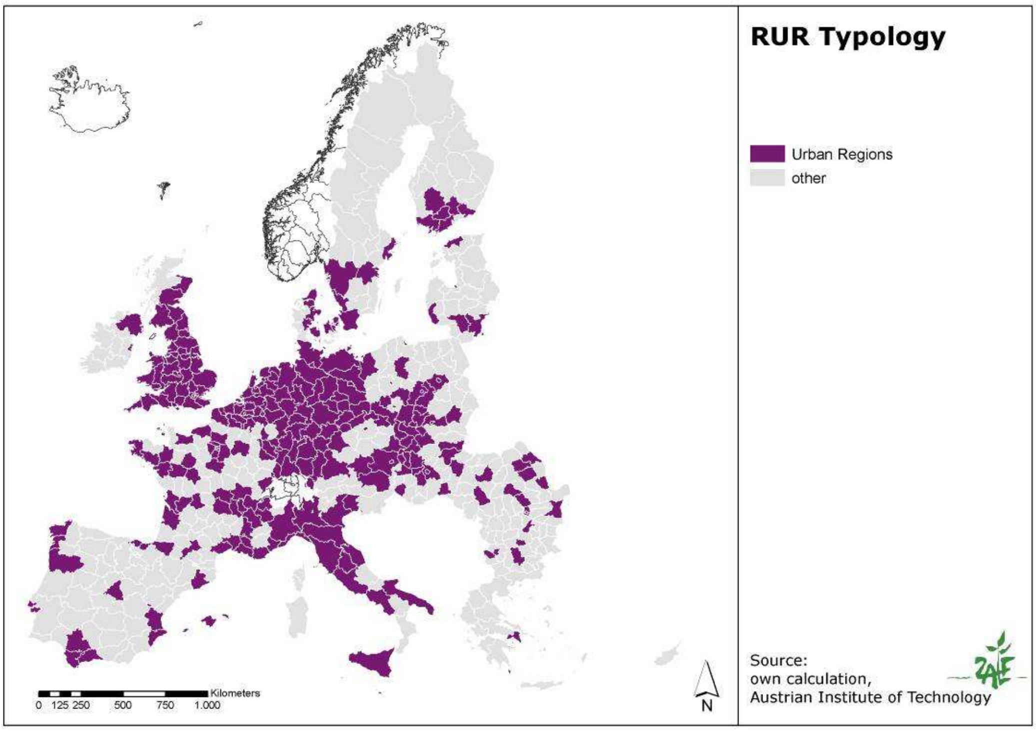


Fig.4.1 - RUR Typology – Urban Regions

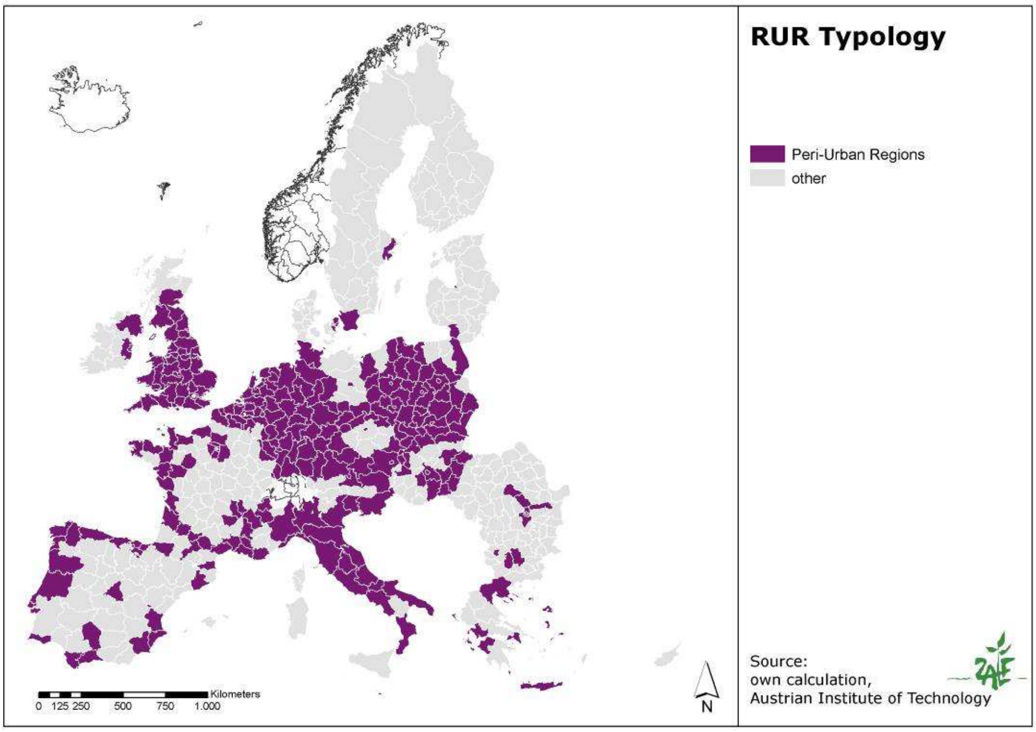


Fig.4.2 - RUR Typology – Peri - Urban Regions

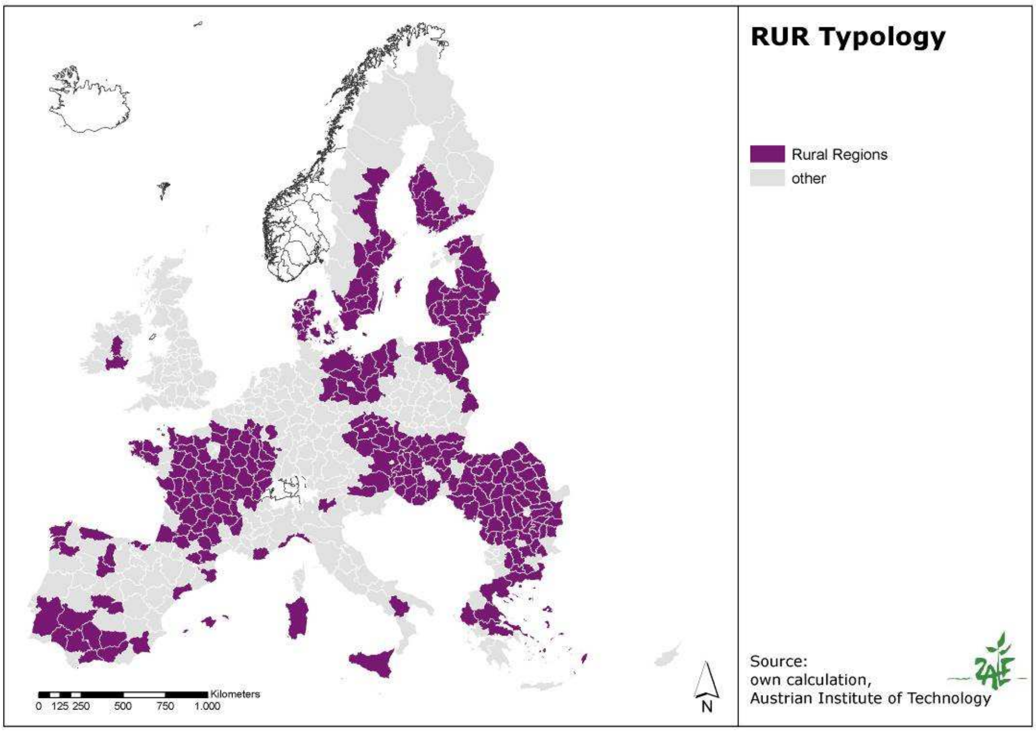


Fig.4.3 - RUR Typology – Rural Regions

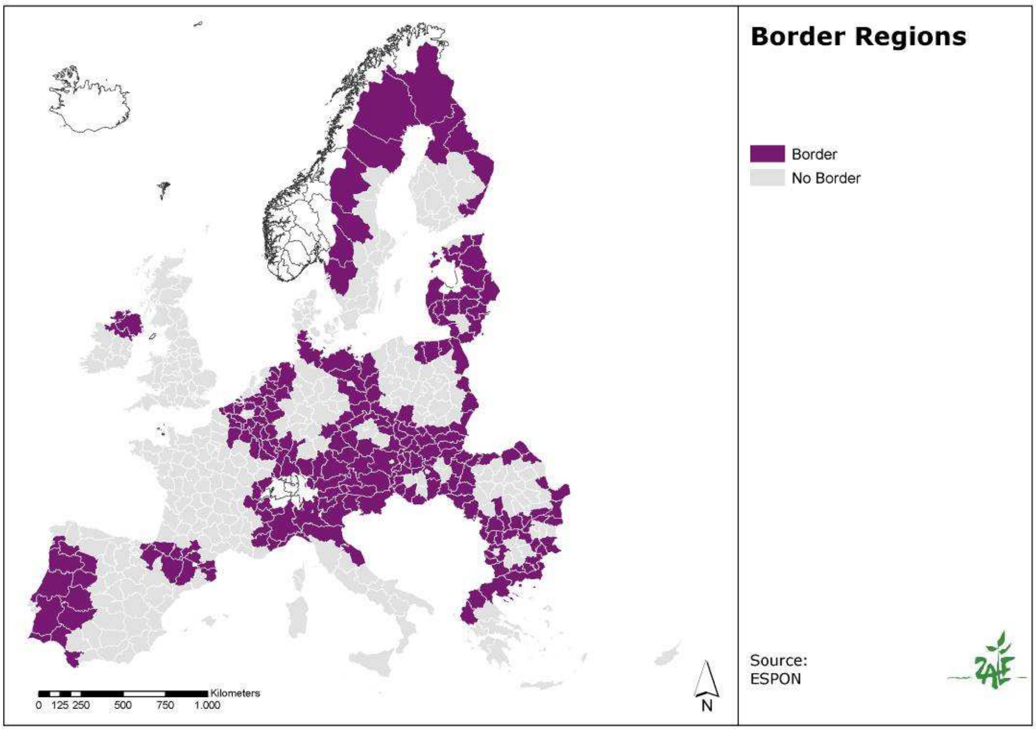


Fig.4.4 - Border Regions

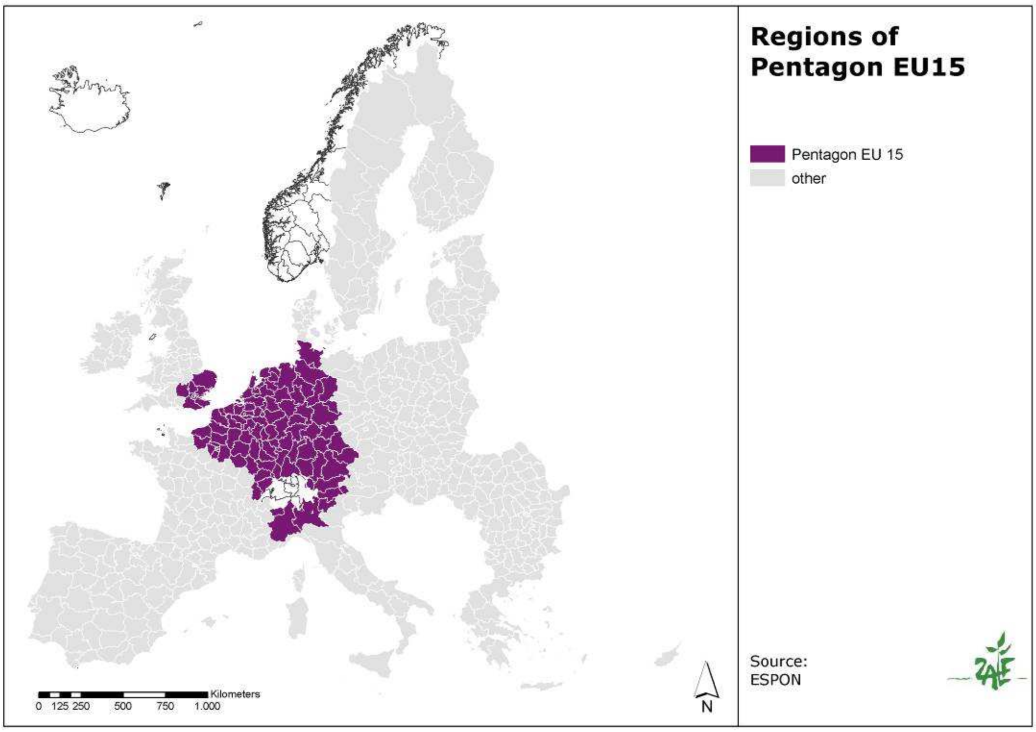


Fig.4.5 - Pentagon EU 15 Regions

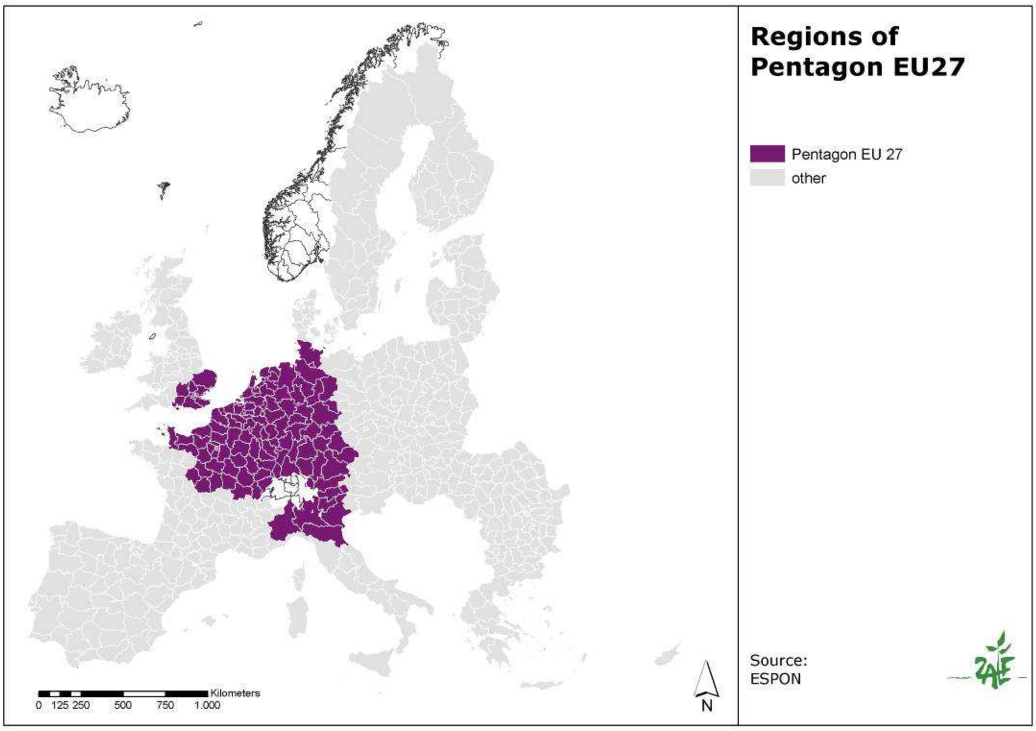


Fig.4.6 - Pentagon EU 27 Regions

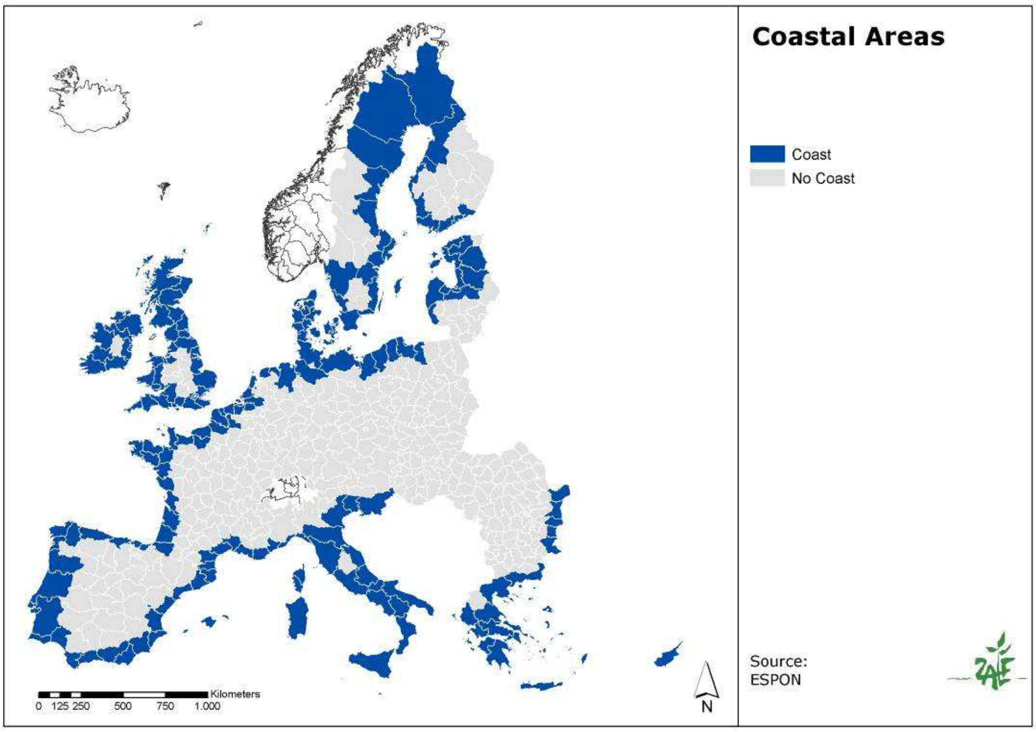


Fig.4.7 - Coastal Regions

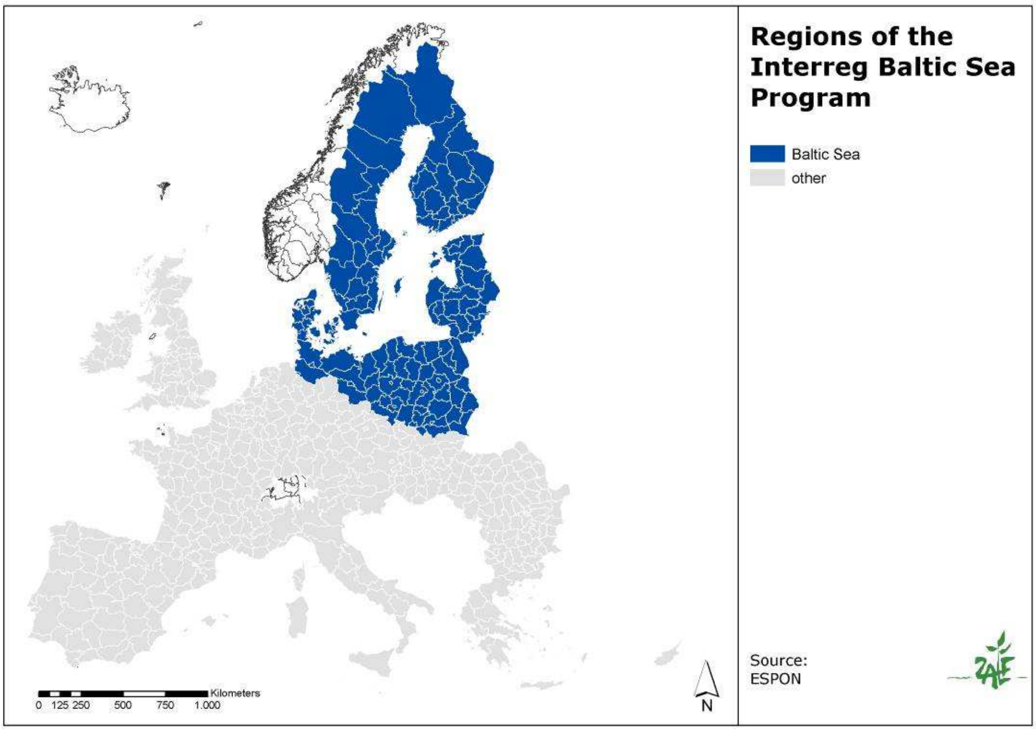


Fig.4.8 - Interreg Baltic Sea Program Regions

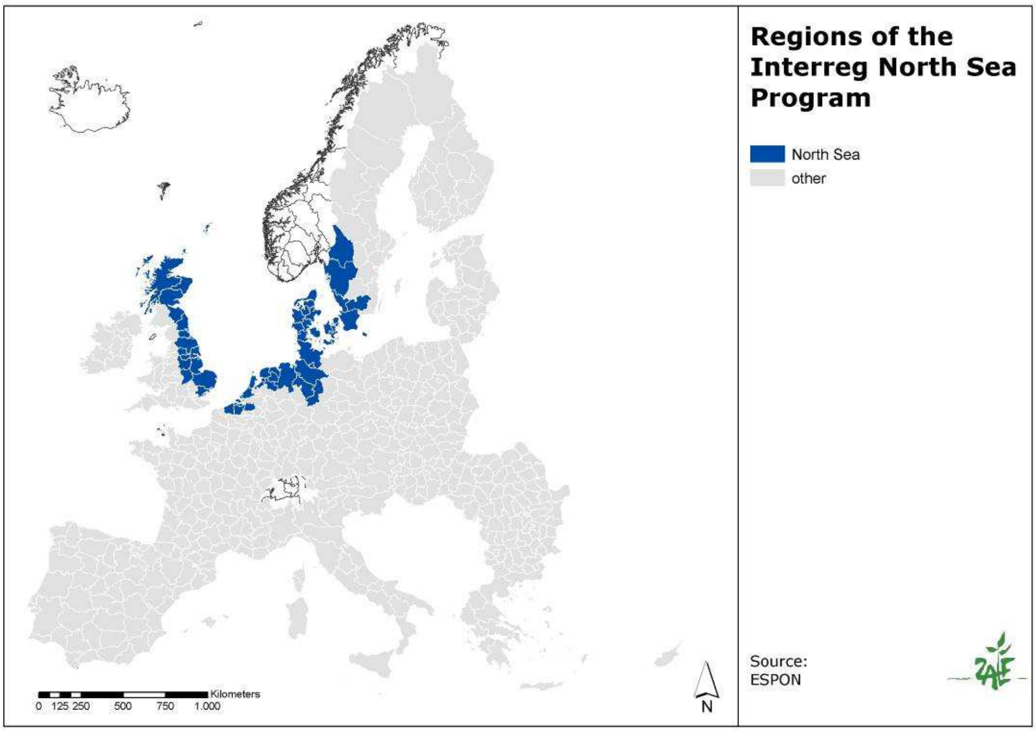


Fig.4.9 - Interreg North Sea Program Regions

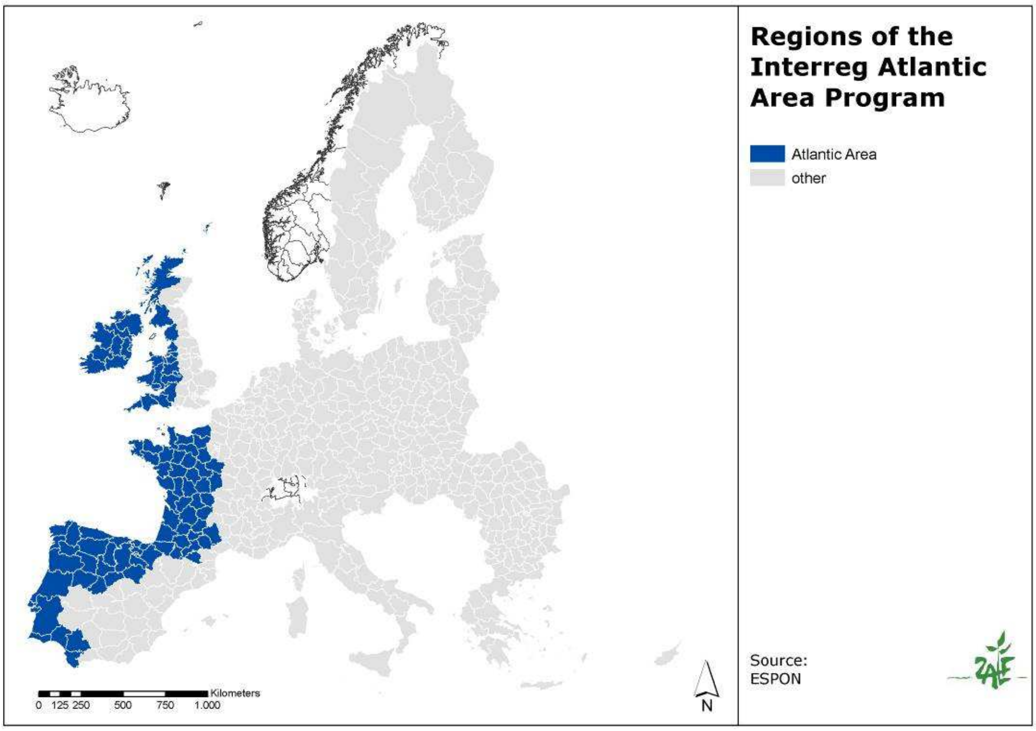


Fig.4.10 - Interreg Atlantic Program Regions

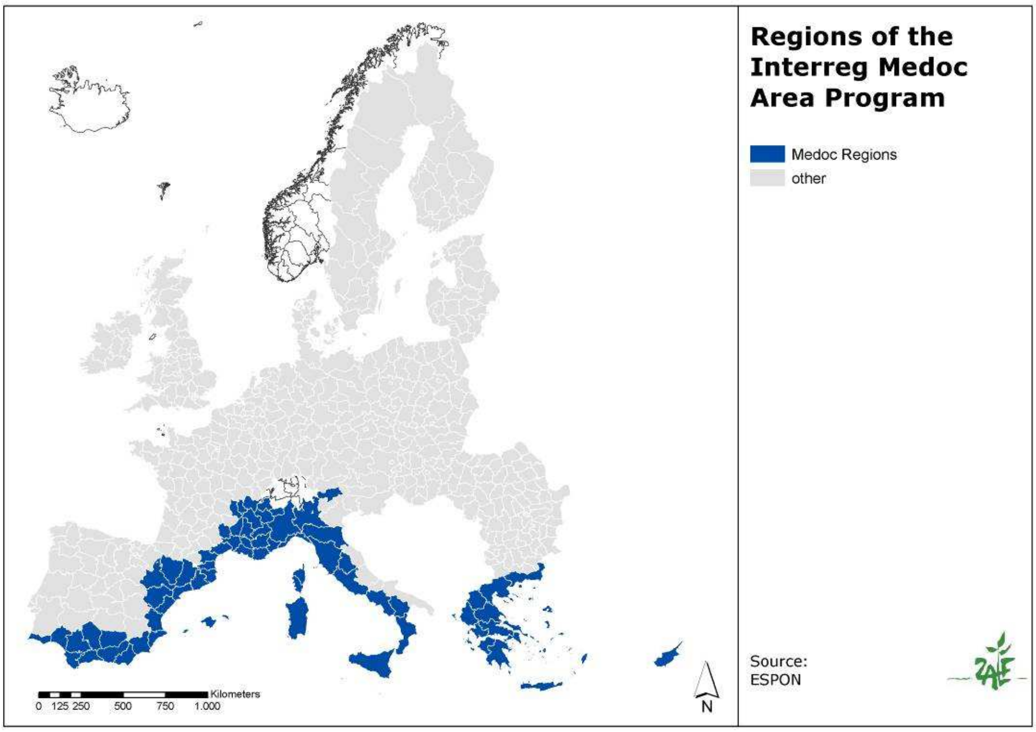


Fig.4.11 - Interreg Medoc Program Regions

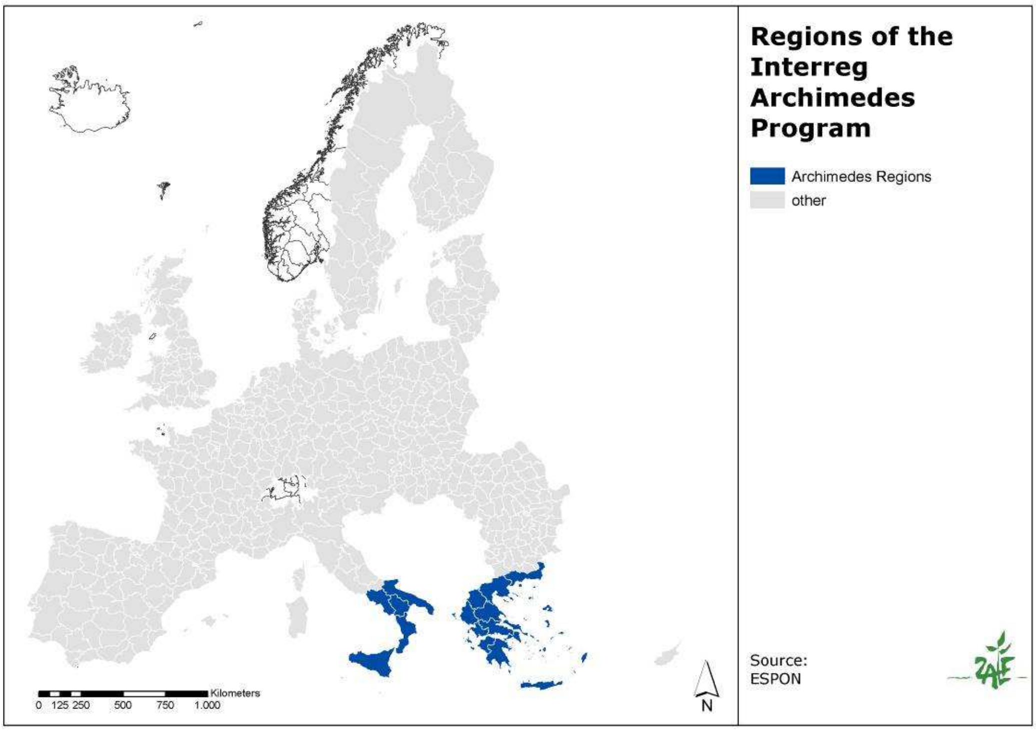


Fig.4.12 - Interreg Archimedes Program Regions

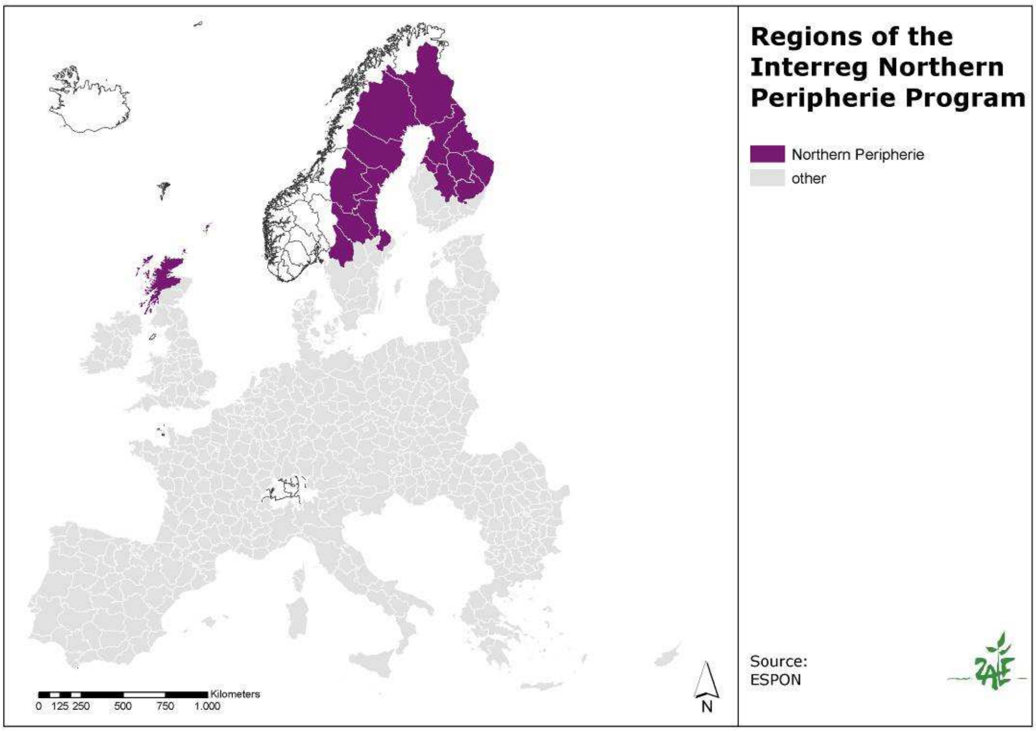


Fig.4.13 - Interreg Northern Peripherie Program Regions

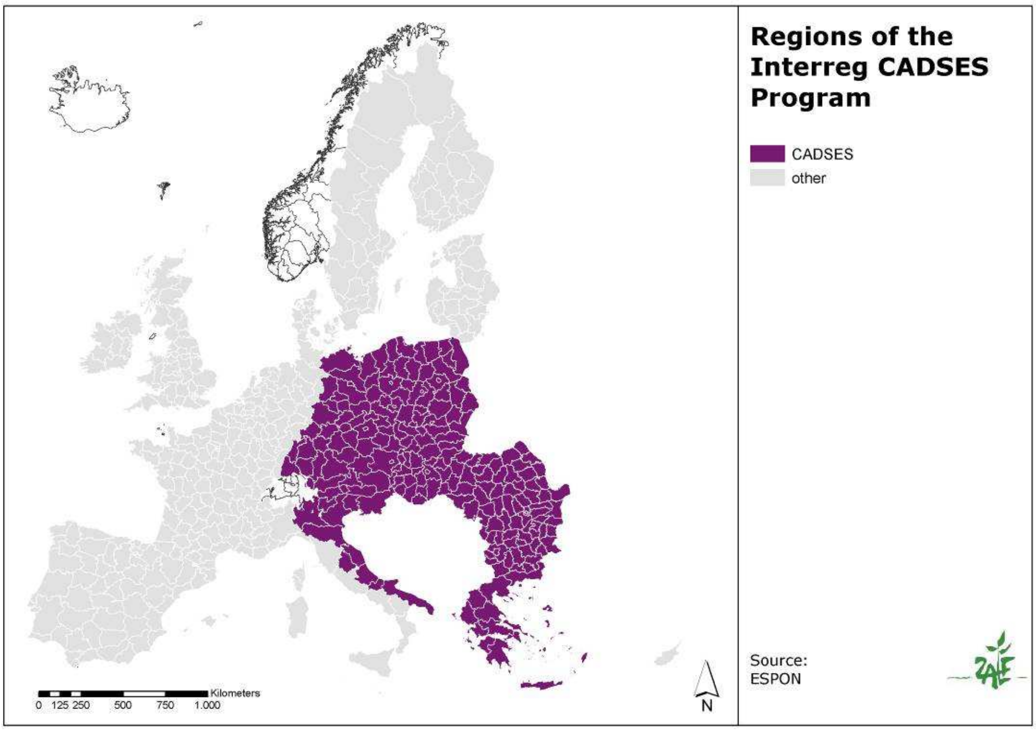


Fig.4.14 - Interreg CADSES Program Regions

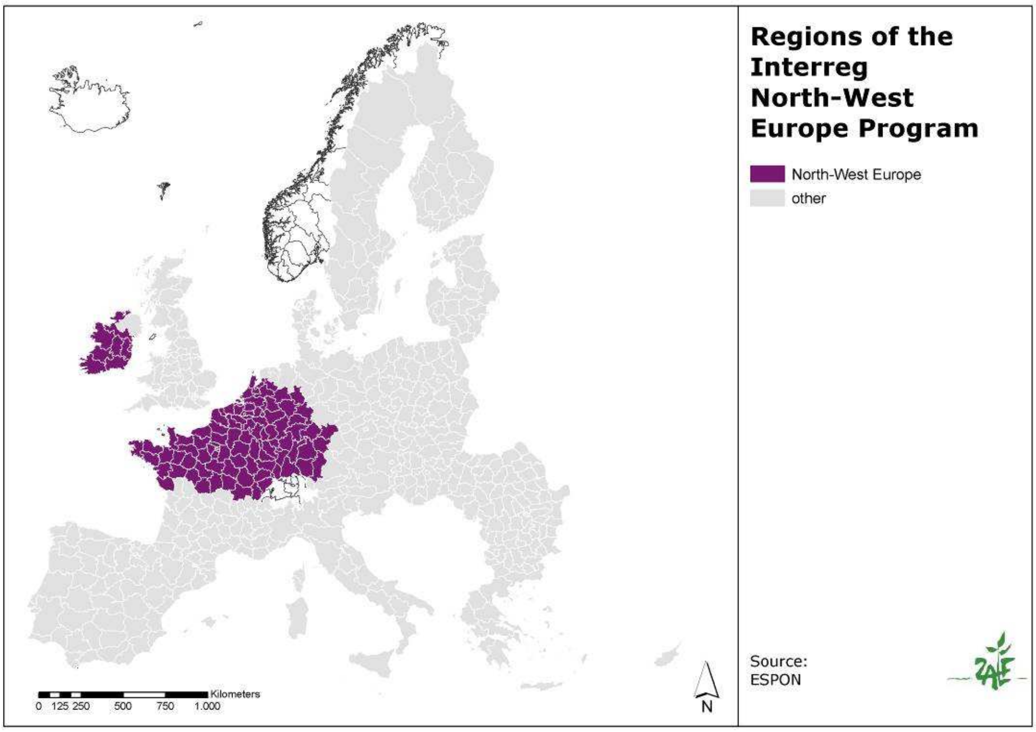


Fig.4.15 - Interreg North-West Europe Program Regions

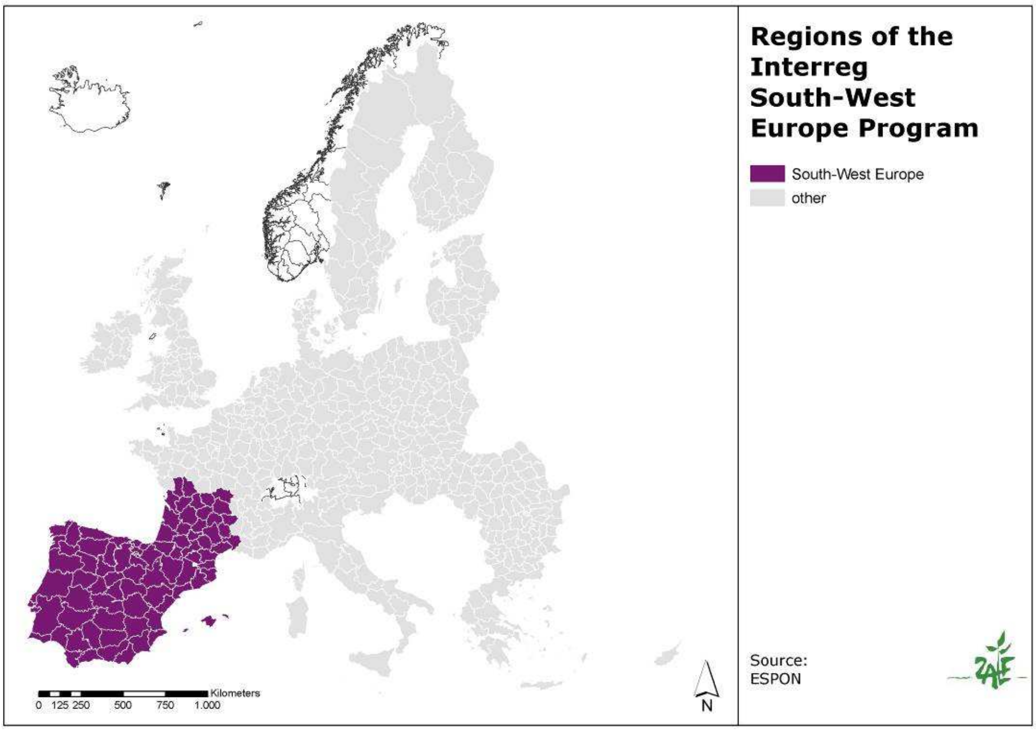


Fig.4.16 - Interreg South-West Europe Program Regions

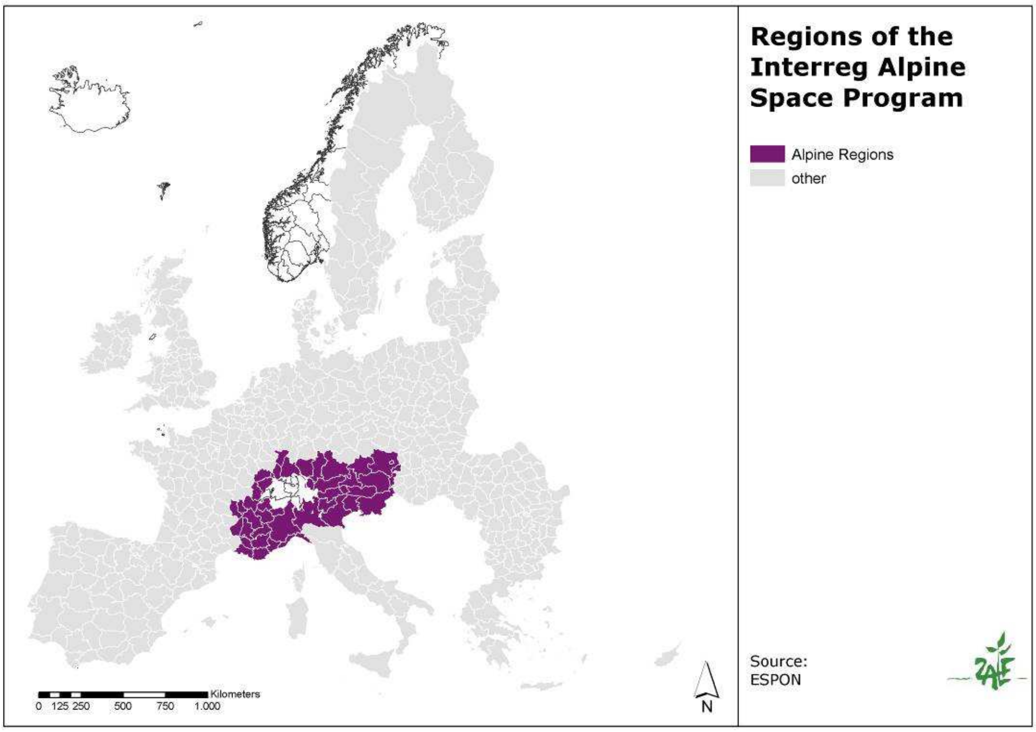
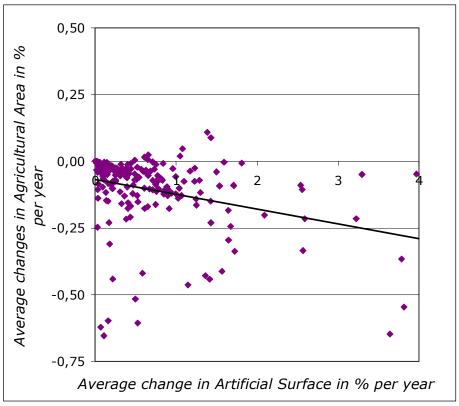


Fig.4.17 - Interreg Alpine Space Program Regions

Annex V - Iterative Indicator Selection Methodology

Theme	No.	Preliminary List	Data Availability	Model Quality	Final List
Landscape Structure	1	Patch Density	Patch Density	R^2 = - /0.13/0.39	
	2	Edge Density	Edge Density	R^2 = - /- /-	
	3	Landscape Shape Index	Landscape Shape Index	R^2 = - /0.36/0.53	Landscape Shape Index
	4	Shannon's Diversity Index	Shannon's Diversity Index	R^2 = - /- / -	
	5	Simpson's Diversity Index	Simpson's Diversity Index	R^2 = - /- / -	
	6	Shannon's Evenness Index	Shannon's Evenness Index	R^2 = - /0.05/0.46	
	7	Simpson's Evenness Index	Simpson's Evenness Index		
	8	Interspersion & Juxtaposition Index	Interspersion & Juxtaposition Index	R^2 = - /0.07/0.40	Interspersion & Juxtaposition Index
	9	Effective Mesh Size	Effective Mesh Size	R^2 = 0.64/0.68/0.79	Effective Mesh Size
	10	Non-interrupted low-traffic Area	Non-interrupted low-traffic Area		
Landscape Land Cover	11	Agricultural Area	Agricultural Area	R^2 = - /0.16/0.52	Agricultural Area
	12	Green Urban & Leisure Area	Green Urban & Leisure Area	R^2 = - /- /-	
	13	Forest & Semi-natural Area	Forest & Semi-natural Area	R^2 = - /- /-	
	14	Pasture Area	Pasture Area	R^2 = - /- /-	
	15	Wetland Area	Wetland Area	R^2 = - /- /-	
Land use Agricultural Themes	16	Farms < 5ha	Farms < 5ha	R^2 = - /- /-	
	17	Farms > 50ha	Farms > 50ha	R^2 = - /- /-	
	18	Arable Land/Agricultural Area	Arable Land/Agricultural Area	R^2 = - /0.15/0.32	
	19	Grassland/Agricultural Area	Grassland/Agricultural Area	R^2 = - /- /-	
	20	Horticulture/Agricultural Area	Horticulture/Agricultural Area	R^2 = - /0.14/0.19	
	21	Abandoned/Agricultural Area			
	22	High Nature Value Farmland			
	23	Part-time farm holders	Part-time farm holders	R^2 = - /0.09/0.40	Part-time farm holders
	24	Farm holders natural person	Farm holders natural person	R^2 = - /- /-	
	25	Farms < 2 ESU	Farms < 2 ESU	R^2 = - /- /-	
	26	Farms > 100 ESU	Farms > 100 ESU	R^2 = - /- /-	
	27	Standard Gross Margin	Standard Gross Margin	R^2 = - /0.14/0.42	Standard Gross Margin
	28	Area under Organic Farming			
Land use Environmental Themes	29	Freshwater Quantity			
	30	Emission Volume Index	Emission Volume Index	R^2 = - /0.22/0.28	
	31	Emission Volume Index soil/water	Emission Volume Index soil/water		
	32	Heavy Metal Emission Volume Index	Heavy Metal Emission Volume Index	R^2 = 0.22/0.18/0.26	Heavy Metal Emission Volume Index
	33	HM Emission Vol. Index soil/water	HM Emission Vol. Index soil/water		
	34	Surface Water Quality	Surface Water Quality	R^2 = - /- /-	
	35	Nitrogen Balance			
	36	Important Bird Areas	Important Bird Areas	R^2 = - /- /-	
	37	Endangered Bird Species	Endangered Bird Species	R^2 = - /0.28/0.31	Endangered Bird Species
	38	Red List Index			
	39	Soil Erosion Risk			
	40	Green Background Index	Green Background Index	R^2 = - /0.12/0.41	Green Background Index
	41	Green Edge	Green Edge		
	42	Urban Green Edge	Urban Green Edge	R^2 = - /- /-	

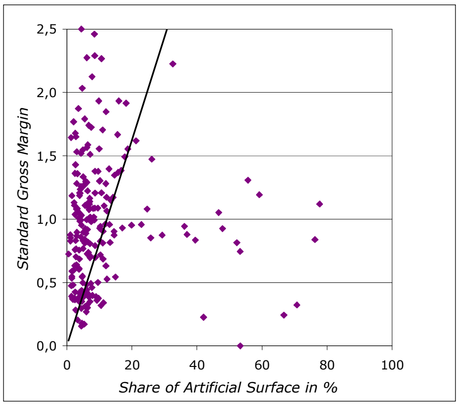
Annex VI - Regression Functions for chosen variables including R² values



RF: y = -0.09 + (-0.04*AS) + (-0.002*RUR1) + (0.001*RUR3) + (-0.03*Border) + (0.06*Archimedes) + (0.04*Baltic) + (0.03*SW-EU)

	Peri-urban NUTS X	+Typology group A	+Typology group B
R^2	0.155	0.404	0.516

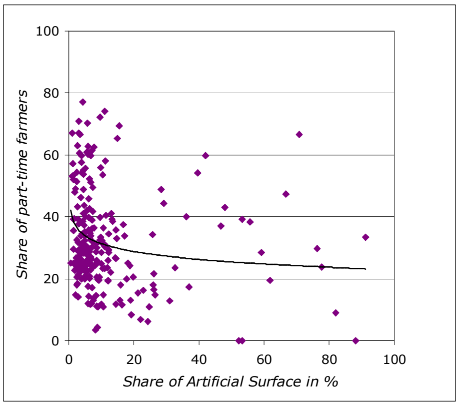
Fig. 6. 1 - Regression for Agricultural Area incl. R^2



RF: y = 1.23 + (0.05*AS) + (- 0.02*RUR3) + (0.38*Coast) + (0.55*North-Sea) + (0.79*Medoc) + (0.42*SW-EU) + (0.83*NW-EU)

	Peri-urban NUTS X	+Typology group A	+Typology group B
R^2	0.138	0.24	0.418

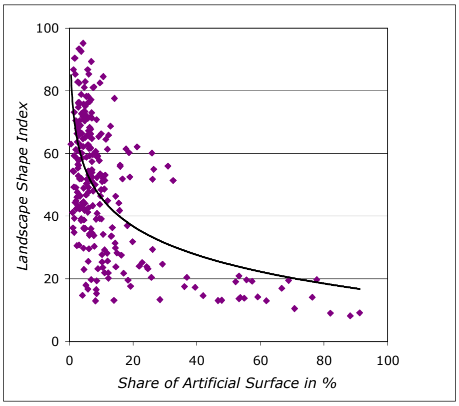
Fig. 6. 2 - Regression for Standard Gross Margin incl. R^2



RF: ln(y) = 3.77 + (-0.02*AS) + (-0.17*Border) + (-0.56*North-Sea) + (-0.28*Atlantic) + (0.37*Archimedes) + (-0.44*NW-EU)

	Peri-urban NUTS X	+Typology group A	+Typology group B
R^2	0.093	0.115	0.403

Fig. 6. 3 - Regression for Part-Time Farmers incl. R^2



RF: ln(y) = 3.39 + (-0.22*ln(AS)) + (0.18*ln(RUR3)) + (0.15*Border) + (0.25*Pent27) + (-0.29*North-Sea) + (0.2*Medoc)

	Peri-urban NUTS X	+Typology group A	+Typology group B
R^2	0.362	0.426	0.525

Fig. 6. 4 - Regression for Landscape Shape Index incl. R^2

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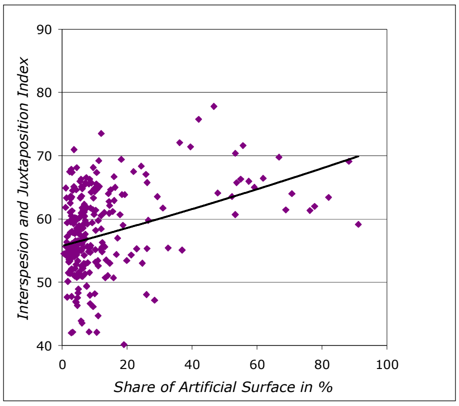
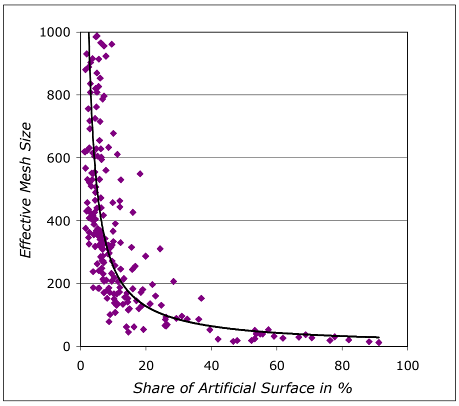


RF: $y = 55.32 + (0.37*AS) + (-2.23*Coast) + (1.91*Border) + (5.3*Pent15) + (-7.76*Pent27) + (-5.47*Atlantic) + (5.46*Medoc) + (4.91*SW\text{-}EU)$

	Peri-urban NUTS X	+Typology group A	+Typology group B
R^2	0.072	-	0.404

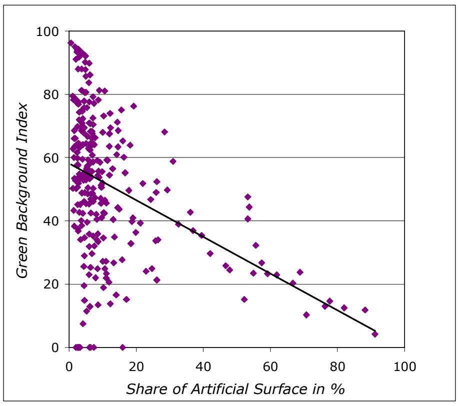
Fig. 6. 5 - Regression for the Interspersion and Juxtaposition Index incl. R^2



RF: $\ln(y) = 6.35 + (-0.72*\ln(AS)) + (0.01*RUR3) + (0.04*Coast) + (-0.53*Archimedes) + (0.7*Medoc)$

	Peri-urban NUTS X	+Typology group A	+Typology group B
R^2	0.683	0.721	0.792

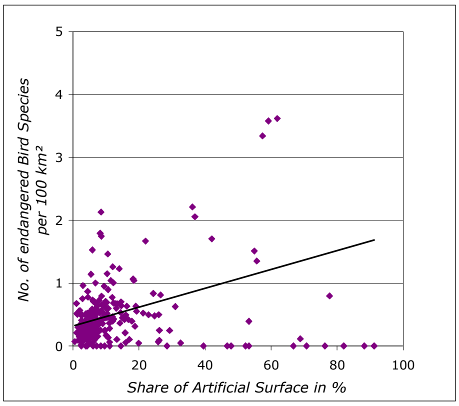
Fig. 6. 6 - Regression for Effective Mesh Size incl. R^2



RF: $y = 68.54 + (-9.7*\ln(AS)) + (6.75*Coast) + (6.25*Border) + (-13.61*North\text{-}Sea) + (-10.22*CADSES) + (7.99*Atlantic) + (18.51*Alpine)$

	Peri-urban NUTS X	+Typology group A	+Typology group B
R^2	0.122	0.139	0.405

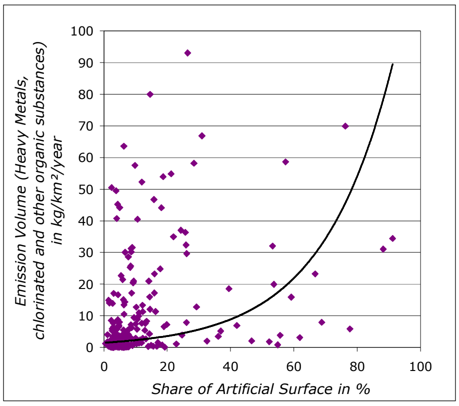
Fig. 6. 7 - Regression for Green Background Index incl. R^2



RF: $y = 0.24 + (0.03*AS) + (0.26*North\text{-}Sea)$

	Peri-urban NUTS X	+Typology group A	+Typology group B
R^2	0.283	-	0.313

Fig. 6. 8 - Regression for endangered bird species incl. R^2



RF: ln(y) = -0.98 + (0.95 *ln(AS)) + (0.71*Coast) + (-1.16*Baltic)

	Peri-urban NUTS X	+Typology group A	+Typology group B
R^2	0.215	-	0.277

Fig. 6. 9 - Regression for Emission Volumes incl. R^2