DISSERTATION

Titel der Dissertation

European spatial reference frameworks for landscape structure analysis and their use for assessing ecological sustainability

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Wien, am

The landscape is changing, the landscape is crying
Thousand of acres of forest are dying
Carbon copies from the hills above the forestline
Acid streams are flowing ill across the countryside

'cause I don't care if you're going nowhere
Just take good care of the world
I don't care if you're going nowhere
Just take good care of the world

Now we're rearranging there's no use denying
Mountains and valleys can't you hear them sighing?
Evolution, the solution, almost certainty
Can you imagine this intrusion of their privacy?

'cause I don't care if you're going nowhere
Just take good care of the world
I don't care if you're going nowhere
Just take good care of the world

Token gestures, some semblance of intelligence
Can we be blamed for the security of ignorance

'cause I don't care if you're going nowhere
Just take good care of the world
I don't care if you're going nowhere
Just take good care of the world

Depeche Mode (1983)

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Kurzfassung

In den letzten Jahren ist die Erfassung von Landnutzungstrends und damit verbundenen Gefährdungen in europäischen Landschaften immer dringlicher geworden. Um jedoch statistisch relevante Aussagen zu treffen, ist es unumgänglich, eine Regionalisierung auf statistischen Methoden aufzubauen, welche stark von der jeweiligen Fragestellung abhängt. In dieser Arbeit werden zwei Regionalisierungen und darauf basierende Landschaftsstrukturanalysen präsentiert: (1) Das Spatial Regional Reference Framework (SRRF), welche die Grundlage für europäische Nachhaltigkeitsanalysen bildet und (2) Regionen entlang des Europäischen Grünen Bandes. Die Methodik der Landschaftsstrukturanalyse wurde gewählt, um ökologische Nachhaltigkeit zu bewerten und Prozesse beiderseits des ehemaligen Eisernen Vorhangs zu vergleichen. Basierend auf einem begrenzten Datensatz biophysikalischer und sozioökonomischer Parameter wurden durch eine Cluster Analyse 27 SRRF-Regionen und neun Regionen am Grünen Band identifiziert. In zehn ausgewählten SRRF-Regionen wurden insgesamt 30 Landschaftsstichproben zufällig ausgewählt, Satellitenbilder segmentiert und mit deren Landbedeckung verschnitten. Für diese Stichprobe und für das gesamte Europäische Grüne Band wurden Landschaftsindizes der Landbedeckung berechnet. Die ökologische Nachhaltigkeit wurde aufgrund der Abweichung vom durchschnittlichen Landschaftsmuster bewertet, welche eine klare Simplifizierung und Geometrisierung zeigte. Entlang des Grünen Bandes sind die Unterschiede in Komposition und Konfiguration in der Landschaft östlich und westlich der Grenze immer noch erkennbar, obwohl sich die sozioökonomische Entwicklung in Osteuropa während der letzten 20 Jahre stark westlichen Mustern angenähert hat. Jedoch würde eine bessere räumliche Auflösung der Landbedeckungsdaten erheblich zur Verbesserung der Strukturanalyse und der darauf basierenden Bewertung von Prozessen beitragen. Die Kombination von Information auf verschiedenen Maßstabsebenen für die Formulierung und Umsetzung von Nachhaltigkeits- und Naturschutzpolitik wird daher empfohlen.

Erweiterte Zusammenfassung

Einleitung

Urbanisierung, Industrialisierung, großräumige Landveränderungen und Klimawandel sind Beispiele für Prozesse, welche breitgefächerte Veränderungen in unserer Landschaft hinterlassen, zu Verlusten an Habitaten und Biodiversität führen und dadurch das menschliche Wohlbefinden enorm beeinflussen (Millenium Ecosystem Assessment, 2003). Internationale und nationale Institutionen reagierten auf diese schwerwiegenden Entwicklungen mit politischen Maßnahmen, um einen besseren Schutz für unsere Landschaften und Habitate zu ermöglichen. Diese ergaben ein breites Spektrum an Europa-weiten Anstrengungen und Maßnahmenkataloge. Ein Beispiel für solch einen Top-Down-Zugang ist die Formulierung der Nachhaltigkeitsstrategie, worin alle EU-Institutionen aufgerufen sind, eine integrative Nachhaltigkeits-Bewertung der jeweiligen Politik-Optionen zu veranlassen (CEC, 2005, 2006).

Auf der anderen Seite gibt es lokale und regionale Initiativen, welche ihre Umwelt, in der sie leben, zu schützen und eine nachhaltige Entwicklung ihrer Landschaften zu fördern suchen. Diese Bottom-up-Entwicklung lässt sich am Beispiel des Grünen Bandes Europas verfolgen (Terry et al., 2006). Die einzigartige historische und naturräumliche Situation betrifft 24 europäische Länder und gibt der Wissenschaft die Möglichkeit, Konsequenzen politischer Entscheidungen in einer Reihe von Landschaften mit unterschiedlichen biophysikalischen Bedingungen zu untersuchen.

Das gemeinsame Ziel beider Beispiele ist die Förderung nachhaltiger Entwicklung und das Entgegenwirken negativer Prozesse. Die Herausforderung dabei ist die wissenschaftliche Untersuchung, diese Prozesse in den Landschaften zu verstehen. Dieses Verständnis ist jedoch notwendig, um eine vergleichende Bewertung der Entwicklungen in den Regionen durchzuführen.

Solch eine Bewertung setzt zwei Anforderungen voraus:

(1) Konsistente räumliche Daten müssen für die Berechnung von den geforderten Indikatoren vorhanden sein.

(2) Landschaften müssen als homogene ökologische und sozioökonomische Einheiten abgegrenzt werden, um eine vergleichende Bewertung zwischen den europäischen Regionen zu ermöglichen.

Der erste Teil dieser Dissertation widmet sich daher der Beschreibung und Herleitung dieser vergleichbaren räumlichen Einheiten, d.h. Landschaften mit gleichen Bedingungen, von Europa und des Europäischen Grünen Bandes. Da Landschaftsstruktur bereits mit Biodiversität (Pino et al., 2000; Zechmeister and Moser, 2001; Zechmeister et al., 2003; Peterseil et al., 2004; Zebisch et al., 2004) und anderen wichtigen Landschaftsfunktionen wie Hochwasserschutz oder Erosionsschutz in Verbindung gebracht wurde (Forman, 1995; Millennium Ecosystem Assessment, 2003; de Groot et al., 2002; Blaschke, 2006), scheint es wert, das Potential der Landschaftsstrukturanalyse für die Bewertung von solch komplexen Themen wie ökologischer Nachhaltigkeit zu beleuchten. Daher findet sich eine konsistente Landschaftsstrukturanalyse von ausgewählten europäischen Regionen und des Europäischen Grünen Bandes im zweiten Teil der Dissertation. Schlussendlich wird die Landschaftsstruktur als Indikator zur Nachhaltigkeitsbewertung in ausgewählten europäischen Regionen benützt.

Methodik und Ergebnisse

(1) Das Spatial Regional Reference Framework

Die Regionalisierung der Europäischen Union (plus Norwegen und der Schweiz) wurde durch statistisches Clustern biophysikalischer und sozioökonomischer Eigenschaften der sogenannten NUTS-Einheiten (Nomenclature of Territorial Units for Statistics – Official Journal of the European Union, 2003) vorgenommen. Umweltvariablen (Klima, Topographie, Untergrund und Landbedeckung) sowie sozioökonomische Daten (Bevölkerungsdichte, Veränderungsrate der Bevölkerung, Aktivitäts- und Arbeitslosenrate, Bruttoinlandsprodukt und funktionale urbane Flächen) stammten aus Datenbanken der European Spatial Planning Observation Network (ESPON, 2006), Eurostat (European Statistical Office), und LANMAP2 (Mücher et al., 2010). K-Means Clusteranalyse mit Euklidischer Distanz wurde für die Umwelt- und die sozio-ökonomischen Daten extra gerechnet. Jede NUTS-Einheit wurde aufgrund der Clusterdistanzen einem Umwelt- und einem sozioökonomischen Cluster zugewiesen. Die endgültigen Regionen ergaben sich durch das Zusammenfügen der NUTS-Einheiten auf Basis ähnlicher Clusterdistanzen und Expertenwissen.

Durch die Regionalisierung resultierten 27 Regionen, basierend auf 25 Umwelt- und 20 sozioökonomischen Clustern. Klima und Landbedeckung sind die hauptsächlichen Unterscheidungsmerkmale, während Topographie, Untergrund, Bevölkerungsdichte und Bruttoinlandsprodukt für die Unterscheidung innerhalb der Klimaregionen verantwortlich waren. Die größten Regionen bedeckten mehr als 500 000 km², während die kleinste Region nur 22 000 km² groß ist. Manche Regionen splitterten sich auf mehrere europäische Länder auf.

Im nächsten Schritt wurden 10 Regionen ausgewählt, welche die biogeographischen Regionen repräsentieren sollen (EEA, 2002). Pro Region wurden zufällig drei Satellitenbilder von 50 x 50 km² im offiziellen europäischen Gridsystem selektiert. Die Bilder wurden segmentiert und danach mit Landbedeckungsinformation überlagert.

Kennzahlen der Landschaftsstruktur wurden berechnet und statistisch analysiert, womit signifikante Unterschiede gezeigt werden konnten. Mann-Whitney-U-Test und Box-and-Whisker-Plots zeigten deutliche Unterschiede in den Landschaftsmustern der einzelnen Regionen. Weiters konnte gezeigt werden, dass die Kennzahlen die Unterschiede je nach Landbedeckung unterschiedlich gut widerspiegeln. Das Landschaftsmuster natürlichen Grünlands zeigte die geringsten Unterschiede zwischen den Regionen, während die größten für nicht-bewässertes Ackerland gefunden wurden. Die Regionen „Continental Forests“ und „Mountain Open Spaces“ zeigten die größten Kontraste, da fast jede Kennzahl in allen untersuchten Landbedeckungsklassen Differenzen erfassen konnte.

Wendet man das „Konzept der Abweichung“ auf die europäischen Landschaftsstichproben an, kann man Flächen geringerer und höherer Nachhaltigkeit (basierend auf den statistischen Ergebnissen der Kennzahlen für Landschaftsstruktur lässt sich die relative Nachhaltigkeit als Abweichung zum Durchschnitt definieren) innerhalb der Regionen aufzeigen. Im allgemeinen ist ein Nachhaltigkeits-Gradient an Landschaften in jeder Proben-Region zu erkennen.

(2) Das Grüne Band Europas

Das Grüne Band Europas ist ein einmaliges Beispiel für ein transkontinentales Bottom-Up-Schutzgebiets-Netzwerk in einer Vielfalt an Landschaften, welches sich in der zweiten Hälfte des vorigen Jahrhunderts entlang des früheren Eisernen Vorhangs entwickelte. Ein 50 km breiter Streifen entlang der Grenzen von 24 europäischen Staaten stellt die geeigneten Habitate und Wanderkorridore für viele bedrohter Arten zur Verfügung. Die Definition von biophysikalischen Regionen entlang des Eurpäischen Grünen Bandes basierend auf statistischen Methoden ergibt die notwendige Basis für die Bewertung und den Vergleich von Themengebieten wie Biodiversität und Naturschutz und die Untersuchung sozio-ökonomischer und ökologischer Prozesse.

Die Regionalisierung erfolgte durch Clustern der Variablen Klima, Topographie, Breitengrad und Küstennähe. Hier ergaben sich neun Regionen: drei Küstenregionen (Boreal-Nemoral, Continental-Baltic und Mediterranean-Black Sea Coast) unterschieden sich von sechs Inland-Regionen (Arctic, Boreal Baltic Inland, Continental Lowlands, South Eastern European Lowlands, Low and High Mountain Ranges und Mediterranean Mountains and Inland). Die nördlichen Regionen waren räumlich zusammenhängender als in Mittel- und Südeuropa, wo die Cluster ein gefleckteres Bild ergaben. Landschaftsstrukturanalyse mittels Berechnung von Kennzahlen der Landbedeckung ergaben den höchsten Simpsons Diversitäts-Wert in den Mittelmeergebieten. Die Kennzahlen zeigten eine außergewöhnlich irreguläre Gestalt der Weidenflächen in „Contintental Baltic Coast“. Die höchsten Konnektivitäts-Werte für Ackerland zeigten sich in „Contintental Lowlands“, diejenigen für Wald in „Boreal Baltic Inland“. Ein Ost-West-Vergleich zeigte Unterschiede im Anteil und der Größe von Ackerland-Flächen in „Low and High Mountain Ranges“ sowie „Continental Lowlands“. Obwohl sich die Landnutzung Osteuropas in den vergangenen 20 Jahren stark der westlichen angenähert hat, sind die Unterschiede östlich und westlich der Grenze immer noch in den Landschaften erkennbar. Die Unterschiede in der Landschaftsdiversität ergibt sich die Verschiedenartigkeit der Kulturlandschaften in Südosteuropa, welche einen besonderen Reichtum an Biodiversität besitzen.

Schlussfolgerungen

Mehrere Schlussfolgerungen können aus der präsentierten Arbeit gezogen werden. Die Wichtigkeit der statistischen Regionalisierung soll betont werden, weil es nur dadurch möglich wird, relevante Information umweltbezogener Themen auf größere Einheiten zu extrapolieren. Allerdings beeinflussen die Zielvorgaben die Wahl der Eingangsvariablen, -daten und Methoden. Darüber hinaus kann eine geometrische Vereinfachung der Landschaften sogar auf europäischer Ebene gesehen werden. So lassen sich geeignete Kennzahlen für Landschaftsstruktur auch als Indikatoren für ökologische Nachhaltigkeit gebrauchen unter der Bedingung, dass Landbedeckung und ein räumlicher Bezugsrahmen berücksichtigt wird. Vernetzung von Maßstabsebenen und Datenbanken, Integration von

Freilanddaten und Nutzung ausgewählter Ferkerkundungsdaten lassen somit zufriedenstellende Ergebnisse erwarten.

Abstract

The need to assess trends and impacts on European landscapes has extremely increased during the last years. In order to draw statistically relevant conclusions, a regionalisation based on statistical procedures is indispensable and dependent on the underlying objectives. In this thesis, two regionalisations and subsequent landscape structure analysis are presented: (1) the Spatial Regional Reference Framework (SRRF) which serves as a basis for a European-wide sustainability impact assessment, and (2) the European Green Belt (EGB) regions. Landscape structure analysis is chosen as the main tool for assessing ecological sustainability in selected SRRF regions and comparing processes on both sides of the former Iron Curtain along the European Green Belt. Cluster analysis on a restricted set of bio-physical and socio-economic variables identified 27 SRRF regions and nine Green Belt regions. 30 sample sites in ten selected SRRF regions were randomly chosen, where segmentation of satellite images and intersection with land cover information was performed. For these 30 sites and the whole EGB, landscape metrics were calculated on land cover data. Ecological sustainability for the SRRF was assessed by the relative deviation from the average pattern as a result of simplification and geometrisation in the landscapes. Along the EGB, the differences in composition and configuration of the landscape east and west of the border were still visible in the regions, although socio-economic processes in Eastern Europe approximated Western patterns during the last 20 years. However, a better spatial resolution of land cover data would add to the refinement of pattern analysis in the regions and therefore improve the assessment of related processes. The combination of information of different scales for the formulation and implementation of sustainability and nature conservation policies is recommended.

Extended Summary

Introduction

Processes like urbanisation, industrialisation, large-scale land transformation, and climate change left their marks in our environment leading to broad-scale changes accompanied by a notable loss of habitats and biodiversity, which affected human well-being enormously (Millenium Ecosystem Assessment, 2003). Reacting to these severe developments, international and national agencies took policy measures for a better protection of our landscapes and habitats resulting in a wide range of European-wide efforts. An example for such a top-down approach is the formulation of the Sustainable Development Strategy urging all EU institutions to perform an integrative sustainability impact assessment for their policy options (CEC, 2005, 2006).

But also on the other hand, there are regional and local initiatives which try to preserve their environment in which they live and want to enhance the sustainable development of the landscapes. This bottom-up development can be followed by the evolvement of the

Green Belt of Europe (Terry et al., 2006). The unique historical and environmental situation affecting 24 European countries gives us the chance of investigating the consequences of political decisions in a variety of landscapes each with different bio-physical preconditions.

Common aim of both examples is to trigger sustainable development and mitigate negative processes. The challenge is to find scientifically sound ways of investigating and understanding the processes in landscapes. Such an understanding is necessary for subsequent impact assessment comparing the regions in their developments.

For such an assessment, two requirements must be fulfilled:

(1) Consistent spatial data need to be available for the calculation of requested indicators;

(2) Landscapes need to be delineated as homogenous ecological entities and socio-economic units for a comparative assessment among the European regions.

The first part of this thesis therefore aims at deriving these comparable spatial units, i.e. landscapes of similar conditions, of Europe and the European Green Belt by means of regionalisation procedures. Since landscape structure has been linked to biodiversity (Pino et al., 2000; Zechmeister and Moser, 2001; Zechmeister et al., 2003; Peterseil et al., 2004; Zebisch et al., 2004) and to other important landscape functions e.g. flood prevention, limiting erosion risk (Forman, 1995; Millennium Ecosystem Assessment, 2003; de Groot et al., 2002; Blaschke, 2006) it seems worthwhile to further explore the potential of landscape structure analysis as a proxy for the evaluation of such complex issues like ecological sustainability. So, consistent landscape structure analysis for selected European regions and the European Green Belt is performed as a second part of this thesis. Finally, landscape structure is used as indicator for sustainability impact assessment of the selected European regions.

Methods and Results

(1) The Spatial Regional Reference Framework

Regionalisation of the European Union (plus Norway and Switzerland) was performed by statistical clustering of biophysical and socio-economic attributes of the Nomenclature of Territorial Units for Statistics (NUTS – Official Journal of the European Union, 2003) as spatial unit. Environmental (climate, topography, bedrock and land cover data), and socio-economic data (including population density, population change rate, activity rate, gross domestic product (GDP), unemployment rate and functional urban areas) were extracted from the European Spatial Planning Observation Network (ESPON, 2006), and Eurostat (European Statistical Office) databases, and LANMAP2 (Mücher et al., 2010). K-Means cluster analysis using Euclidean distance was performed separately for environmental and socio-economic variables. Each NUTS unit was assigned to an environmental and a socio-economic cluster on the basis of similar cluster distances. The final regions were constructed by merging NUTS units based on similarity in cluster distances and expert knowledge.

The regionalisation resulted in 27 regions, based on 25 environmental clusters and 20 socio-economic clusters. Climate and land cover were the main discriminators, while topography, parent material, population density, and GDP played an important role in differentiation between the major climate zones. The largest regions cover more than 500 000 km², while the smallest region covers only 22 000 km². Several regions cover areas in many European countries.

In the next step, 10 regions were selected with the condition of representing European biogeographic regions (EEA, 2002). Within the selected regions, three satellite images by 50 x 50 km² were randomly selected using the official European grid system. Segmentation of the images was performed and subsequently overlaid with land cover information.

Landscape metrics were calculated and statistically analysed revealing significant differences among the landscape metrics. Mann–Whitney U-test and box-and-whisker-plots revealed significant differences of landscape pattern among the ten regions. We also detected that the metrics regarding the different land covers performed differently in depicting these differences. The landscape pattern of natural grassland was least different among the regions, while the highest differences were uncovered for non-irrigated arable land. The most contrasting regions were "Continental Forests" and "Mountain Open Spaces" as nearly every metric in each land cover class distinguished them significantly.

Applying the 'Concept of Deviation' to the European landscape samples, areas of lower and higher sustainability (based on the statistical results of the landscape metrics the relative sustainability can be defined as deviation from to the average) within the European regions were detected. Generally, a gradient of landscapes with different sustainability areas can be seen in each sampling region.

(2) The European Green Belt

The European Green Belt presents a unique example of a transcontinental bottom-up conservation network in a big diversity of landscapes which evolved in the second half of the last century along the former Iron Curtain. A strip of 50 km along the borders of 24 European countries provides suitable habitats and migration corridors of many endangered species. The definition of biophysical regions along the European Green Belt based on statistical regionalisation procedure gives the necessary basis for the assessment and comparison of biodiversity and nature conservation issues and for investigating socio-economic and ecological processes.

The regionalisation was based on clustering the variables of climate, topography, latitude, and coastal influence. Nine regions resulted, three coastal regions (Boreal-Nemoral, Continental-Baltic, and Mediterranean-Black Sea Coast) differentiated from six inland regions (Arctic, Boreal Baltic Inland, Continental Lowlands, South Eastern European Lowlands, Low and High Mountain Ranges, and Mediterranean Mountains and Inland). The northern regions were spatially more coherent whereas in Central and Southern Europe, the clusters showed a patchier picture. Landscape structure analysis, done by calculating landscape metrics for land cover maps, revealed that Mediterranean regions showed the highest Simpsons' diversity values. Patch metrics showed particularly irregular shape for pastures in the Continental Baltic Coast region. Arable land had maximum values of connectivity in the Continental Lowlands. Forests showed highest connectivity in the Boreal Baltic Inland region. The East-West comparison exposed differences in proportion and size of arable land patches in Low and High Mountain Ranges and Continental Lowlands. Although approximation towards western land use practices occurred in Eastern Europe during the last 20 years, differences in the landscapes east and west of the border were still visible. The differences in landscape diversity are mainly based on the heterogeneity of the cultural landscapes in South-Eastern Europe that are particularly rich in biodiversity.

Conclusions

Several main conclusions can be drawn from the presented work. First, the importance of statistical regionalisation procedures is stressed as only here it is possible to extrapolate relevant information on environmental issues to larger areas. Still, the underlying objectives strongly influence the choice of input variables, data sets and methods. Moreover, a geometrical simplification of landscapes can be seen even at the European scale, thus making sensitive landscape indices utilisable indicators for ecological sustainability of land use when applied together with land cover types in a spatial regional reference. As such, satisfying results are expected if they link scales and databases appropriately, making use of field observations in combination with carefully selected and adapted Earth observation data.

Introduction

Background

The research topic of this thesis is situated within the science of landscape ecology. As the name already reveals, the main object of investigation is the landscape. But what is a landscape?

A wide variety of definitions of this term exists, many of them relating to the expanse of an area with certain characteristics. In general, the scope of the definition is strongly influenced by the individual area of expertise. Turner et al. (2001) suggest a rather general description: *"a landscape is an area that is spatially heterogeneous in at least one factor of interest".* This should ensure the independence of scale (and size) and of human impact.

On the other hand, the European Landscape Convention (Council of Europe, 2000) clearly involves humans' perception into the definition of landscape: *"'Landscape' is defined as a zone or area as perceived by local people or visitors, whose visual features and character are the result of the action of natural and/or cultural (that is, human) factors. This definition reflects the idea that landscapes evolve through time, as a result of being acted upon by natural forces and human beings. It also underlines that a landscape forms a whole, whose natural and cultural components are taken together, not separately."*

In the last years, the need to assess the impact of broad-scale changes in our environment has been recognised. Processes like urbanisation, industrialisation, large-scale land transformation, and climate change have induced a notable loss of habitats and biodiversity, and affected human well-being enormously (Millennium Ecosystem Assessment, 2003). National and international agencies acknowledged to this impact of land use changes. They were forced to take policy measures in order to give a higher degree of protection to our landscapes and habitats.

Landscapes seen as ecological entities and socio-economic territories have therefore become a central item on international research and political agendas.

- European Landscape Convention (Council of Europe, 2000): this international treaty was formulated for the protection, management and enhancement of the European landscape. It applies to natural, urban and peri-urban areas, whether on land, water or sea. The convention acknowledges the value of landscapes for the quality of the environment and stresses the point that many areas are experiencing transformations which need closer consideration from society.
- Convention on the Conservation of European Wildlife and Natural Habitats (Council of Europe, 1979): It is also called the Bern Convention and its major objectives are to conserve as well as to monitor and control wild species and their natural habitats.

- Natura 2000 (Council of the European Union, 1992): This ecological network of protected areas is designed to protect the most seriously threatened habitats and species in Europe and contribute to the aims of the Bern Convention. The network clearly acknowledges the importance of the habitats' surrounding landscape context for the status of the protected areas.
- Pan-European Biological and Landscape Diversity Strategy (PEBLDS; Council of Europe, 1996): The aims here are to ensure the conservation of habitats and species, and to preserve important European landscapes. It promotes the integration of biological and landscape diversity considerations into social and economic sectors. Furthermore, the Strategy developed a framework for the implementation of the Convention on Biological Diversity.
- Common Agricultural Policy (CAP; http://ec.europa.eu/agriculture/publi/fact/index_en.htm): One of the aims of this very important European policy is to preserve the rural heritage of European landscapes. Its central tool is the payment of subsidies to farmers for specified crop- or set-aside management. Since 2004, environmental requirements need to be fulfilled and observed to maintain subsidies. The need of environmental indicators to observe the environmental performance of agricultural policy was stressed by the development of the IRENA-indicators (EEA, 2005). Here, data on species, habitat and landscape level need to be provided for their calculation, although the scientific foundation of the indicators has not been provided sufficiently and lacks operationalisation.

All these conventions and strategies aim at preserving the values of the landscapes and the habitats and species they are including. On the other hand, the scientific coverage is not given; operationalisation and detailed empirical data collection is still missing or focus of ongoing research projects. So there is an urgent need to empirically investigate and understand the processes in landscapes. Here, landscape ecology can essentially contribute.

There are two main aspects identified by Turner et al. (2001) which all definitions of 'landscape ecology' have in common:

(1) Importance of spatial configuration for ecological processes:

(2) Focus on spatial extents larger than those traditionally studied in ecology

Thus, landscape ecology is revealing the importance of spatial patterning on the dynamics of interacting ecosystems, the causes and consequences of spatial heterogeneity across a range of scales.

Following the concept of landscape ecology by Forman and Godron (1986), three different attributes of any landscape are distinguished. At first there is the structural level (**'structure'**) which is dealing with the spatial relations between individual, distinct local ecosystems – the so-called landscape elements, as well as the distribution of energy, resources and species in relation to size, shape, number and type of such elements.

Furthermore, there is the functional level (**'function'**) of the landscape describing the interaction between adjacent landscape elements including material- and energy flow as well as the exchange of species between them.

Finally, changes in structure and function of the ecological mosaic over time are investigated in order to better understand the dynamic aspects of landscapes (**'change'**).

The structure of landscape is reflecting not only the natural settings of the landscape but also its history and the impact of mankind throughout the centuries (Antrop, 2005; Ernoult et al., 2006). The present spatial patterns are a result of former activities and processes in the landscape (Turner et al., 2001). Many European cultural landscapes developed their own regionally distinct pattern of landscape elements which is the aim of ongoing or recently finalised European research projects.

According to the above mentioned "pattern & process" paradigm – the basic unit of any landscape is the so-called landscape element. It is defined as being the smallest spatial unit, which can be identified and delineated as ecologically homogeneous in regard to crucial land attributes like soil type, microclimatic and hydrological conditions, actual vegetation etc. Technically, a landscape element is the smallest mapable unit at the given spatial scale of investigation. Forman and Godron (1986) identified three basic types of landscape elements, according to spatial extent, shape and functionality:

a. The **matrix** is composed of the local ecosystems which cover a large part of the area and significantly influence the ecological functions of the landscape. It gives the 'background information' in which other important landscape features are settled.

b. **Corridors** can be identified by their significant elongated shape as a line or a band depending on their width. They are playing an important role in material and energy transport but especially in migration of animals and plants. In almost any case, corridors are organised as networks, showing clear differences between the connecting and dissecting function of their respective individual elements. Especially in highly impacted landscapes dissecting corridors are represented by transportation networks, whereas rivers together with their tributaries can act as a connecting network. This concept is the research focus of ecological restoration projects dealing with the so-called blue, green and red veining (Opdam et al., 2006).

c. In between matrix and corridors, **patches** are situated. These are small-scaled landscape elements which can be distinguished by their origin (disturbance, regeneration, resource dependant, introduced...), thus indicating significant differences in functionality and genesis of comparable types of mosaics.

This “pattern and process” paradigm, which interprets the spatial relationship of crucial landscape elements as frozen processes (Wrbka, 1996) thus allowing researchers drawing conclusions about the functioning of comparable landscape units.

Providing the Spatial Reference

In order to derive these comparable units, i.e. landscapes of similar conditions, regionalisation procedures seem appropriate. They provide the spatial reference framework of investigating the processes reflected in the spatial arrangement of the landscape elements. The classification of knowledge and data is essential for the analysis, summary and communication of the complexity of ecological and socio-economic systems.

Landscapes compose of different factors. Turner et al. (2001) identifies climate and landform as the main abiotic causes; as well as competition between species and human land use as the major biotic reasons for landscape patterns. Mücher et al. (2010) expand the abiotic range of factors by hydrology, soils and include vegetation and fauna into the biotic aspects. Mücher et al. (2010) argue for ordering these features by increasing dependency as it can support classification and mapping by: *“(i) in the selection of data that are considered important, (ii) by ranking these according to the hierarchy shown and therefore, (iii) can contribute to the architecture of a classification from which, and (iv) a legend of a map can be derived.”*

Following the concept of Ružicka and Miklos (1990) and O’Neill et al. (1986), “primary – secondary – tertiary landscape structure”, an approach that tries to systematically assign any landscape attribute to the biophysical (= primary landscape structure or PLS), the land-management / socio-economic (= secondary landscape structure or SLS) and the planning / policy domain (= tertiary landscape structure or TLS), most studies formulate the relationships between pattern and process on the SLS domain.

In this concept, parameters which can hardly be altered; e.g., climate, topography and bedrock; are the main drivers of land cover and are therefore assigned as PLS. Landscape change resulting from human interaction with PLS can be rapid; e.g., from forest to pasture; and is therefore at the second hierarchical level. Landscape policy and / or planning and administrative boundaries are often dynamic, but in general their influence is not readily quantifiable. These aspects are assigned to the lowest level of the concept – the TLS.

A classification of landscape shaping factors is necessary if these want to be compared in a reproducible way and thus allows the analysis of changes and effects separately from environmental heterogeneity by using standard statistical procedures (Bunce et al., 1996a). Spatial stratifications can be used (1) as basis for up-scaling, (2) for stratified random sampling, (3) for the selection of representative sites for studies across the continent, and (4) for the provision of frameworks for modelling exercises (Metzger et al., 2005).

Quite a few approaches to European wide landscape classifications were merely driven by expert judgement and personal intuitive description of environmental regions such as Meeus' map of European landscapes (1995) or the Biogeographic Regions Map of Europe (EEA, 2002). Although Bohn et al. (2004) produced a map of potential vegetation for Europe, it still delineates regions with similar environmental conditions. While these descriptions deliver very important information about landscape characteristics, statistical sampling and extrapolation is not possible.

Other procedures for a European classification relied on quantitative and statistical methods. Important steps forward triggered by the increasing availability of consistent European data sets were Jones and Bunce (1985) or (Bunce et al., 1996b). Since then, a wide variety of regionalisation approaches have been developed (Hazeu et al., 2010; Metzger et al., 2005; Mücher et al., 2010; Renetzeder et al., 2008).

Hazeu et al. (2010) and Mücher et al. (2010) stress the point that the choice of input variables and data set is strongly dependent on the underlying objectives of the respective regionalisation approach. In the following part, I will therefore explain the background and assumptions for the regionalisation of the (1) Spatial Regional Reference Framework (SRRF) for sustainability impact assessment, and (2) European Green Belt Regions.

Regionalisation for Sustainability Impact Assessment

Although the roots of the term 'sustainability' reach back to forestry of the 19th century (Schuler, 1998), nowadays the meaning comprises a central concept of regional development and environmental policy. Sustainability has become keynote of policy for the past 30 years.

The current understanding is strongly influenced by the Brundtland-Report *"Our Common Future"* from the United Nations World Commission on Environment and Development published in 1987 (Unite Nations, 1987). Herein, sustainable development is defined to *"meet the needs of the present without compromising the ability of future generations to meet their own needs"*. This report yielded in a still-enduring discussion about environmental issues also on the political agenda. In 1992, the "Rio Declaration on Environment and Development" was adopted by 178 United Nations member countries at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro. In Rio, also the Commission on Sustainable Development was established to monitor the progress of the agreements.

One of these agreements was the Agenda 21 (United Nations, 1992), which required the development national sustainable development strategies. It demands to *"improve and* *restructure the decision-making process, so that economic as well as social and environmental issues are fully taken into consideration and stakeholder participation is assured"* (§ 8.3). Although 40% of UN member countries had developed and begun to implement a national sustainable development strategy by 2006 (Silveira, 2006), the concept of sustainable development has been kept merely vague. One tool to overcome this vagueness may be Sustainability Impact Assessment (SIA) (CEC, 2007).

In June 2006, the European Union adopted its Sustainable Development Strategy (Council of European Union, 2006). Therein, high quality impact assessment is stressed to be of major importance for better policy making. All EU institutions are urged to assess all policy proposals in terms of the social, environmental and economic dimensions of sustainable development. This integrated assessment procedure (CEC, 2005) now replaces all single sector impact assessment types carried out before on EC policy proposals.

The EU defines impact assessment as *"a process aimed at structuring and supporting the development of policies. It identifies and assesses the problem at stake and the objectives pursued. It identifies the main options for achieving the objective and analyses their likely impacts in the economic, environmental and social fields. It outlines advantages and disadvantages of each option and examines possible synergies and trade-offs"* (European Commission, http://ec.europa.eu/governance/impact/index_en.htm). It needs to be process-oriented, multidisciplinary and interactive.

The challenges to disciplinary science of SIA are outlined in de Vries and Peterson (2009). They stress the importance of incorporating social and economic science into the sustainability research. On basis of their conceptual framework are the natural conditions and resources providing ecological/environmental services. They form entities which give the range of possible capabilities and choices for human well-being. As such, interdisciplinary research is indispensable for providing a sound SIA.

In the spatial context, land use is a human activity with strong impact on the environment (Helming et al., 2008) and thus strongly heavily effecting Sustainable Development. Therefore, spatially explicit approaches are of high relevance.

At the moment, there is no available European regionalisation specifically focusing on sustainable development. The integration of socio-economic data and environmental data into spatially explicit units still remains a challenge. Recently, progresses were made through modelling approaches and land functions (Fohrer et al., 2002; Verburg et al., 2009).

Despite the attempts already being made in spatial regionalisation, the perspective appears to have shifted in the last years from a pure ecological one to include socio-cultural domains (Naveh and Liebermann, 1994, Wascher, 2005). Landscape descriptions which are acknowledging the human aspect have a long tradition in geographical science (Humboldt, 1780; Passarge, 1929, amongst others). Existing interdependencies between landscape character and the socio-economic context in which they reside were also affirmed by Peterseil et al. (2004) and Wrbka et al. (2004) in their investigations. Considering this, it seems a logical step to form an integrated approach when developing regional classifications for SIA.

We argue for a development of a Spatial Regional Reference Framework (SRRF) based on a combination of both bio-physical and socio-economic parameters to overcome the methodological fragmentation of most existing regionalisation approaches. Because regional characteristics determine the scale and scope of impacts on sustainability that have resulted from policy-induced land use changes, the SRRF should further serve as the prerequisite of analysing the synergies and trade-offs between the three different sustainability dimensions.

Regionalisation of the European Green Belt

The European Green Belt (EGB) is an international nature conservation initiative that aims at preserving the diverse landscapes along the former Iron Curtain and sustainably safeguarding their natural and cultural assets (Frobel et al., 2009; Terry et al., 2006). It extends over a length of 12 500 km across 24 European countries crossing nearly all European biogeographic regions (Figure 1), and is embedded for the most part in variegated cultural landscapes. Schlumprecht et al. (2009) developed a database for the numerous nature conservation areas which represent the backbone of a transcontinental habitat network and is a unique example of a transcontinental bottom-up conservation network. Conservation projects are ongoing in all 390 protected areas along the EGB, but its spatial and qualitative continuity still needs improvement and is threatened by fragmentation due to various multinational developments involving land use change and traffic infrastructure (Debinski and Holt, 2000; Jongman, 2002).

This special situation makes the EGB a very interesting subject to landscape ecological research. The north-south direction of the EGB involves the wide range of the European climatic gradient; lowlands as well as high mountain ranges occur. The major geo-ecological landscapes are described by Renetzeder et al. (2009) on basis of biogeographic regions (EEA, 2002), altitude, geological units and land cover (Mücher et al., 2001). This was the first attempt of a typology to stress the uniqueness of the EGB. Nevertheless, a statistical classification of the EGB was still missing.

Since the establishment of the Green Belt 20 years ago, the political and socio-economic conditions approximated the ones of the Western neighbours (Riecken et al., 2006). As human land use is reflected in the landscape structure (see above), differences of anthropogenic impacts should be visible in the landscape, although biophysical preconditions are the same. In order to compare the influence of these political and socio-economic processes on landscape structure, it is therefore necessary to delinate spatial units representing a homogeneous primary landscape structure as defined by Ružicka & Miklos (1990).

This spatial stratification enables further the analysis of the influence of landscape structure on the subjects of protection for each biophysically defined region. The establishment of ecological networks along the EGB would on the one hand contribute to the mitigation of climate change impacts (Vos et al., 2008) and at the same time give the possibility to provide suitable habitats and migration corridors for the return of species that have been extinct in Central Europe like lynx, wild cat, bear or wolf (Kubalek, 2009).

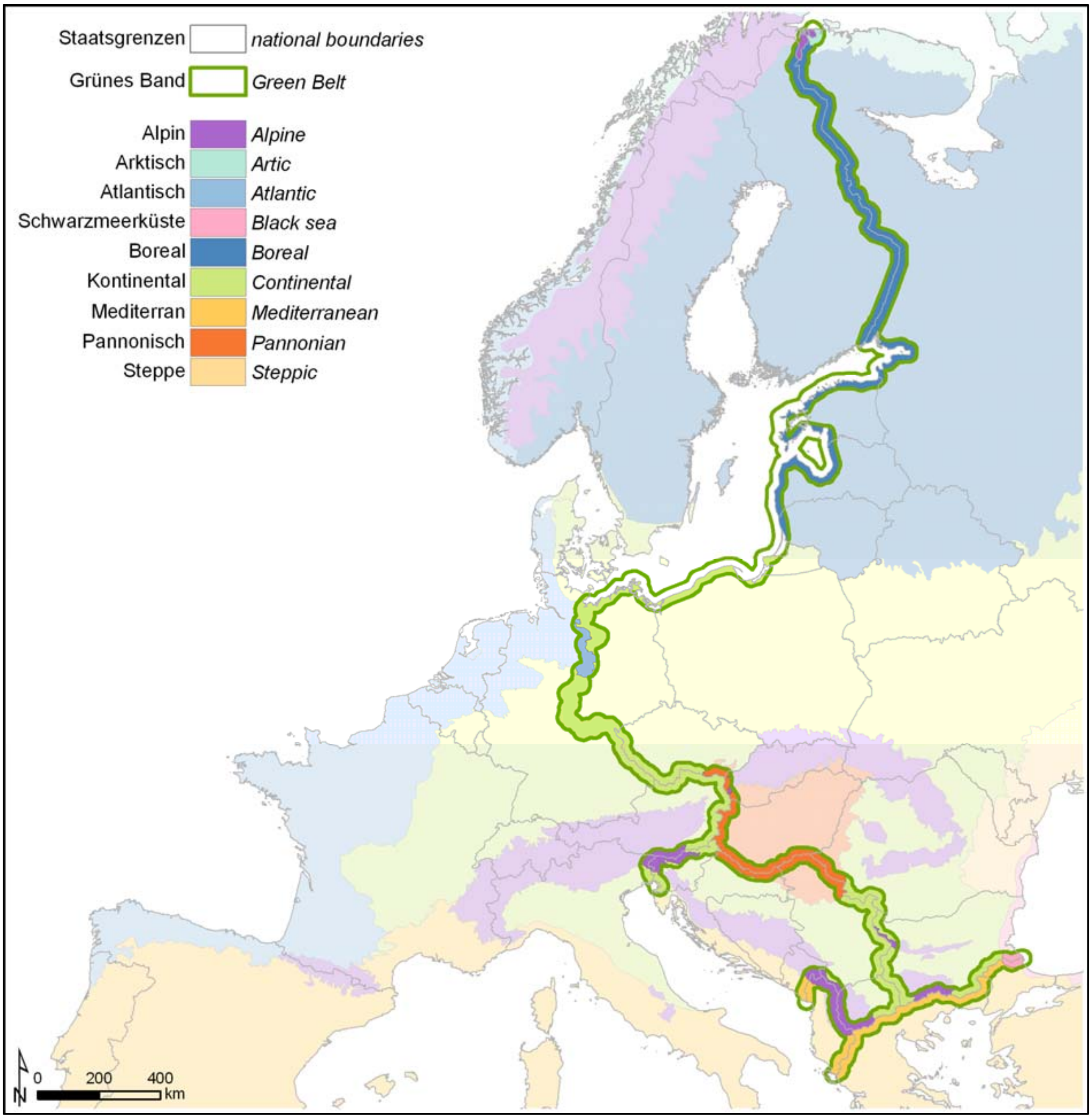

Figure 1: The European Green Belt stretching from North to South crossing all biogeographic regions (EEA, 2002).

Assessment of ecological sustainability

The assessment of complex issues like sustainability needs measurement tools that can simplify, quantify and communicate the requested information. Haberl et al. (2004) stress the need for the development of such targeted tools. As such, the use of indicators for SIA is eminent. There is a wide range of different sustainability assessment methodologies. Singh et al. (2009) provide an exhaustive overview on sustainability indicators and composite indices. As indicators should summarise complex phenomena into one value, they are acknowledged to be the main tool for policy making in conveying information on sustainable development.

In principle, there are three main groups of indicators: monetary, physical and composite indicators. The latter intend to integrate values of different "sub-indicators" into one figure. All the methodologies cover a wide range of aspects: innovation, knowledge, technology, economy, industries, health and many more. Some environmental indicators are integrated in the assessment like the Living Planet Index (Loh et al., 1998) or the Ecological Footprint (Wackernagel and Rees, 1996).

These indicators address ecological sustainability mostly by calculating the area required for raw material, recycling, water and energy consumption, pollution, or product life cycles. Others consider species' population trends. The United Nations Commission on Sustainable Development (UNCSD) developed a core set of 50 indicators for all countries to use. Here, indicators are no longer explicitly categorised into four pillars of sustainable development but into 14 themes. Table 1 provides an overview of the indicators which are in relation to landscape and can therefore be covered by landscape ecological research.

Also, the OECD (Organisation for Economic Co-operation and Development) realised the need to observe the development of environmental conditions and therefore built the structure of an 'pressure' - 'state' - 'response' - indicator framework (OECD, 1993, 2003). It considers that human activities put pressures on the environment and therefore affect the state of natural resources, whereas these changes in state causes society to environmental, general economic and political responses. Although the core set includes 40 to 50 indicators, only a fraction (key-indicators) is available in the majority of the countries and from this key-set, no more than two indicators are directly related to the landscape: 'Species and habitat or ecosystem diversity', and 'area of key ecosystems'.

The OECD explicitly aims at the harmonisation of existing indicators among the countries although it clearly acknowledges the need for adaptation at the national level. Haberl et al. (2004) stress the need for putting indicators into the regional context; the same indicator may not work everywhere equally well.

Table 1. Core indicators suggested by the United Nations Commission on Sustainable Development (UNCSD, 2007), which are directly related to landscape ecology.

Theme	Sub-theme	Core indicator	Other indicator
Land	Land use and status		Land use change
			Land degradation
	Desertification		Land affected by desertification
	Agriculture	Arable and permanent cropland area	Fertilizer use efficiency
			Use of agricultural pesticides
			Area under organic farming
	Forests	Proportion of land area covered by forests	Percent of forest trees damaged by defoliation
			Area of forest under sustainable forest management
Biodiversity	Ecosystem	Proportion of terrestrial area protected, total and by ecological region	Management effectiveness of protected areas
			Area of selected key ecosystems
			Fragmentation of habitats

So, the need to indentify environmental trends with indicators which are adapted to the regional scale is obviously formulated. Here, landscape ecological concepts can contribute a lot. Much of the existing knowledge in landscape ecology is not efficiently used for these objectives.

Peterseil (2001) showed the significant relationship of species diversity and richness of landscape mosaics as well as the length of ecotones. Also, land use intensity clearly influences geometrical landscape complexity and this in turn determines species diversity (Moser et al., 2002). Since landscape structure has been linked to biodiversity (Pino et al., 2000; Zechmeister and Moser, 2001; Zechmeister et al., 2003; Peterseil et al., 2004; Zebisch et al., 2004) and to other important landscape functions e.g. flood prevention, limiting erosion risk (Forman, 1995; Millennium Ecosystem Assessment, 2003; de Groot et al., 2002; Blaschke, 2006) it seems worthwhile to further explore the potential of landscape structure analysis as a proxy for the evaluation of such complex issues like ecological sustainability.

Human activity leads to geometrisation of the landscape (Forman, 1995; Turner et al., 2001). The complexity of boundaries in the landscape decreases, while at the same time, the landscape elements become more compact (Forman, 1995). In contrast, the pattern of semi-natural landscapes is more complex. Odum and Turner (1989) have shown in their classical work how increasing consumption of fossil energy and agrochemicals are coupled with a geometrical simplification of landscapes expressed by a decrease in Fractal Dimension. Although the driving forces behind the process of simplifying landscape patterns are manifold, some general conclusions can be drawn. Agricultural land generally shows regular patterns caused by modern cultivation methods (Krummel et al., 1987; Moser et al., 2002), remnant semi-natural areas are normally bounded by cultivated land and therefore show straight boundaries (Hulshoff, 1995; Krummel et al., 1987) and the intensification of land use often leads to a decline of natural and semi-natural areas (Mander et al., 1999; Wrbka et al., 2008). These processes are linked also in a reduction in habitat diversity and heterogeneity. The removal of small biotopes or changes in the patch size of land use parcels to larger units can therefore be seen as an unsustainable development, at least in terms of ecological sustainability. Opposing processes, such as the introduction of small biotopes can be seen as sustainable development in its ecological dimension.

For the assessment of ecological sustainability in Austrian landscapes, Peterseil et al. (2004) could show significant correlations of hemeroby (Naveh and Liebermann, 1984) and landscape metrics. An ordinal regression model was used for the production of a national-wide hemeroby probability map and applied for sustainability assessment. As at European level, there is no consistent data available on human impact or hemeroby to correlate with, simple rules for assessing trends in sustainability were applied. A first indication is the deviation of landscape metrics from the average, based on the Austrian 'Concept of Relative Deviance' (Peterseil, 2005). The deviation of the landscape metrics state in each landscape compared to the average situation of the respective landscape type is applied as indicator of sustainability in ecological terms. In each region, the confidence interval of the median of the landscape metrics is used to define an ordinal scale of three (un)sustainable classes – below average (-1), average (0), above average (1) for the individual land cover classes.

Aim of this thesis

(1) to provide the spatial reference on the European level for Sustainability Impact Assessment (Article 1, 2) and for the European Green Belt (Article 3),

(2) to provide consistent landscape structure analysis for the selected European regions (Article 4) and the European Green Belt (Article 3),

(3) to assess ecological sustainability in selected European regions (Article 4, 5).

Chapter 1: Regionalisations

In the first chapter, different approaches to regionalisation and stratification are explored. Here, it becomes obvious that the underlying objectives for the stratification strongly influence the choice of input variables, data sets and methods.

Article 1:

Renetzeder, C., van Eupen, M., Mücher, C. A., & Wrbka, T. (2008). *A Spatial Regional Reference Framework for Sustainability Assessment in Europe.* In: Helming, K., Perez-Soba, M., & P. Tabbush, (Eds.), Sustainability Impact Assessment of Land Use Changes pp 249- 268. Berlin Heidelberg New York: Springer.

Here, the development of the Spatial Regional Reference Framework (SRRF) is described. Its major objective was the integration of both biophysical and socioeconomic characteristics into European regions which were as uniform as possible for subsequent sustainability impact assessment in the frame of the FP6 integrated project SENSOR (http://www.zalf.de/home_ip-sensor/index.html).

The regionalisation resulted in 27 regions, based on 25 environmental clusters and 20 socio-economic clusters. Climate and land cover were the main discriminators, while topography, parent material, population density, and GDP played an important role in differentiating between the major climate zones.

Article 2:

Hazeu, G. W., Metzger, M. J., Mücher, C. A., Perez-Soba, M., **Renetzeder, C.,** & Andersen, E. (2010) *European environmental stratifications and typologies: an overview.* Agriculture, Ecosystems and Environment, in press, doi: 10.1016/j.agee.2010.01.009

In this paper, the SRRF is placed in the context of other European classification systems, with the focus on presenting most up to date methods for classifying the European environment.

The five stratifications and typologies presented here give an overview of different research objectives for constructing such classifications. In addition they illustrate the most up to date methods for classifying the European environment, including their limitations and challenges. As such, they provide a sound basis for describing the factors affecting the robustness of such datasets. The latter is especially relevant, since there is likely to be further interest in European environmental assessment. In addition, advances in data availability and analysis techniques, will probably lead to the construction of other typologies in the future.

Article 3:

Renetzeder, C., Kuttner, M., Schindler, S., & Wrbka, T. *Characterisation, regionalisation and landscape structure analysis of major biophysical regions along the European Green Belt* (to be submitted to the Journal of Nature Conservation in February 2010)

This work presents a regionalisation of the European Green Belt. The aim was to provide a European basis for (1) further landscape structure analysis, (2) enabling future assessment and comparison of biodiversity and nature conservation issues and (3) investigation of socioeconomic and ecological processes on both sides of the border.

Nine regions resulted; the northern regions were spatially more coherent whereas in Central and Southern Europe, the clusters showed a patchier picture. Landscape structure analysis revealed showed high diversity values in the Mediterranean regions, high connectivity values for arable land in the Continental lowlands and for forest in the Continental Baltic Coast region. Although approximation towards western land use practices occurred in Eastern Europe during the last 20 years, differences in the landscapes east and west of the border were still visible.

Chapter 2: Ecological sustainability

The main focus of the second chapter is the assessment of ecological sustainability with landscape ecological approaches. It is concluded that a combination of information of different scales for the formulation and implementation of sustainability policies should be used.

Article 4:

Renetzeder, C., Wrbka, T., Mücher, S., van Eupen, M., & Kiers, M. (2010) *Does Landscape Structure Reveal Ecological Sustainability?* In: J. Andel, I. Bicik, P. Dostal, Z. Lipsky, & S.G. Shahneshin (Eds.), Landscape modelling: geographical space, transformation and future scenarios, pp. 159-170. Urban and Landscape Perspectives Series, Vol. 8, Berlin Heidelberg New York: Springer.

In the first paper of the second chapter, the process of a consistent European pattern analysis is examined, results of the differences in landscape structure among ten European regions are presented and the use for sustainability impact assessment of agricultural landscapes is discussed.

In univariate analysis, many single class level metrics depicted differences in regions depending on land cover. Mean Patch Edge, for instance, showed significant differences for “arable land”. Discriminant analysis did not reveal statistically significant differences among the 10 regions. At landscape level, no relationship was visible between diversity indices (Simpson’s and Shannon’s Diversity of land cover classes) and configuration indices.

Article 5:

Renetzeder, C., Schindler, S., Peterseil, J., Prinz, M.A., Mücher, S., & Wrbka, T. (2010). *Can we measure ecological sustainability? Landscape pattern as an indicator for naturalness and land use intensity at regional, national and European level.* Ecological Indicators 10, 39-48.

The final paper looks at landscape pattern as a tool for ecological sustainability assessments at different scales: the regional (Austrian Cultural Landscapes), national (Austria) and European (European Union + Norway, Switzerland) level.

The analyses revealed that several landscape metrics, particularly the ''Number of Shape Characterising Points'' showed a high correlation with the degree of naturalness. The sustainabilitymap of Austria based on an ordinal regression model revealed well-known problem regions of ecological sustainability. At the European level, the relative deviation from the average pattern showed clearly the simplification processes in the landscapes. However, a better spatial resolution of land cover data would add to the refinement of pattern analysis in regions and therefore the assessment of sustainability. The combination of information of different scales for the formulation and implementation of sustainability policies is recommended.

Project frames of the articles

SENSOR

Articles 1, 2, 4 and 5 yield from the FP6 Integrated Project SENSOR – 'Tools for Environmental, Social and Economic Effects of Multifunctional Land Use in European Regions'. This 4 years-project was implemented by a team of 36 institutes in 15 European countries, China, Argentina, Brazil and Uruguay. Its major objective was to develop 'Sustainability Impact Assessment Tools' ('SIAT') that support *ex ante* assessment of new policies on six land use sectors: agriculture, forestry, nature conservation, transport and infrastructure, energy and tourism. SIAT was designed to integrate knowledge across all these sectors at the European level. Its outcome is designed to provide decision makers with scientifically sound assessment of European policies on regional impacts of land use changes and sustainable development

The project worked on three different scales:

1. European scale: analysis of land use policy scenarios is done based on selected sustainability indicators
2. Regional scale: Specific problems, risk and threshold assessment are done within a Spatial Regional Reference Framework in order to account for regional characteristics, using land use functions and participatory processes
3. Local scale: in sensitive areas of mountains, islands, coastal zones and post-industrial areas, case studies were implemented using local specific, detailed information on sustainability issues with the involvement of local stakeholders.

The presented work focuses on the regional scale. The Spatial Regional Reference Framework presented in Article 1 and 2, served as the necessary frame for adapting indicator thresholds implemented into SIAT. The SRRF regions have been used to reflect biophysical and socio-economic variation within the EU, for the assessment of Land Use Functions (cf. De Groot et al., 2006). These functions were linked to the sustainability impact indicators developed in SENSOR and weighed within each of the SRRF regions (Pérez-Soba et al., 2008).

The Green Belt of Europe

Article 2 aims at contributing to a fascinating conservation initiative crossing nearly all of the Europeans' biogeographic regions. The Green Belt of Europe aims at maintaining areas along the former Iron Curtain from the Barents Sea to the Black Sea. The restrictive access especially at the Eastern side of the border allowed nature to develop and provided habitat for many endangered species. After the fall of the Iron Curtain, negative impacts of increased land use activities were soon visible and lead to gaps within the valuable corridor. Thus, many local initiatives aimed at preserving their valuable landscapes and at triggering sustainable development in their regions. Starting in Germany in 1989, the idea of the Green Belt spread over to the other countries touched by the former Iron Curtain leading finally to the commitment of the IUCN of coordinating the implementation of the European Green Belt in 2003.

To improve the management of the Green Belt and in respect to specific conditions found in different regions, the network is divided into three sections:

- The Fennoscandian Green Belt – Norway, Finland and Russia;
- The Central European Green Belt – Estonia, Lithuania, Latvia, Poland, Germany, Czech Republic, Slovakia, Austria, Hungary, Slovenia, Croatia and Italy;
- The South Eastern European Green Belt – Serbia and Montenegro, Bulgaria, Romania, Macedonia, Albania, Greece and Turkey.

The rich cultural and political history is also an important component of the Green Belt and forms part of the cultural heritage of the regions. To foster this nature conservation project, it is crucial to provide a sound scientific foundation. This was acknowledged recently and put forward by a symposion at the IALE congress 2009 (International Association of Landscape Ecology) in Salzburg. There, the need of scientific knowledge for effective nature conservation was stressed. In this frame, the regionalisation of the European Green Belt and landscape structure analysis war performed.

References

Antrop, M. (2005). Why landscapes of the past are important for the future?. Landscape and Urban Planning, 70, 21–34.

Blaschke, T. (2006). The role of the spatial dimension within the framework of sustainable landscapes and natural capital. Landscape and Urban Planning, 75, 198-226.

Bohn, U., Gollub, G., Hettwer, C., Neuhäuslová, Z., Raus, Th., Schlüter, H., Weber H. [Bearb./Eds.] (2004). Karte der natürlichen Vegetation Europas/Map of the Natural Vegetation of Europe, Maßstab/Scale 1:2.500.000, Interaktive/Interactive CD-ROM - Erläuterungstext, Legende, Karten / Explanatory Text, Legend, Maps. Landwirtschaftsverlag, Münster.

Bunce, R. G. H., Barr, C. J., Clarke, R. T., Howard, D. C., & Lane, A. M. J. (1996a). Land classification for strategic ecological survey. Journal of Environmental Management, 47, 37–60.

Bunce, R. G. H., Barr, C. J., Gillespie, M. K., & Howard, D.C. (1996b). The ITE Land Classification: providing an environmental stratification of Great Britain. Environmental Monitoring and Assessment, 39, 39–46.

CAP. Agriculture and Rural Development – Publications - Factsheets. 12/2003 - Agriculture and the environment. http://ec.europa.eu/agriculture/publi/fact/index_en.htm (last accessed 17 January 2010)

Commission of the European Communities (CEC) (2005). Impact assessment guidelines. SEC(2005) 791.

Commission of the European Communities (CEC) (2007). Progress Report on the Sustainable Development Strategy 2007. COM(2007) 642 final.

Council of the European Communities (1992). Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Official Journal of the European Communities, series L, 206, 7–50.

Council of European Union (1979). Convention on the Conservation of European Wildlife and Natural Habitats. ETS No. 104, Bern. http://www.conventions.coe.int/Treaty/en/Treaties/Html/104.htm (last accessed 07 January 2010)

Council of European Union (2000). European Landscape Convention. ETS No. 176, Florence. http://www.conventions.coe.int/Treaty/EN/Treaties/Html/176.htm (last accessed 07 January 2010)

Council of European Union (2006). Review of the EU Sustainable Development Strategy (EU SDS) - Renewed Strategy EU 10917/06; http://ec.europa.eu/sustainable/docs/renewed_eu_sds_en.pdf (last accessed 03 January 2010)

Council of European Union, UNEP, & ECNC (1996). The Pan-European Biological and Landscape Diversity Strategy: a vision for Europe's natural heritage. Strasbourg, Council of Europe Publishing. http://www.peblds.org/ (last accessed 07 January 2010)

Debinski, D.M., & Holt, R.D. (2000). A survey and overview of habitat fragmentation experiments. Conservation Biology, 14, 342-355.

de Groot, R. S., Wilson, M. A., & Boumans, R. M. J. (2002). A Typology for the Classification, Description and Valuation of Ecosystem functions, Goods and Services. Ecological Economics, 41, 393-408.

de Groot, R. (2006). Function analysis and valuation as a tool to assess land use conflicts in planning for sustainable, multifunctional landscapes. In: Potschin, M., Haines-Young, R.H. (Eds.), Landscapes and Sustainability. Landscape and Urban Planning, 75, 175–186.

de Vries, B. J. M., & Petersen, A. C. (2009). Conceptualizing sustainable development - An assessment methodology connecting values, knowledge, worldview and scenarios. Ecological Economics, 68, 1006-1019.

EEA (2002). The biogeographical regions map of Europe. European Environment Agency, Copenhagen, Denmark.

EEA (2005). Agriculture and environment in EU-15 - the IRENA indicator report. EEA Report No 6/2005.

Ernoult, A., Freiré-Diaz, S., Langlois, E., & Alard, D. (2006). Are similar landscapes the result of similar histories?. Landscape Ecology, 21, 631–639. doi:10.1007/s10980-005-5321-1.

European Commission. http://ec.europa.eu/governance/impact/index_en.htm (last accessed 08 January 2010)

Fohrer, N., Moller, D., & Steiner, N. (2002). An interdisciplinary modelling approach to evaluate the effects of land use change. Physics and Chemistry of the Earth, 27, 655-662.

Forman, R., & Godron, M. (1986). Landscape Ecology. Wiley & Sons, New York.

Forman, R. T. T. (1995). Land Mosaics – The Ecology of Landscapes and Regions, Cambridge University Press.

Frobel, K., Riecken, U., & Ullrich, K. (2009). The Green Belt – Nature conservation and German reunification. Natur und Landschaft, 84, 399-404.

Haberl, H., Wackernagel, W., & Wrbka, T. (2004). Land use and sustainability. An introduction. Land Use Policy, 21, 193-198.

Hazeu, G. W., Metzger, M. J., Mücher, C. A., Perez-Soba, M., Renetzeder, C., & Andersen, E. (2010). European environmental stratifications and typologies: an overview. Agriculture, Ecosystems and Environment, in press, doi: 10.1016/j.agee.2010.01.009

Helming, K., Pérez-Soba, M., & Tabbush, P. [Eds.] (2008). Sustainability Impact Assessment of Land Use Change. Springer-Verlag, Berlin, Heidelberg, Germany.

Hulshoff, R. M. (1995). Landscape indices describing a Dutch landscape. Landscape Ecology, 10, 101-111. doi: 10.1007/BF00153827

Humboldt, A. V. (1780). Ansichten der Natur mit wissenschaftlichen Erläuterungen. Cotta, Stuttgart.

Jones, H. E., & Bunce, R. G. H. (1985). A preliminary classification of the climate of Europe from temperature and precipitation records. Journal of Environmental Management, 20, 17-29.

Jongman, R.H.G. (2002). Homogenisation and fragmentation of the European landscape: ecological consequences and solutions. Landscape and Urban Planning, 58, 211-221.

Krummel, J.R., Gardner, R.H., Sugihara, G., & O'Neill, R.V. (1987). Landscape patterns in a disturbed environment. Oikos, 48, 321–324.

Kubalek, C. (2009). The return of the brown bear, lynx & company. In: Wrbka, T., Zmelik, K., & Grünweis, F.M. (eds). The European Green Belt. Borders. Wilderness. Future. Bibliothek der Provinz, Weitra. 236-239.

Loh, J., Randers, J., MacGillivray, A., Kapos, V., Jenkins, M., Groombridge, B. & Cox, N. (1998). Living Planet Report 1998. Gland, Switzerland: WWF.

Mander, Ü., Mikk, M., & Kulvik, M. (1999). Ecological and low intensity agriculture as contributors to landscape and biological diversity. Landscape Ecology, 46, 169-177. doi:10.1016/S0169-2046(99)00042-0

Meeus, J. H. A. (1995). Pan-European landscapes. Landscape and Urban Planning, 31, 57-79.

Metzger, M. J., Bunce, R. G. H., Jongman, R. H. G, Mücher, C. A., & Watkins, J. W. (2005). A climatic stratification of the environment of Europe. Global Ecology and Biogeography, 14, 549-563.

Millennium Ecosystem Assessment (2003). Ecosystems and Human Well-being: A Framework for Assessment. Island Press.

Moser, D., Zechmeister, H.G., Plutzar, C., Sauberer, N., Wrbka, T., & Grabherr, G. (2002). Landscape patch shape complexity as an effective measure for plant species richness in rural landscapes. Landscape Ecology, 17, 657-669. doi: 10.1023/A:1021513729205

Mücher, C. A., Champeaux, J. L., Steinnocher, K. T., Griguolo, S., Wester, K., Heunks, C., Winiwater, W., Kressler, F. P., Goutorbe, J. P., ten Brink, B., van Katwijk, V. F., Furberg, O., Perdigao, V., & Nieuwenhuis , G. J. A. (2001). Development of a consistent methodology to derive land cover information on a European scale from Remote Sensing for environmental monitoring; The PELCOM report. Alterra Report 178, CGI report 6, 178 pp., Wageningen, ALTERRA, Green World Research.

Mücher, C. A., Klijn, J. A., Wascher, D. M., & Schaminée, J. H. J. (2010). A new European Landscape Classification (LANMAP): A transparent, flexible and user-oriented methodology to distinguish landscapes. Ecological Indicators, 10, 87–103.

Naveh, Z., & Lieberman, A.S. (1994). Landscape Ecology – Theory and Application. Springer, Berlin Heidelberg New York.

Odum, E. P., Turner, M. G. (1989). Georgia Landscape: A Changing Resource. In: I.S. Zonneveld, R.T.T. Forman (Eds.), Changing Landscapes: An Ecological Perspective, Springer, New York, USA, 137–146.

OECD (1993). OECD core set of indicators for environmental performance reviews: a synthesis report by the group on the state of the environment. Environment Monographs 83, Organisation for Economic Co-operation and Development, Paris.

OECD (2003). OECD environmental indicators: development, measurement, use. Reference Paper. http://www.oecd.org/dataoecd/7/47/24993546.pdf (last accessed 17 January 2010).

O'Neill, R. V., De Angelis, D. L., Waide, J. B., & Allen, T. F. H. (1986). A hierarchical concept of ecosystems. Princeton University Press, Princeton New Jersey USA.

Opdam, P., Steingröver, E., & van Rooij, S. (2006): Ecological networks: spatial concept for multi-actor planning of sustainable landscapes. Landscape and Urban Planning, 75, 322-332.

Passarge, S. (1929). Die Landschaftsgürtel der Erde. 2. Auflage, Hirt-Verlag, Breslau.

Pérez-Soba, M., Petit, S., Jones, L., Bertrand, N., Briquel, V., Omodei-Zorini, L., Contini, C., Helming, K., Farrington, J., Tinacci Mossello, M., Wascher, D., Kienast, F., & De Groot, R. (2008). Land use functions – a multifunctionality approach to assess the impact of land use change on land use sustainability. In: Helming, K., Perez-Soba, M., & Tabbush, P. (Eds.). Sustainability Impact Assessment of Land Use Changes. Springer, Berlin Heidelberg New York, 375 -404.

Peterseil, J. (2001). Landscape Structure – the Key to Biodiversity?. In: Mander, Ü., Printsman, A., Palang, H. (Ed.): Development of European Landscapes. Publicationes Instituti Geographici Universitatis Tartuensis 92, Proc. of the IALE European Conference 7/2001, Tartu. 474-479.

Peterseil, J., Wrbka, T., Plutzar, C., Schmitzberger, I., Kiss, A., Szerencsits, E., Reiter, K., Schneider, W., Suppan, F., & Beissmann, H. (2004). Evaluating the ecological sustainability of Austrian agricultural landscapes: the SINUS approach. Land Use Policy, 21, 307-320.

Peterseil, J. (2005). Bewertung der ökologischen Nachhaltigkeit in österreichischen Kulturlandschaften. Dissertation, Universität Wien.

Pino, J. Rodà, F., Ribas, J., & Pons, X. (2000). Landscape structure and bird species richness: implications for conservation in rural areas between natural parks. Landscape and Urban Planning, 49, 35-48.

Renetzeder, C., van Eupen, M., Mücher, C. A., Wrbka, T. (2008). A Spatial Regional Reference Framework for Sustainability Assessment in Europe. In: Helming, K., Perez-Soba, M., & Tabbush, P. (Eds.). Sustainability Impact Assessment of Land Use Changes. Springer, Berlin Heidelberg New York, 249- 268.

Renetzeder, C., Wrbka, T., & Grünweis, F.M. (2009). European Diversity in review – the major landscapes on the Green Belt. In: Wrbka, T., Zmelik, K., & Grünweis, F.M. (eds). The European Green Belt. Borders. Wilderness. Future. Bibliothek der Provinz, Weitra. 27-31.

Riecken, U., Ullrich, K., & Lang, A. (2006). A vision for the Green Belt in Europe. In: Terry, A., Ullrich, K., & Riecken, U. (Eds). The Green Belt of Europe: From Vision to Reality. IUCN, Gland, Switzerland and Cambridge, UK. 3-10.

Ružicka, M., & Miklos, L. (1990). Basic premises and methods in landscape ecology planning and optimization. In: Zonneveld, I.S. & Forman, R. T. T. (eds). Changing landscape, an ecological perspective. Springer, 233-260.

Schlumprecht, H., Kreutz, M., & Lang, A. (2009). Landscapes of conservation value along the Green Belt – A pan-European overview as foundation for cross-border management and action. Natur und Landschaft 84, 409-414.

Schuler, A. (1998). Sustainability and biodiversity—forest historical notes on two main concerns of environmental utilisation. In: Bachmann, P., Köhl, M., & Päivinen, R. (Eds.). Assessment of Biodiversity for Improved Forest Planning. Forestry Sciences, 51. Kluwer Academic Publishers, Dordrecht, 353–360.

SENSOR. http://www.ip-sensor.org (last accessed 17 January 2010).

Silveira, M.P. (2006). Introduction National sustainable development strategies: Moving from theory to practice. Natural Resource Forum, 30, 86-89.

Singh, R.K., Murty, H.R., Gupta, S.K., & Dikshit, A.K. (2009). An overview of sustainability assessment methodologies. Ecological Indicators, 9, 189-212.

Terry, A., Ullrich, K., & Riecken, U. (2006). The Green Belt of Europe: From Vision to Reality. IUCN, Gland, Switzerland and Cambridge, UK.

Turner M.G., Gardner, R.H., & O'Neill, R.V. [Eds.] (2001). Landscape ecology in theory and practice, pattern and process. Springer, New York.

United Nations (1987). Our Common Future. Oxford University Press. ISBN 0-19-282080-X

United Nations (1992). Agenda 21: The United Nations Programme of Action from Rio. United Nations, New York.

UNCSD Indicators of Sustainable Development – 3rd edition (2007). http://www.un.org/esa/dsd/dsd_aofw_ind/ind_csdindi.shtml (last accessed 03 January 2010)

Verburg, P.H., van de Steeg, J., Veldkamp, A., & Willemen, L. (2009). From land cover change to land function dynamics: A major challenge to improve land characterization. Journal of Environmental Management, 90, 1327-1335.

Vos, C.C., Berry, P., Opdam P., Baveco, H., Nijhof, B., O'Hanley, J, Bell, C., & Kuipers, H. (2008). Adapting landscapes to climate change: examples of climate-proof ecosystem networks and priority adaptation zones. J. Appl. Ecol. 45, 1722-1731. doi: 10.1111/j.1365-2664.2008.01569.x

Wackernagel, M., & Rees, W. (1996). Our Ecological Footprint: Reducing Human Impact on the Earth. BC, New Society Publishers, Gabriola Island.

Wascher, D.M. (Ed.) (2005). European Landscape Character Areas – Typologies, Cartography and Indicators for the Assessment of Sustainable Landscapes. Final Project Report as deliverable from the EU's Accompanying Measure project European Landscape Character Assessment Initiative (ELCAI), funded under the 5th Framework Programme on Energy, Environment and Sustainable Development (4.2.2). Alterra rapport 1254. Alterra, Wageningen.

Wrbka, T. (1996). Die österreichische Kulturlandschaftskartierung als Grundlage naturschutzfachlicher Erhebungen und Bewertungen. Sauteria, 8, 293-304.

Wrbka, T., Erb, K.-H., Schulz, N., Peterseil, J., Hahn, C., & Haberl, H. (2004). Linking pattern and process in cultural landscapes. An empirical study based on spatially explicit indicators. Land Use Policy, 21, 28-306. doi:10.1016/j.landusepol.2003.10.012.

Wrbka, T., Schindler, S., Pollheimer, M., Schmitzberger, I., & Peterseil, J. (2008). Impact of the Austrian Agri-Environmental Scheme on diversity of landscape, plants and birds. Community Ecology, 9, 217-227. doi: 10.15556/ComEc.9.2008.2.x

Zebisch, M., Wechsung, F., & Kenneweg, H. (2004). Landscape response functions for biodiversity - assessing the impact of land use changes at the county level. Landscape and Urban Planning, 67, 157-172.

Zechmeister, H. G., Schmitzberger, I., Steurer, B., Peterseil, J., & Wrbka, T. (2003). The influence of land-use practices and economics on plant species richness in meadows. Biological Conservation, 114, 165-177.

Zechmeister, H.G. & Moser, D. (2001). The influence of agricultural land-use intensity on bryophyte species richness. Biodiversity and Conservation, 10, 1609-1625.

Chapter 1 – Regionalisations

Article 1

Renetzeder, C., van Eupen, M., Mücher, C. A., & Wrbka, T. (2008). *A Spatial Regional Reference Framework for Sustainability Assessment in Europe.* In: Helming, K., Perez-Soba, M., & P. Tabbush, (Eds.), Sustainability Impact Assessment of Land Use Changes pp 249- 268. Berlin Heidelberg New York: Springer.

Own contribution:

Study design 20%, implementation 70%, writing 70%

A Spatial Regional Reference Framework for Sustainability Assessment in Europe

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Abstract

A Spatial Regional Reference Framework (SRRF) has been produced which will allow an efficient assessment of sustainability impact indicators across Europe. In order to achieve this goal, it was necessary to define relatively homogeneous regions, in terms of both biophysical and socio-economic characteristics. The major objective was the integration of these dimensions into European regions that were as uniform as possible. Therefore, in order to retain comparability, it was necessary to use consistent European databases. The spatial framework consisted of three levels, which were necessary to incorporate data on different tiers of spatial aggregation: (1) the INSPIRE Reference Grid, (2) a newly established NUTSx classification, which is a trade-off between administrative European NUTS2 and NUTS3 regions, and (3) the construction of SRRF cluster regions. The last were produced by using a statistical cluster analysis based on a restricted set of important biophysical and socio-economic parameters. 27 cluster regions resulted, which provided a flexible tool for further impact assessment at regional level.

Keywords

European cluster regions, statistical clustering, NUTSx classification, LANMAP2, Spatial Regional Reference Framework (SRRF), primary landscape structure, secondary landscape structure, regional impact assessment

1 Introduction

1.1 Background

Since the late 1980s, sustainable development has become a keynote in EU planning and policy. In general, three main policy dimensions are associated with sustainable development: economic, environmental and social. In order to assess the policy impact within the three dimensions, indicators and guidelines have been developed to provide the basis for in-depth analysis of sustainability impact assessment (CEC 2005). The SENSOR project seeks to identify regional sustainability thresholds, by considering regional differences in the socio-economic and biophysical settings. The analysis required regions that were comparable both in biophysical and socio-economical factors, and at a consistent spatial scale that is practical for European impact assessments. As a consequence, there is a need to identify and delineate spatial units which are relatively homogeneous, in order to be able to assess sustainability impact issues. Previous stratification approaches have mainly been based on biophysical parameters, although they had the potential for including landmanagement and selected socio-economic factors into the frameworks. Some of these classifications are highlighted below and were important sources for meeting the final goal:

- European Landscapes Map described by Meeus (Meeus, 1995): this pan-European landscape typology describes 30 European landscapes. The map integrates not only land form, soil and climate and but also regional culture, habits and history. Its spatial accuracy is not high since it is based mainly on expert-knowledge.
- Environmental Zones (Mücher et al. 2003, Metzger et al. 2005): this classification is derived from climatic, altitude, latitude, slope and oceanity variables. The resulting 84 environmental strata have been aggregated into 13 Environmental Zones. They are useful strata for stratified random sampling of ecological resources.

- LANMAP 2 (Mücher et al. 2003, Mücher et al. 2006): this is a European Landscape Classification that was produced in parallel with the Environmental Classification. LANMAP2 is hierarchical and has four levels. The first level is determined by climate (Environmental Classification) and has eight classes (aggregated), the second level uses climate and topography and has 31 classes, and the third level also includes parent material and has 76 classes. The database contains more than 14,000 mapping units and the minimum unit is 11 km^2. The fourth and final level is determined by climate, topography, parent material and land cover and has 350 landscape types. LANMAP2 already has many applications in the field of environmental stratification, indicator reporting and analysis of changes at the landscape level.

While classical environmental assessment builds upon purely biophysical research at the ecosystem or biogeographic level, most socio-economic studies are based mainly on demographic, economic or policy information. However, landscape scientific research, which once had a purely ecological perspective, is broadening to include wider socio-cultural domains (Naveh & Lieberman 1994; Wascher 2005). The interdependencies that exist between landscape character and the socio-economic context have also been stressed (Peterseil et al. 2004; Wrbka et al. 2004). Therefore, it seems to be a logical step, when defining European regions, to consider socio-economic factors that will help to provide the background for assessing sustainability, sensitivity to change and multi-functionality in the landscape. It is on this basis that an integrated approach for identifying homogenous regions in Europe has been selected. Both bio-physical and socio-economic parameters have been combined into a spatial stratification of land, which is an innovative concept because it is designed to overcome the methodological fragmentation of most current approaches.

1.2 Objective

In the current analysis, the objective is to establish a Spatial Regional Reference Framework (SRRF) for Europe, by stratifying the European land surfaces into relatively homogeneous regions, integrating biophysical, socio-economic and regionally specific characteristics The underlying rationale for conducting a more in-depth regional characterisation is to quantify the high degree of cultural and natural diversity that exists between European regions (Wascher 2005; Mücher et al. 2003). The approach is based upon the following assumptions:

1. regional characteristics determine the scale and scope of impacts on sustainability that have resulted from policy-induced land use changes;
2. environmental and socio-economic profiles are independent of administrative boundaries and define regional coherence and differences across the entire EU;
3. taking regional characteristics into account will facilitate expert assessments (e.g., for the identification of regional thresholds) and stakeholder participation;
4. understanding and addressing these regional characteristics will greatly improve the interpretation of impacts with regard to their likely environmental and socio-economic effects.

2 Methods

2.1 Building up the framework

The smallest spatial unit available for a European-wide assessment of socio-economic and regional administrative aspects is the NUTS2 or 3 level (Official Journal of the European Union, 2003). The Nomenclature of Territorial Units for Statistics (NUTS) was established by Eurostat more than 25 years ago, in order to provide a single uniform breakdown of territorial units for the production of regional statistics for the European Union (http://ec.europa.eu/comm/eurostat/ramon/nuts/introduction_regions_en.html). This information is only meaningful at the level of spatial aggregation, in contrast with the majority of the biophysical aspects, which can be up- or downscaled more easily. Hence, it is necessary to take these NUTS levels into account as the smallest spatial units when looking for homogeneous regions, although there are obvious limitations.

The framework is made up of three levels (Figure 1): Grids with available biophysical information, NUTS regions as the spatial level of available socio-economic information and SRRF clusters which combine all these data. Together, all three levels create an interrelated spatial framework with grid cell level as the smallest unit.

In order to derive homogeneous regions, it is necessary to take into account both spatial integration of biophysical aspects and also how NUTS regions can be used for threshold analysis. Cluster analysis of NUTS regions into SRRF regions is the most appropriate statistical approach, considering the fact that the resultant classes will always be heterogeneous to some degree. The result of the statistical clustering procedure was intended to provide the basis for environmental and socio-economic profiling by identifying relevant and important variables for sustainability assessment.

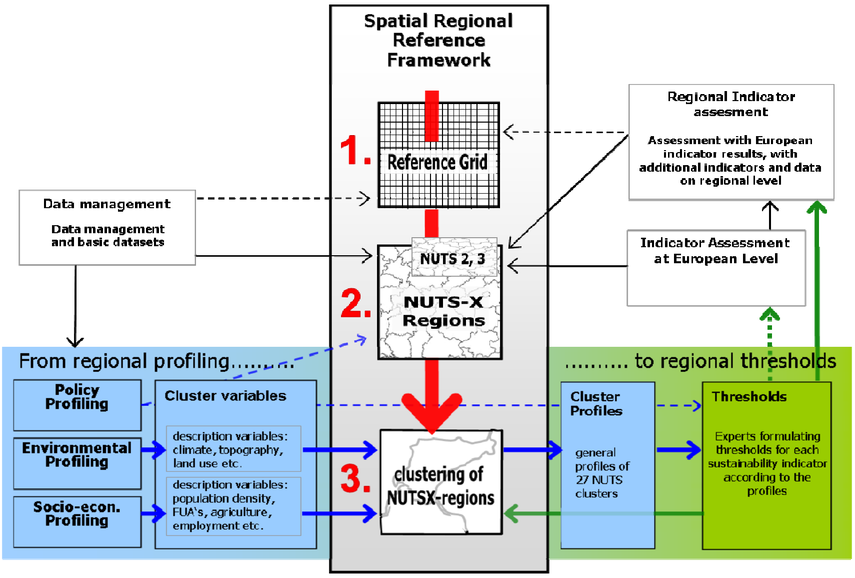

Fig. 1. The three main levels of the Spatial Regional Reference Framework: 1. Reference grid, 2. NUTS-regions and 3. SRRF clusters, creating a related spatial framework with its applicability in the regional assessment.

2.2 Deriving a comparable level of NUTS-regions: the NUTS-X map

It is essential for the NUTS regions to have comparable landscape areas in order to achieve reliable clustering with a degree of homogeneity. In addition, administrative boundaries should be taken into account to ensure that units are comparable for statistical procedures. In order to derive data compatibility between the different variables, the EU common standard of geographical sample grids of the European Environment Agency (EEA) was adopted; using the INSPIRE standards (INSPIRE 2002). The result is termed a NUTSx map and is a selective composition of NUTS2 and 3 units on the basis of the IRENA methodology (EEA 2005).

However, the IRENA project involved only 15 countries, whereas the SENSOR project covers all 27 EU countries, plus Norway, Iceland and Switzerland. Therefore, it was necessary to define the NUTSx level for the additional 12 countries.

Proposals were made on the basis that the chosen level should be comparable to the size of the IRENA regions as regards area, population size and administrative status.

For some of these 12 countries it was difficult to find the appropriate trade-off between the NUTS2 or 3 levels. For example, in Hungary, the Czech Republic and Slovakia, NUTS2 is appropriate on the basis of area or NUTS3 because of population size. In Hungary the choice of NUTS3 could also be made on the basis of its administrative status: the Megyek is the traditional regional division in Hungary, whereas NUTS2 regions are only for statistical purposes. Using the same logic, the opposite choice could be made in Poland. For both countries, the area and population size that are closest to an IRENA region would fall between NUTS2 and NUTS3.

Table 1. - Overview of final NUTS-X regions for the SRRF

Nr	Code	EU 27 + 3	IRENA coverage	Member EU	Average NUTS-X size (km2)	Final Sensor NUTS-X-level	Number of NUTS-X regions	Number of NUTS-2 regions	Number of NUTS-3 regions	NUTS-2 / NUTS-3 ratio	NUTS-2 (km2)	NUTS-3 (km2)	COUNTRY (km2)
1	LU	Luxembourg	Yes	Yes	2565	3	1	1	1	1.0	2565	2565	2565
2	BE	Belgium	Yes	Yes	2752	2	11	11	43	3.9	2752	704	30273
3	NL	Netherlands	Yes	Yes	2920	2	12	12	40	3.3	2920	876	35039
4	DK	Denmark	Yes	Yes	2835	3	15	1	15	15.0	42527	2835	42527
5	IE	Ireland	Yes	Yes	8662	3	8	2	8	4.0	34647	8662	69295
6	AT	Austria	Yes	Yes	9239	2	9	9	35	3.9	9239	2376	83150
7	PT	Portugal	Yes	Yes	13306	2	7	7	30	4.3	13306	3105	93139
8	GR	Greece	Yes	Yes	10280	2	13	13	51	3.9	10280	2620	133642
9	UK	United Kingdom	Yes	Yes	6529	2	37	37	133	3.6	6529	1816	241576
10	IT	Italy	Yes	Yes	14341	2	21	21	103	4.9	14341	2924	301167
11	FI	Finland	Yes	Yes	17083	3	20	5	20	4.0	68333	17083	341667
12	DE	Germany	Yes	Yes	8608	2	41	41	439	10.7	8608	804	352909
13	SE	Sweden	Yes	Yes	21506	3	21	8	21	2.6	56452	21506	451620
14	ES	Spain	Yes	Yes	10208	3	50	17	50	2.9	30024	10208	510402
15	FR	France	Yes	Yes	5681	3	96	22	96	4.4	24788	5681	545340
16	MT	Malta	No	Yes	323	2	1	1	2	2.0	323	162	323
17	CY	Cyprus	No	Yes	9499	3	1	1	1	1.0	9499	9499	9499
18	SI	Slovenia	No	Yes	1678	3	12	1	12	12.0	20135	1678	20135
19	EE	Estonia	No	Yes	8982	3	5	1	5	5.0	44910	8982	44910
20	SK	Slovakia	No	Yes	6060	3	8	4	8	2.0	12121	6060	48484
21	LV	Latvia	No	Yes	10643	3	6	1	6	6.0	63858	10643	63858
22	LT	Lithuania	No	Yes	6405	3	10	1	10	10.0	64050	6405	64050
23	CZ	Czech Republic	No	Yes	5566	3	14	8	14	1.8	9741	5566	77925
24	HU	Hungary	No	Yes	4611	3	20	7	20	2.9	13174	4611	92218
25	BG	Bulgaria	No	Yes	3966	3	28	6	28	4.7	18506	3966	111039
26	RO	Romania	No	Yes	5642	3	42	8	42	5.3	29622	5642	236974
27	PL	Poland	No	Yes	6839	3	45	16	45	2.8	19235	6839	307763
28	CH	Switzerland	No	No	5778	2	7	7	26	3.7	5778	1556	40448
29	IS	Iceland, Island	No	No	104253	3	1	1	1	1.0	104253	104253	104253
30	NO	Norway	No	No	17242	3	19	7	19	2.7	46799	17242	327596
		Average			**11133**		**19**	**9**	**44**	**4.5**	**26311**	**9229**	**159459**
		Total					**581**	**277**	**1324**				

It was decided that for these countries the NUTS3 level should be used in SENSOR.

Choosing NUTS3 prevents dilution of available information by keeping the spatial regionalisation at the most detailed level. If necessary (e.g., if there were to be a change in the availability of information), the NUTSx level could be changed. Table 1 gives an overview of the final NUTSx level used in the cluster analysis.

2.3 Development of SRRF regions

Conceptual Approach

The methodology for developing and profiling homogeneous regions was guided by the hierarchical concept of "primary – secondary – tertiary landscape structure" (O'Neill et al. 1986, Ružicka & Miklos 1990), an approach which tries to assign systematically any landscape attribute to three domains: the biophysical (Primary Landscape Structure or PLS), the land-management / socio-economic (Secondary Landscape Structure or SLS) and planning / policy which is the Tertiary Landscape Structure, or TLS (see Figure 2).

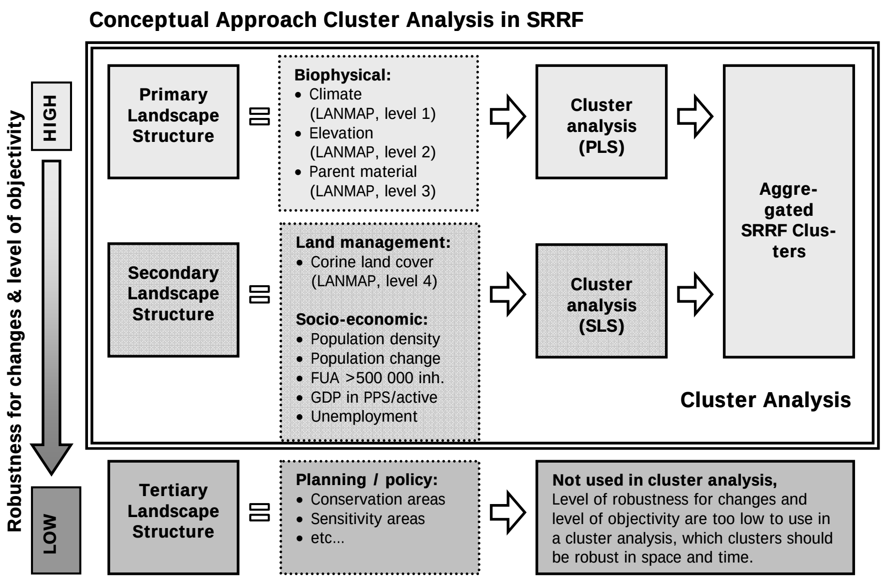

Fig. 2: Conceptual approach for establishing clusters in the Spatial Regional Reference Framework; (FUA = Functional Urban Area, GDP in PPS/active = GDP per worker (active population) in 1999 in purchasing power standards (PPS)

In this concept, parameters which cannot be altered; e.g., climate, topography and bedrock; are the main drivers of land cover and are therefore assigned as PLS.

Landscape change resulting from human interaction with PLS can be rapid; e.g., from forest to pasture; and is therefore at the second hierarchical level. Landscape policy and / or planning and administrative boundaries are often dynamic, but in general their influence is not readily quantifiable. These aspects are assigned to the lowest level of the concept – the TLS.

This approach was chosen to keep the subsequent statistical procedures as simple and transparent as possible. However, it was also decided that the whole classification approach should allow flexibility for any necessary improvements by stepwise integration of additional variables and/or knowledge. Biophysical/socio-economic and land cover data have been clustered in two separate steps. This offers more transparency in separating the results for the biophysical variables from the relatively more dynamic socio-economic and land use management variables (see Figure 2).

The tertiary landscape structure level (the planning / policy domain) is not suitable for a cluster analysis, because the levels of resistance to change and the objectivity are too low.

The next stage was to aggregate the two resulting data sets to form reasonably homogenous clusters within Europe. A matrix of NUTSx regions was therefore constructed, comprising a combination of a PLS / SLS clusters (see Figure 3).

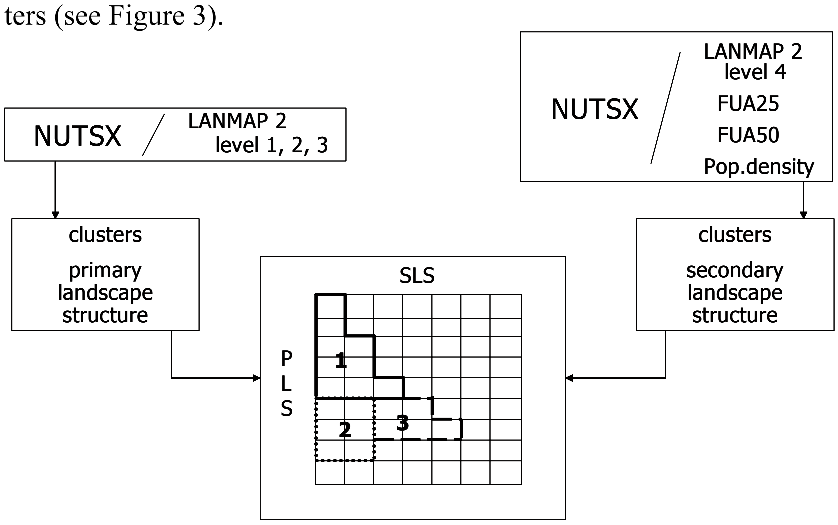

Fig. 3: Concept of aggregating PLS and SLS clusters to SRRF clusters; PLS = Primary Landscape Structure; SLS = Secondary Landscape Structure; SRRF = Spatial Regional Reference Framework

Aggregation of the two sets of clusters was carried out by building a matrix, arranging the clusters according to the relative distance between the cluster centres. Clusters with a small distance between each other, were merged with their neighbours, whereas clusters that were further apart, were grouped separately. In this matrix, columns and/or lines, which represent a given degree of similarity, were joined into one SRRF cluster, but there remained some options for generalising or further dividing some groups.

Methodological Implementation

Input data

To create a meaningful Europe-wide clustering of NUTSx regions, consistent data are essential, therefore only two accepted data sets were used. The biophysical data representing PLS were derived from LANMAP2 (Mücher 2005) and socio-economic data for the SLS were extracted from the ESPON and EUROSTAT database (http://www.espon.eu/; http://epp.eurostat.ec.europa.eu).

All levels of LANMAP2 were intersected in GIS with the NUTSx regions to calculate the percentages of area of the variables for each NUTSx. Since it is generally assumed that coastal influence is important, as is emphasised by many institutions; e.g., the Integrated Coastal Zone Management of the EU (http://ec.europa.eu/environment/iczm/home.htm); the length of coastline per NUTSx region was calculated and incorporated into the cluster input data.

The socio-economic data set, which was proposed by Briquel (2007), consisted of 16 variables which needed to be redefined and re-aggregated. Because several of these attributes showed strong correlations with each other, a selection had to be made. Therefore, the parameters were grouped according to their different information content (demography, GDP & (un-)employment and FUAs). Within each of the groups a Principal Components Analysis (PCA) (Jongman et al. 1995) was carried out, revealing the most significant parameters. The final selection was based on the highest correlation of variables with the resulting axes of the PCA; this is shown in Table 2, as input data for the cluster-analysis.

Because it proved impossible to obtain complete coverage of Europe, there are still gaps in the existing data concerning a few NUTSx regions[1].

[1]The excluded regions are: Las Palmas, Tenerife, Andorra, Bjornoya, the Channel Islands, Cyprus, the Faeroe Islands, Gibraltar, the Isle of Man, Iceland, Jan Mayen, Liechtenstein, Monaco, the Azores, Madeira, San Marino and the Vatican City

Because of this, these regions have not been integrated into the clustering process.

Table 2. Selected variables for cluster-analysis

PLS		
LANMAP2	climate	Alpine North % area
		Alpine South % area
		Arctic % area
		Atlantic Central % area
		Atlantic North % area
		Boreal % area
		Continental % area
		Lusitanian % area
		Mediterranean Mountains % area
		Mediterranean North % area
		Mediterranean South % area
		Nemoral % area
		Pannonian % area
		Steppic % area
	topography	lowland % area
		hills % area
		mountains % area
		high mountains % area
		DEM alpine % area
	parent material	river alluvium % area
		marine alluvium % area
		glaciofluvial deposits % area
		calcereous rocks % area
		soft clayey materials % area
		hard clayey materials % area
		sands % area
		sandstone % area
		soft loam % area
		siltstone % area
		detrital formations % area
		crystalline rocks and migmatites % area
		volcanic rocks % area
		other rocks % area
		organic materials % area
		unclassified (urban/water/ice) % area
		coastline % perimeter

SLS		
ESPON / EUROSTAT		population density 2003
		population annual change rate % 1998-2003
		activity rate in %
		index of GDP in PPS/active in €
		unemployment rate 2003
		FUAs with > 500000 habitants population in thousands
LANMAP2	land cover	artificial surfaces % area
		arable land % area
		intertidal flats % area
		forest % area
		heterogeneous agric. areas % area
		open spaces with little or no vegetation % area
		pastures % area
		permanent crops % area
		shrubs & herbaceous vegetation % area
		waterbodies % area
		wetlands % area

Cluster Analysis

The aim of the cluster analysis was to generate groups of NUTSx regions to enable the development of sustainability profiles, and the calculation of regional indicators and thresholds.

The resulting NUTS groups were presented as maps (see Figures 4, 5 and 6). A stepwise clustering method, as described in the conceptual approach, delivered the best results and generated 27 clusters; with variance being kept as low as possible *within* clusters, and as high as possible *between* clusters.

Clustering PLS and SLS

The structure of the input data (building on experience from the draft calculations with SPSS 12.0) led to the conclusion, that K-Means clustering using Euclidean distance was the most appropriate clustering technique. This procedure is suitable for calculations with metric data. The main advantage, compared to the hierarchical method, is that objects which are part of one cluster can be removed and allocated to another in the following iterative step. Iteration is done as long as the optimal cluster solution is found and the sum of variation square is minimised within the clusters (Janssen & Laatz, 2005).

In this method, the number of clusters has to be specified beforehand. It was therefore necessary to run some trials in order to achieve a tenable result. A point was reached when it became unproductive to enlarge the number of clusters, because those with many NUTSx regions did not split up, but a significant number of single NUTSx regions were created that formed a cluster on their own. Based on the results of the trials, it was found that 25 PLS cluster and 20 SLS cluster satisfactorily represented heterogeneity at the European level. This resulted in the avoidance of isolated individual clusters with fewer than 3 NUTSx regions (spatial homogeneity), while retaining the ability to show differences at the highest possible level.

Aggregation to Spatial Regional Reference Framework Clusters

After clustering NUTSx regions according to their PLS and SLS, it was necessary to join them together and form relatively homogenous regions throughout Europe. Each NUTSx region combines two different clusters (one PLS, one SLS). The cluster results created the possibility of constructing a matrix with PLS in rows and SLS in columns (Figure 3).

Distances between the cluster centres show how strongly clusters are linked. Small distances indicate a greater similarity and they were therefore grouped next to each other, and clusters which differed more were arranged further apart. Some clusters have a connection with several groups and it was therefore necessary to use expert knowledge in order to find the appropriate allocation. Depending on what degree of detail the regional profiles required, it was possible to formulate around 100 regions (the number of existing combinations) or to generalise them if required. The first attempt defined 30 groups which appeared to show clear differences between regions, from the European perspective.

3 Results

3.1 Regional Clusters

Primary Landscape Structure (PLS)
Basically, 25 clusters could be identified from the analysis of PLS. In Figure 4, a map shows the classification of the NUTSx regions, based on biophysical variables. One result is the cluster centre values, which are the calculated mean of the variables of the NUTSx regions belonging to the cluster, and provide the basis for describing each one.

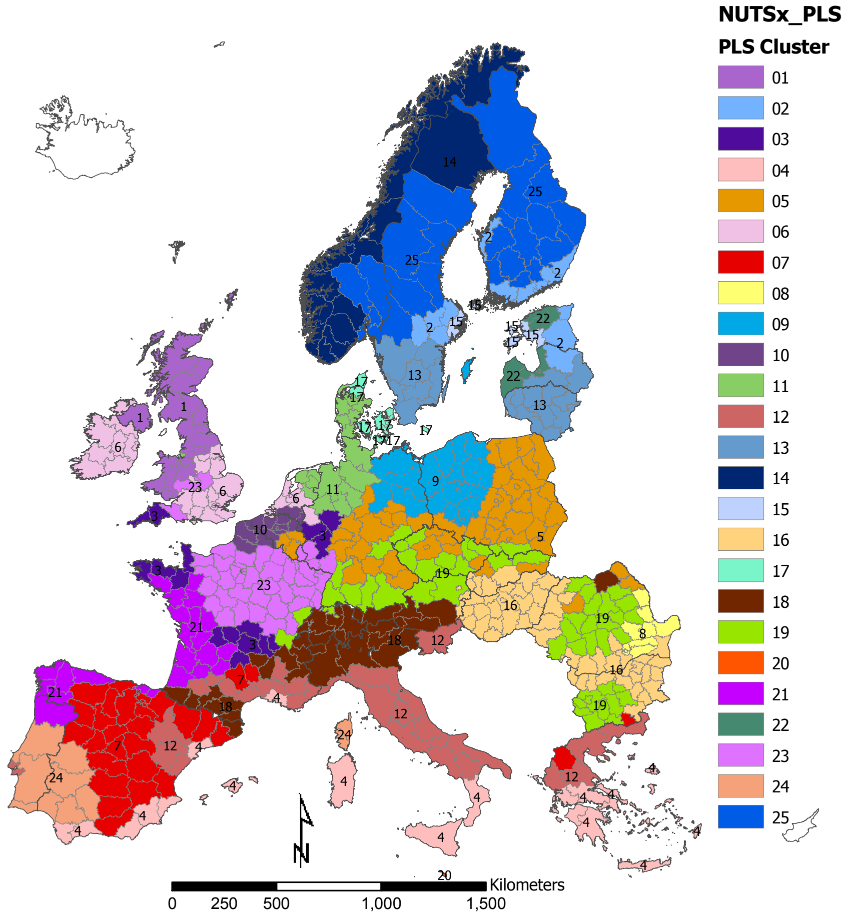

Fig. 4. PLS cluster regions of Europe

Table 3: ANOVA analysis of PLS clusters, variables which are significant in forming the clusters are highlighted in orange (higher significance) and blue (lesser significance)

	ANOVA					
		Cluster		Error		
		mean square	df	mean square	df	F
Climate	Alpine North	2,864.36	24	16.496	539	173.635
	Alpine South	4,387.63	24	83.952	539	52.264
	Arctic	0.144	24	0.095	539	1.523
	Atlantic Central	25,831.14	24	88.086	539	293.248
	Atlantic North	9,262.43	24	79.588	539	116.38
	Boreal	11,564.55	24	33.038	539	350.035
	Continental	26,076.77	24	181.415	539	143.741
	Lusitanian	6,162.97	24	40.137	539	153.548
	Med. Mountains	2,257.71	24	65.675	539	34.377
	Mediterranean North	4,553.53	24	112.339	539	40.534
	Mediterranean South	6,025.18	24	75.218	539	80.102
	Nemoral	8,648.57	24	27.826	539	310.808
	Pannonian	12,760.92	24	64.697	539	197.24
	Steppic	2,180.02	24	17.795	539	122.507
topography	Coastline	10,365.03	24	378.589	539	27.378
	intertidal flats	4.812	24	1.054	539	4.564
	hills	17,101.79	24	337.414	539	50.685
	lowland	21,717.98	24	269.544	539	80.573
	mountains	12,884.47	24	213.174	539	60.441
	high mountains	2,176.26	24	33.442	539	65.075
	alpine (DEM)	1.468	24	0.176	539	8.357
parent material	river alluvium	1,520.19	24	137.783	539	11.033
	marine alluvium	175.364	24	23.119	539	7.585
	glaciofluvial sediments	20,445.34	24	146.891	539	139.187
	calcareous	6,297.39	24	176.024	539	35.776
	soft clayey	988.273	24	132.27	539	7.472
	hard clayey	28.924	24	12.535	539	2.307
	sands	4,024.47	24	149.964	539	26.836
	sandstone	212.63	24	43.958	539	4.837
	soft loam	8,247.91	24	219.202	539	37.627
	siltstone	4.734	24	1.18	539	4.012
	detrital formations	67.408	24	28.359	539	2.377
	crystalline	10,267.62	24	273.085	539	37.599
	volcanic	55.303	24	21.708	539	2.548
	other rocks	176.62	24	35.033	539	5.042
	organic materials	85.299	24	14.061	539	6.066
	unclassified	3.757	24	0.824	539	4.559

The ANOVA analysis (Table 3) provides information about the significance of attributes for the classification. The high F-values indicate that climatic variables are the most important distinguishing feature on a broad scale. However, topography and parent material are discriminators for classifying regions within.

Secondary Landscape Structure (SLS)

On the basis of the input data, the NUTSx regions were assigned to 20 clusters. Figure 5 presents the European SLS clusters. The ANOVA analysis presented in Table 4 reveals that land cover is mainly responsible for creating clusters; other socio-economic variables play a less important role.

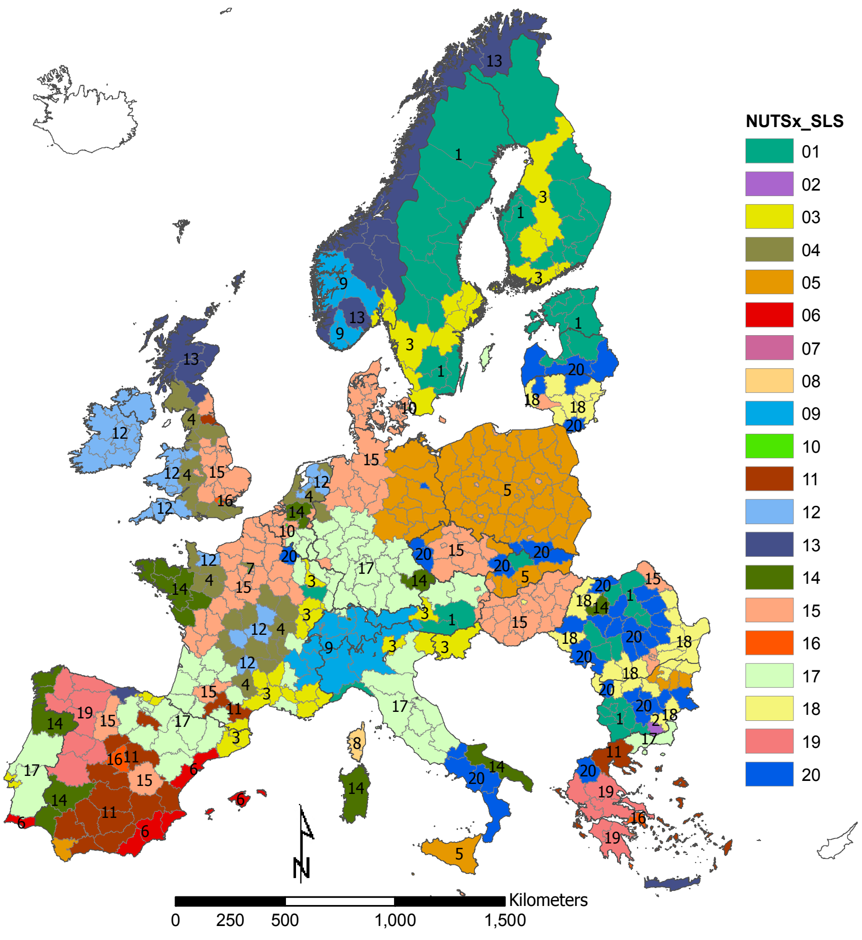

Fig. 5. SLS cluster regions of Europe

Table 4. ANOVA analysis of SLS clusters, variables which are significantly forming the clusters are highlighted in orange (higher significance) and blue (lesser significance)

ANOVA					
	Cluster		Error		
	mean square	df	mean square	df	F
pop.density	796.951	19	10.222	544	77.968
pop.change	9,455.269	19	178.736	544	52.901
activity rate	222.055	19	36.432	544	6.095
GDP	3,296.948	19	65.859	544	50.060
unemployment rate	5,188.289	19	103.909	544	49.931
FUA	1,300.655	19	112.421	544	11.570
artificial surfaces	2,056.768	19	10.620	544	193.670
arable land	30,142.035	19	166.882	544	180.619
intertidal flats	1.526	19	1.173	544	1.301
forest	23,136.604	19	127.593	544	181.331
heterogeneous agric. areas	3,513.123	19	76.378	544	45.996
open spaces (unvegetated)	2,523.869	19	17.245	544	146.352
pastures	11,369.805	19	43.295	544	262.615
permanent crops	136.243	19	19.706	544	6.914
shrubs & herbaceous vegetation	5,515.312	19	53.432	544	103.221
waterbodies	4.000	19	1.604	544	2.494
wetlands	5.201	19	1.379	544	3.772

Aggregation to SRRF clusters

Each NUTSx region belongs to one PLS and one SLS cluster. In total, there are 107 different combinations of clusters; those most alike are grouped next to each other. In the matrix, lines indicate where aggregations are statistically not feasible.

The method is flexible because it combines a statistical base and still allows for expert judgement. Depending upon which level of detail seems to be necessary, aggregation can be adjusted.

When working with the SRRF clusters in terms of applications, it was apparent that the first result of the “scientific” clustering had limitations, because policy makers require spatial coherence in order to reflect regional character. Therefore, in a second phase SRRF clusters were modified, using the PLS / SLS matrix based on the following pre-defined rules:

Individual or groups of identical SRRF clusters which lie more than 350 km apart were treated as follows:

- cluster regions with up to three NUTS regions were reallocated according to the matrix, or in exceptional cases to neighbouring classes (‘changes with boundaries’);

- if there were more than three NUTS regions then these were allocated to a separate cluster ('split-up');
- urban clusters, e.g. Paris, London, Berlin, Madrid, ('city rule') were allocated to surrounding clusters to keep consistency, because other significant conurbations were not included, e.g. Amsterdam;

Application of these rules resulted in 27 SRRF cluster regions (Figure 6). The reallocation of the outline of NUTS-X regions is improving the socio-economic cohesion, and is therefore easier to interpret and communicate to policy makers.

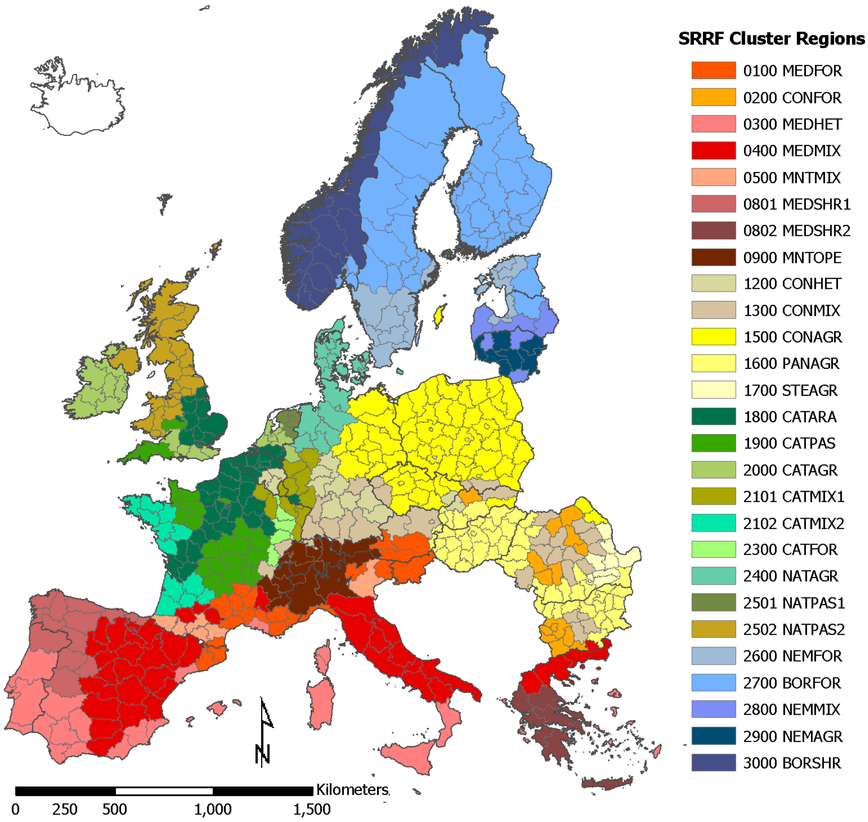

Fig. 6. Final SRRF cluster regions after implementing the post-processing procedure; identifiers and abbreviations of the SRRF cluster regions are presented in the adjacent legend.

4 Discussion

For the SENSOR project it is essential to find appropriate reference units for which thresholds and limits can be defined. As the impact assessment is based on three pillars of sustainability (economic, environmental and social), the development of these reference units has to be based on variables which represent all policy domains. Hence the approach described above.

Previously developed landscape classifications such as Environmental Zones (Metzger et al., 2005) and LANMAP2 (Mücher et al., 2006) are more appropriate for ecological investigations.

For a Europe wide classification it is important to rely on consistent data. Therefore the major data sources have been identified as LANMAP2 (Mücher et al. 2006) and the ESPON data base. Biophysical and land cover data were available on as grid or as vector data. But socio-economic parameters, e.g. GDP per capita, population density, unemployment rate etc., were in most cases available for administrative units (NUTS-regions). Therefore the interface of NUTS-X regions was developed in order to have the possibility to combine all data sets. This is one of the crucial points of the SRRF. On the one hand, NUTS-X show several limitations like different size, heterogeneity and different composition of land cover classes, but on the other hand, European projects and administrations are almost solely using these units (Official Journal of the European Union, 2003).

There remains a major constraint in that some socio-economic data from LANMAP for some NUTSx regions were not available for incorporation into the SRRF. A possible solution is to find other data-sources which offer comparable information and to integrate these data into the cluster regions. From a political and pragmatic point of view, this could be an administratively useful first step towards a classification system covering the whole of Europe. Other European institutions, e.g., the EEA may not find the SRRF as suitable, because environmental questions may need other spatial units.

The clustering and profiling for threshold analysis is based on primary and secondary landscape structure. Only the SLS is expected possibly to change in future, leaving the PLS as a robust basis of the current clustering method. In the timescale of the SENSOR project small administrative changes in NUTS boundaries will have limited effects on the clustering results. Major NUTS changes could influence the final clustering (e.g., new grouping of two NUTS regions, which are now in two different clusters). Since the original PLS and SLS values are known it is possible to regroup the new regions manually, with expert knowledge, as has been carried out in this version.

Another possible improvement would be to update the data. The ESPON data used covered the years 1999 / 2000, whereas land cover data were derived from CORINE 1990. Calculating a cluster-analysis with newer data may also result in slight changes. However, they are not expected to cause major re-arrangements of cluster regions since the change in land cover between the year 1990 and 2000 is relatively small (http://terrestrial.eionet.europa.eu/CLC2000/changes).

5 Conclusion

The SRRF can be considered as the first real attempt to integrate biophysical, socio-economic and regional specific characteristics into a robust spatial reference framework. It provides the basis for regional indicator assessment and acknowledges the heterogeneity of European geography and cultural identity. It is flexible and can be re-arranged if future generalisation, or major changes in boundaries and land use so require. Updating of input data and statistical improvements will be the main future tasks if the SRRF stays in use after the project-period of SENSOR.

References

Briquel, V (2008) Regional socio-economic profiles for European land use related policies assessment: the SENSOR experience. In: Helming K, Tabbush P, Pérez-Soba M (eds). Sustainability impact assessment of land use changes. Springer, 231-248

Commission of the European Communtities (2005) Impact assessment guidelines. SEC(2005) 791

EEA (2005). Agriculture and environment in EU-15 - the IRENA indicator report; EEA Report No 6/2005

INSPIRE (2002) INSPIRE Architecture and Standards Working Group Position Paper

Janssen J and Laatz W (2005) Statistische Datenanalyse mit SPSS für Windows. Springer, Berlin Heidelberg New York, 5th Edition

Jongman RHG, Ter Braak CJF and van Tongeren OFR (eds) (1995) Data analysis in community and landscape ecology. Wageningen: Pudoc. Cambridge University Press

Meeus JHA (1995) Pan-European landscapes. Landscape and Urban Planning 31: 57-79

Metzger MJ, Bunce RGH, Jongman RHG, Mücher CA and Watkins JW (2005) A climatic stratification of the environment of Europe. Global Ecology and Biogeography 14: 549-563

Mücher CA, Bunce RGH, Jongman RHG, Klijn JA, Koomen AJM, Metzger MJ and. Wascher DM (2003). Identification and Characterisation of Environments and Landscapes in Europe. Alterra rapport 832, Alterra, Wageningen.

Mücher CA, Wascher DM, Klijn JA, Koomen AJM and Jongman RHG (2006) A new European Landscape Map as an integrative framework for landscape character assessment. In: Bunce RGH and Jongman RHG (eds) Landscape Ecology in the Mediterranean: inside and outside approaches. Proceedings of the European IALE Conference 29 March – 2 April 2005 Faro, Portugal. IALE Publication Series 3, 233-243.

Naveh Z and Lieberman AS (1994) Landscape Ecology – Theory and Application. Springer, Berlin Heidelberg New York

Official Journal of the European Union (2003) Regulation (EC) No 1059/2003 of the European Parliament and of the Council 26 May 2003 on the establishment of a common classification of territorial units for statistics (NUTS)

O'Neill RV, De Angelis DL, Waide JB and Allen TFH (1986) A hierarchical concept of ecosystems. Princeton University Press, Princeton New Jersey USA

Peterseil J, Wrbka T, Plutzar C, Schmitzberger I, Kiss A, Szerencsits E, Reiter K, Schneider W, Suppan F, Beissmann H (2004) Evaluating the ecological sustainability of Austrian agricultural landscapes: the SINUS approach. Land Use Policy 21: 307-320

Ružicka M, Miklos L (1990) Basic premises and methods in landscape ecology planning and optimization. In: Zonneveld IS and Forman RTT (eds) Changing landscape, an ecological perspective. Springer, Berlin Heidelberg New York, 233-260

Wascher DM (ed) (2005) European Landscape Character Areas – Typologies, Cartography and Indicators for the Assessment of Sustainable Landscapes. Final Project Report as deliverable from the EU's Accompanying Measure project European Landscape Character Assessment Initiative (ELCAI), funded under the 5th Framework Programme on Energy, Environment and Sustainable Development (4.2.2), Alterra rapport 1254, Wageningen

Wascher DM (2003). Overview on agricultural landscape indicators across OECD countries. In: Damstad W and Sogge C (eds) Agricultural impacts on landscapes: developing indicators for policy analysis. Proceedings from NIJOS/OECD Expert Meeting on Agricultural Landscape Indicators in Oslo, Norway, October 7-9, 2002. 19-36

Wrbka T, Erb KH, Schulz N, Peterseil J, Hahn C and Haberl H (2004) Linking pattern and process in cultural landscapes. An empirical study based on spatially explicit indicators. Land Use Policy 21: 28-306

internet sources:

EUROPA – Eurostat: http://epp.eurostat.ec.europa.eu (21.03.2006)

EUROPA – European Commission – Environment – Integrated Coastal Zone Managment: http://ec.europa.eu/environment/iczm/home.htm (21.03.2006)

INSPIRE: The INfrastructure for SPatial InfoRmation in Europe: http://inspire.jrc.it/ (21.03.2006)

EIONET – CLC changes database information:
http://terrestrial.eionet.europa.eu/CLC2000/changes (21.03.2006)
EUROPA – Eurostat – Regions – Introduction to the NUTS:
http://ec.europa.eu/comm/eurostat/ramon/nuts/introduction_regions_en.html (07.01.2008)
European Spatial Planning Observation Network (ESPON): http://www.espon.eu/ (07.01.2008)

Article 2

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European environmental stratifications and typologies: An overview

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ABSTRACT

A range of new spatial datasets classifying the European environment has been constructed over the last few years. These datasets share the common objective of dividing European environmental gradients into convenient units, within which objects and variables of interest have relatively homogeneous characteristics. The stratifications and typologies can be used as a basis for up-scaling, for stratified random sampling of ecological resources, for the representative selection of sites for studies across the continent and for the provision of frameworks for modeling exercises and reporting at the European scale.

This paper provides an overview of five recent European stratifications and typologies, constructed for contrasting objectives, and differing in spatial and thematic detail. These datasets are: the Environmental Stratification (EnS), the European Landscape Classification (LANMAP), the Spatial Regional Reference Framework (SRRF), the Agri-Environmental Zonation (SEAMzones), and the Foresight Analysis for Rural Areas Of Europe (FARO-EU) Rural Typology. For each classification the objective, background, and construction of the dataset are described, followed by a discussion of its robustness. Finally, applications of each dataset are summarized.

The five stratifications and typologies presented here give an overview of different research objectives for constructing such classifications. In addition they illustrate the most up to date methods for classifying the European environment, including their limitations and challenges. As such, they provide a sound basis for describing the factors affecting the robustness of such datasets. The latter is especially relevant, since there is likely to be further interest in European environmental assessment. In addition, advances in data availability and analysis techniques, will probably lead to the construction of other typologies in the future.

1. Introduction

Integrated assessments have become increasingly important to explore the state and trends of the European environments by identifying threats, evaluating existing policy targets and supporting future policy development (Tol and Vellinga, 1998). The classification of knowledge and data is essential for the analysis, summary and communication of the complexity of ecological and socio-economic systems. Furthermore, spatial stratifications can be used as basis for up-scaling, for stratified random sampling, for the selection of representative sites for studies across the continent, and for the provision of frameworks for modeling exercises (Metzger et al., 2005a). Such stratifications have been developed for this purpose in a range of countries (e.g., Great Britain (Bunce et al., 1996a,b), Spain (Elena-Rosselló, 1997), New Zealand (Leathwick et al., 2003), Austria (Peterseil et al., 2004), and Norway (Bakkestuen et al., 2008)).

At the European scale, classification and mapping of the environment have been carried out since the Nineteenth Century. The original methods for spatially classifying environmental differences relied upon the intuitive interpretation of observed patterns, based on personal experience. Recent examples include maps of European landscapes (Meeus, 1995), Biogeographic Regions Map of Europe (Roekaerts, 2002) and the Potential Natural Vegetation map (Bohn et al., 2000). These classifications provide descriptions of environmental regions, but are not suitable for sampling stratification or up-scaling, since class divisions depend on subjective judgment and cannot be reproduced independently.

There were also early quantitative approaches. Firstly, there are the climatic vegetation classifications (cf. Köppen, 1900), and biome

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classifications used in dynamic global vegetation modeling (cf. Prentice et al., 1992). However, they distinguish only a few classes for Europe which is not sufficient to enable a suitable stratification (Metzger et al., 2005a). Secondly, statistical approaches in the construction of environmental stratifications have also been developed. Jones and Bunce (1985) defined 11 classes on a 50 km grid for Europe. More than a decade later, improved data availability, software, and computing power allowed the classification of 64 classes on a 0.5° grid (Bunce et al., 1996c). Although this latter classification was used in a range of studies (e.g., Duckworth et al., 2000; Petit et al., 2001), its coarse resolution limited its application. Since then, a range of new European stratifications and typologies has been produced, stimulated by the increased availability of spatial environmental datasets, rapid advances in spatial data processing, and motivated by the requirements of European Union projects.

Five of these datasets, constructed for different objectives, are discussed and compared in this paper: (1) The Environmental Stratification of Europe (EnS; Metzger et al., 2005a; Jongman et al., 2006) was developed to provide generic strata for sampling, reporting and modeling, following the earlier work by Bunce et al. (1996c). (2) Mücher et al. (2006, 2010) developed the European Landscape Classification (LANMAP) to provide a consistent delineation of European Landscapes for sampling, reporting and modeling. (3) The Spatial Regional Reference Framework (SRRF; Renetzeder et al., 2008) was developed to assess the sustainability of administrative regions. (4) The Agri-Environmental Zonation (SEAMzones) (Hazeu et al., 2006, 2010) was constructed to provide a framework for integrated modeling of European agriculture. Finally, (5) the Foresight Analysis for Rural Areas Of Europe (FARO-EU) Rural Typology was developed to provide a consistent definition of variability in European rural regions. Table 1 provides a summary of the mentioned datasets, while Fig. 1 shows maps of the stratifications and typologies for the Iberian Peninsula.

Unfortunately, some of the terminology used to describe the datasets can be confusing. The most generic term, *classification* is defined as *the act or system of putting in classes* (Chambers dictionary). However, when classes are not meant as descriptive units, but specifically designed to divide gradients into relatively homogeneous subpopulations we prefer to use the statistical term *stratification*. By contrast, a *typology* tends to refer to distinct entities that have well-marked characteristics. Although we try to adhere to these subtle differences throughout the manuscript, in practice classification, stratification and typology are often used interchangeably.

In the following sections the objectives, background, and construction of the classifications are described for each dataset, followed by a discussion of their robustness. The latter considers the reliability of the input data, a comparison with other classifications, and a discussion of the residual heterogeneity within the strata. Finally, applications of each dataset are summarized. The paper concludes with a comparison of the five classifications and their robustness.

2. European environmental stratifications

2.1. The environmental stratification of Europe

2.1.1. Objectives and background

The Environmental Stratification of Europe (EnS) was developed to provide a high-resolution stratification of the principal European environmental gradients. In existing maps (e.g., for Biogeography (Roekaerts, 2002) or Eco-Regions (Olson et al., 2001)), classes were not defined statistically, but depend on the experience and judgment of the originators and rely upon the intuition of the observer in interpreting patterns on the basis of personal experience. These classifications, while important as descriptions of environmental regions, are not suitable for statistical stratification (Metzger et al., 2005a).

The EnS aimed to identify relatively homogeneous regions suitable for strategic random sampling of ecological resources, the selection of sites for representative studies across the continent, and the provision of strata for modeling exercises. The dataset provides a generic classification that can be adapted for a specific objective; as illustrated in this paper; as well as providing suitable zonation for environmental reporting.

2.1.2. Construction

The EnS was created using tried-and-tested statistical clustering procedures on primary biophysical variables, and covers a 'Greater European window' (11°W–32°E, 34°N–72°N), extending into northern Africa. This wider extent was needed to permit statistical clustering that could distinguish environments whose main distribution is outside the European continent. Data were analysed at 1 km^2 resolution.

Twenty of the most relevant available environmental variables were selected, based on those identified by statistical screening (Bunce et al., 1996c). These were (1) climate variables from the Climatic Research Unit (CRU) TS1.2 dataset (Mitchell et al., 2004), (2) elevation data from the United States Geological Survey HYDRO1k digital terrain model, and (3) indicators for oceanicity and northing. Principal Component Analysis (PCA) was used to compress 88% of the variation into three dimensions, which were subsequently clustered using an ISODATA clustering routine. The classification procedure is described in detail by Metzger et al. (2005a).

The EnS comprises 84 strata, aggregated into 13 Environmental Zones (EnZs). These were constructed using arbitrary divisions of the mean first principal component score of the strata, with the exception of Mediterranean mountains, which were separated on altitude. Within each EnZ, the EnS strata have been given systematic names based on a three-letter abbreviation of the EnZ to which the stratum belongs and an ordered number based on the mean first principal component score of the PCA. For example, the EnS stratum with the highest mean principal component score within the Mediterranean South EnZ is named MDS1 (Mediterranean South one).

2.1.3. Robustness

Input data for the EnS were selected on the basis of previous experience (Bunce et al., 1996c) and are consistent with the accepted scientific understanding that at a continental scale of climatic factors are main determinants of ecosystems patterns (Klijn and De Haes, 1994). Although the data used in the present study have limitations, e.g., in deriving climate surfaces from the spatial interpolation of weather stations, they are recorded consistently across Europe and are the best data currently available.

Bunce et al. (2002) have shown that statistical environmental classifications have much in common, identifying the major gradients and assigning classes in similar locations despite differences in statistical clustering techniques or input datasets. Kappa analysis of aggregations of the EnS strata shows a 'good comparison' (Monserud and Leemans, 1992) with other European classifications (Metzger et al., 2005b). In addition, the EnS shows strong statistical correlations with European environmental datasets (e.g., for soil, growing season and species distributions (Metzger et al., 2005a) and habitats (Bunce et al., 2008)).

Despite distinguishing 84 strata there can still be considerable environmental heterogeneity with a stratum, especially in regions with many regional gradients, e.g., in topography or soil types. For example, the stratum ALS1 (Alpine South one) covers a range of altitudes from mountain valleys at 630 m to summits at 4453 m. In such cases, regional subdivisions can be constructed based on ancillary datasets such as altitude and soils (Jongman et al., 2006).

Table 1
Comparison of five European stratifications and typologies.

Stratification	Reference	Objectives	Extent	Resolution	Construction	Input variables	Classes
Environmental Stratification of Europe (EnS)	Metzger et al. (2005a) marc.metzger@ed.ac.uk	Generic strata suitable for sampling, reporting, modelling	11°W, 32°E, 4°N, 72°N, encompassing	1 km grid	Multivariate statistical clustering	Climatic variables, altitude, slope	84 environmental strata 13 environmental zones
European Landscape Map (LANMAP)	Mücher et al. (2006, 2010) sander.mucher@wur.nl	A hierarchical framework for European policy implementation, integrated impact assessments, monitoring and reporting	Pan-European	1 km grid	Multi-scale segmentation and majority rules for typology	Climate (C) Altitude (A) Parent material (P) Land cover (L)	Landscape types Level 1: 8 (C) Level 2: 31(C, A) Level 3: 76 (C, A., P) Level 4: 350 (C, A, P, L)
Spatial Regional Reference Framework (SRRF)	Renetzeder et al. (2008) marta.perezsoba@wur.nl christa.renetzeder@univie.ac.at	Stratification for integrated sustainability impact assessment	European Union, Switzerland and Norway	NUTSx	K-Means clustering, geographical coherence and expert knowledge	Climate, topography, bedrock, population density, population change rate, activity rate, gross domestic production, unemployment rate, functional urban areas, land cover	27 SRRF regions
Agri-Environmental Zonation (AEnZ)	Hazeu et al. (2006,2010) eran@life.ku.dk, gerard.hazeu@wur.nl	Spatial framework for integrated modelling in agriculture	European Union, Switzerland and Norway	Agri-environmental zones (building on 1 km grid).	Other stratifications and principal component analysis	Administrative regions, environmental zones, carbon content in topsoil	242 agricultural regions 555 climate zones 3 287 agri-environmental zones
FARO rural-typology	marta.perezsoba@wur.nl	A flexible and transparent framework of rural classes to describe the high diversity of European rural areas at high spatial resolution. Suitable for mapping, reporting and modelling.	European Union, Switzerland and Norway	1 km grid	Multivariate statistical clustering	Economic density (GDP per km^2), accessibility (travel time to the nearest destination of interest given the transportation network per km^2) and EnS	Nine rural classes aggregated into three rural types (peri-urban, rural and deep-rural)

To contact for further information on methodology and availability for each stratification an e-mail address is added to the reference column.

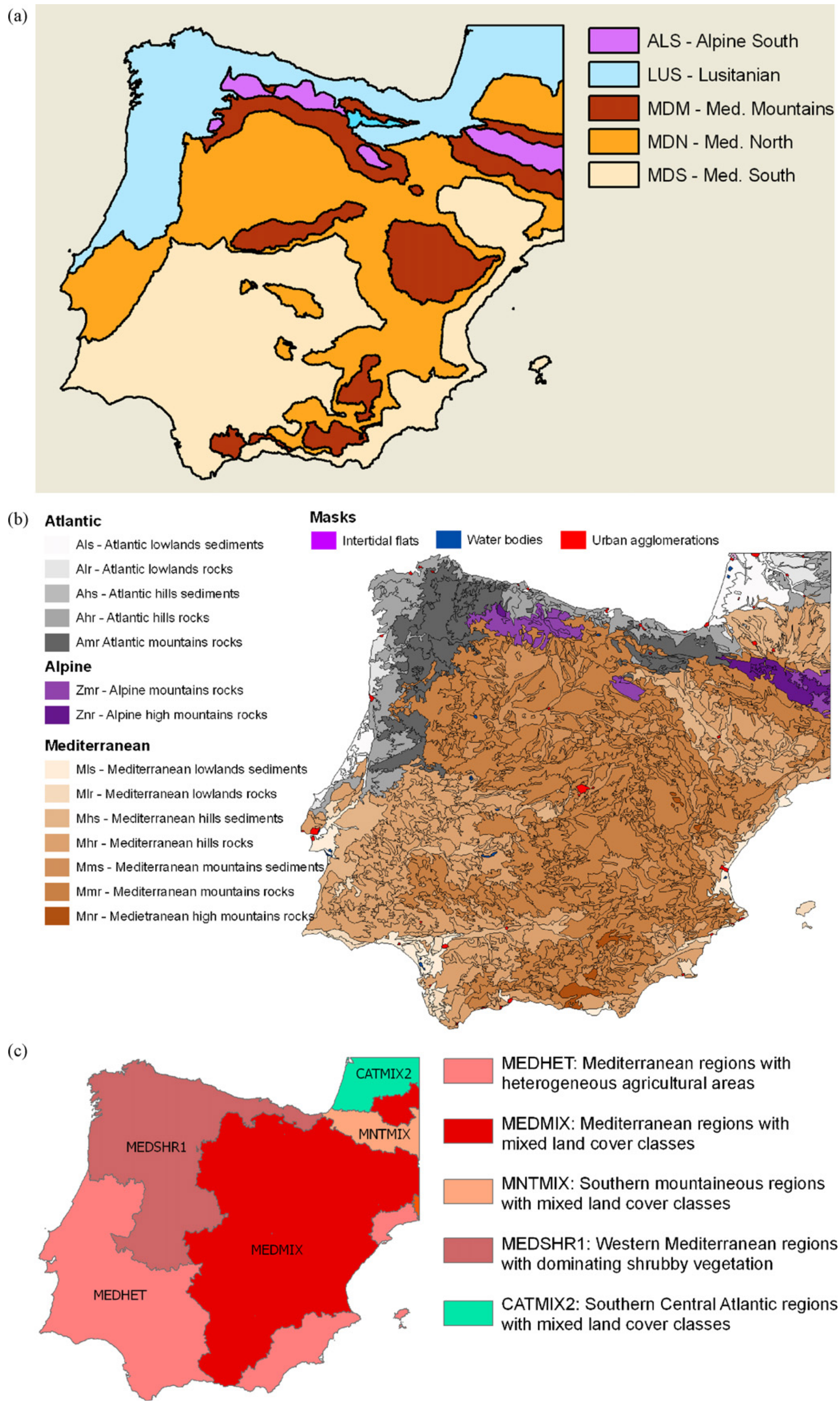
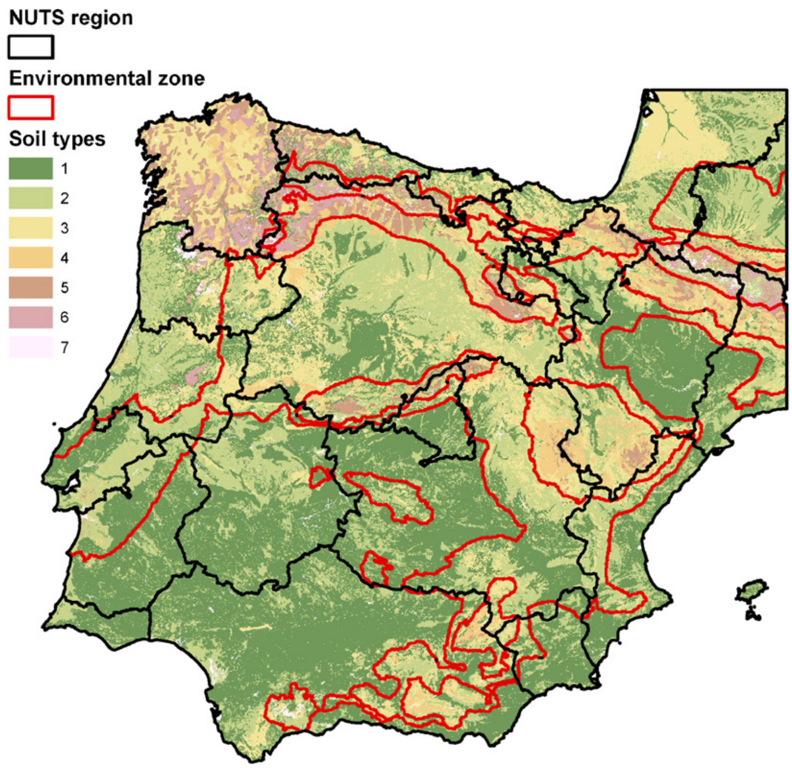


Fig. 1. A spatial overview of the five different classifications of the Iberian Peninsula. The Peninsula is characterized by five Environmental Zones (EnZs) (a). (b) The 14 LANMAP classes at the third level (climate, topography and parent material combined). The five SRRF regions in the Iberian Peninsula are presented in (c). The SEAMzones displayed are a combination of 23 NUTS regions, 5 EnZs and 7 soil types defined by different topsoil organic carbon content (d). The spatial distribution of the nine FARO-EU rural classes (3 GDP classes * 3 accessibility classes) is presented in e.

(d)



(e)

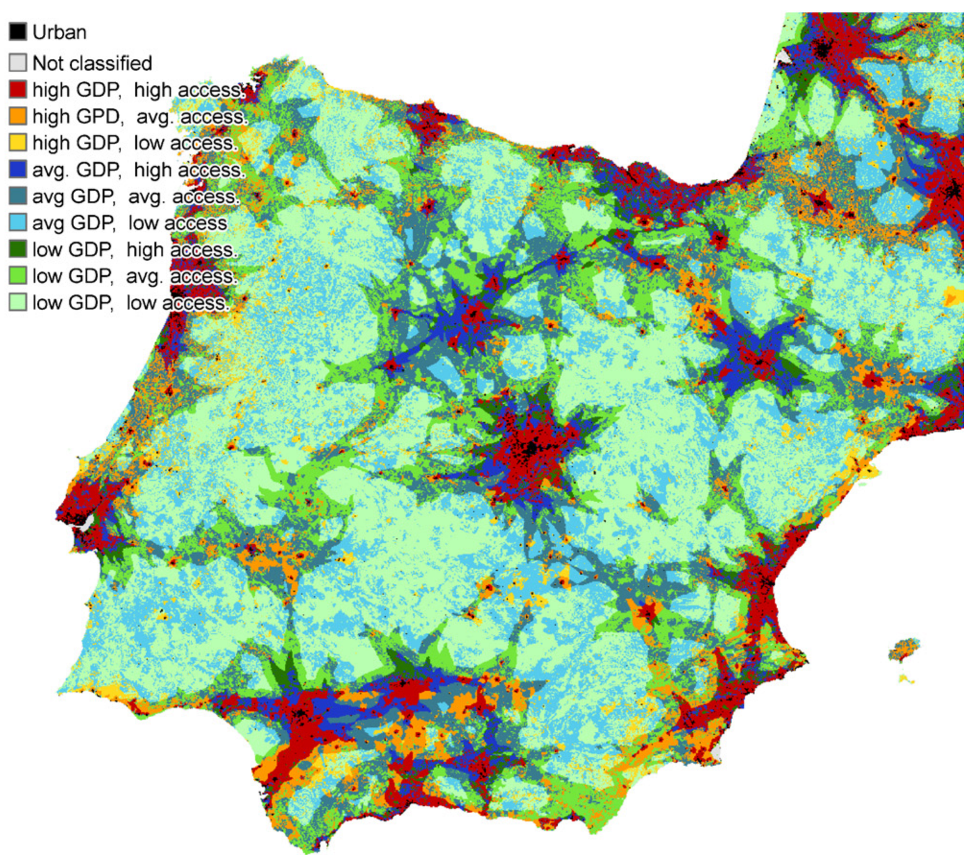


Fig. 1. (*Continued*).

2.1.4. Applications

Over the last few years the dataset has been used in numerous studies. In the most simple form, the EnZs have been used to provide broad European environmental patterns (e.g., Di Filippo et al., 2007; Holland et al., 2009), and as units for summary reporting (e.g., Thuiller et al., 2005; Metzger et al., 2008a; Smit et al., 2008). The European Commission has used the EnZs as the basis for assessing High Nature Value farmland (Paracchini et al.,

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2008) and the identification of potential areas for cultivation of bio-energy crops (EEA, 2007). Bunce et al. (2008) have illustrated how the EnS can be used as a sampling framework for assessing stock and trends in European habitats. The EnS will be developed further under the European Union (EU) European Bio-diversity Network (EBONE) project, which aims to create a framework for surveillance and monitoring of species and habitats in Europe. In addition, the EnS strata can be linked to climate change scenarios, providing insights into broad environmental shifts (Metzger et al., 2008b) as well as providing a basis for the prediction of future crop yields (Ewert et al., 2005) and changes in biodiversity (Verboom et al., 2007). Finally, the EnS has been used as a core data layer in a number of other European classifications, including the four described below.

2.2. The European landscape classification

2.2.1. Objectives and background

A unified European landscape typology could greatly support the Pan-European Biological and Landscape Diversity Strategy (PEBLDS) (Council of Europe, UNEP and ECNC, 1996). Although there were early attempts at producing such a map (e.g., Milanova and Kushlin, 1993; Meeus, 1995), the subjective nature of these maps led to discussions urging more quantitative and reproducible approaches (Jongman and Bunce, 2000; Klijn, 2000; Wascher, 2000; Vervloet and Spek, 2003).

The European Landscape Map (LANMAP) has a hierarchical structure derived from the latest high-resolution spatial datasets and quantitative classification techniques. Such a dataset is potentially useful for European policy implementation and consistent landscape-level integrated assessments, monitoring, and reporting across the continent.

2.2.2. Construction

LANMAP was constructed using a segmentation technique that recognizes objects based on spatial characteristics, a technique most often used in the interpretation of satellite imagery (Mücher et al., 2006, 2010). Input variables were selected following a review of the most suitable data sources. LANMAP covers a Pan-European extent, which includes Iceland, Europe, Turkey, and the former Soviet states west of the Ural mountains. All data were analysed at a 1 km^2 resolution.

Climate, elevation, parent material and land cover were identified as the major components for the delineation of landscape units (Mücher et al., 2010). Climate data were derived from the EnZs (previous section; Metzger et al., 2005a) and Roekaerts (2002). USDA Global Digital Elevation Model (GTOPO30) provided elevation data, while the European Soil Database (CEC, 1985) and the FAO Soil Map of the World (FAO, 1991) were used for parent material. Information on land cover was derived from the CORINE land cover database (CEC, 1994), the Global Land Cover (GLC2000) (Bartholomé and Belward, 2005) and the Pan-European Land Cover Monitoring (PELCOM) database (Mücher et al., 2000, 2001). The spatial identification of the landscape units was based on a multi-scale segmentation procedure of altitude and parent material as the first level, and land cover data as a sub-level. Climate data were attributed to each landscape unit using the majority values for each landscape unit. Thematic aggregation of the four data layers used for the delineation of the landscape units resulted in a typology with a limited number of classes. The classification procedure is described in detail by Mücher et al. (2010).

LANMAP is a hierarchical Pan-European landscape classification with four nested levels, ranging from eight climatically defined classes to 350 landscapes types at the most detailed level, defined by combinations of the four landscape components. In total, more than 14,000 mapping units are distinguished with an average size of 774 km^2. The smallest mapping unit is 11 km^2 and the largest 739,000 km^2.

2.2.3. Robustness

LANMAP is based on a transparent, repeatable methodology in combination with the most appropriate environmental datasets. However, there are limitations in the spatial and thematic detail and accuracy of currently available datasets. Furthermore, the integration of various data sources for one specific theme and the combination of the four data layers invokes error propagation, which is not easily resolved. The constant improvements in European spatial datasets will reduce these errors, and the incorporation of landscape structure, as derived from remotely sensed images, could further refine the dataset (Mücher et al., 2008b).

A geo-spatial cross-analysis of LANMAP with ten national and regional landscape classifications showed that national landscape typologies differ so much in scales, methods, and techniques that it is difficult to make meaningful comparisons (Kindler, 2005). However, an additional questionnaire, sent to a wide range of European environmental institutes, indicated that LANMAP gives a consistent view across Europe and provides a common framework for discussing European landscapes, even though it cannot replace any of the national typologies.

2.2.4. Applications

Information about the use of LANMAP was obtained form the LANMAP website, where users indicate their intended use of the dataset. LANMAP is for both academic teaching and research (visualization, ecology, wildlife management, soils, habitats, spatial economics, bio-fuels and leisure studies). Many applications relate to the study of ecological processes at the landscape-level, e.g., modeling of invasive species and developing EU wide monitoring schemes. Renetzeder et al. (2008, section 2.3) used LANMAP in constructing the Spatial Regional Reference Framework (SRRF). More recent applications concern the analysis of land cover changes across European landscapes (Mücher et al., 2008a) and the analysis of phenological trends in European landscapes related to changes in climate and land use (De Wit and Mücher, 2009).

2.3. The spatial regional reference framework

2.3.1. Objectives and background

The EU Sustainable Development Strategy (CEC, 2007) demands a balanced impact assessment of the three sustainability dimensions – social, environmental and economic – for all major policy decisions. Human activities have a major impact on the environment and thus also on sustainable development (Helming et al., 2008). The basic association between landscape character and the socio-economic context (Wrbka et al., 2004) shows the need for spatially explicit approaches which combine both biophysical and socio-economic parameters into a spatial stratification. This is the prerequisite of analysing the synergies and trade-offs between the three different sustainability dimensions. Nevertheless, existing European classifications have a rather mono-thematic focus, ranging from urban-rural delineation defined by socio-economic conditions (Pizzoli and Gong, 2007) to purely environmentally defined stratifications (e.g., Metzger et al., 2005a), land use elements sometimes being included as a socio-economic component (Mücher et al., 2006).

The EU funded Integrated Project SENSOR (Sustainability Impact Assessment: Tools for Environmental, Social and Economic Effects of Multifunctional Land Use in European Regions) developed ex-ante Sustainability Impact Assessment Tools (SIAT) to support decision making on land use policies in European regions (Helming et al., 2008). In this frame, the Spatial Regional Reference Framework (SRRF) was designed in order to acknowledge the high degree of cultural and natural diversity in Europe (Wascher, 2005), as regional characteristics determine the scale and scope of impacts on sustainability that have resulted from policy-induced land use changes. It combines environmental and socio-economic parameters into one framework that can be used for an integrated sustainability assessment.

2.3.2. Construction

The SSRF was constructed by statistical clustering biophysical and socio-economic attributes of the Nomenclature of Territorial Units for Statistics (NUTS – Official Journal of the European Union, 2003). The extent of the NUTS-regions level three is highly variable (e.g., mean size of NUTS3 in Germany is 80,681 ha whereas in Norway it is 1,609,060 ha). Grasland et al. (2000) already recognized the methodological problems of generalization and interpolation of statistical surfaces of variable size. In order to harmonize the size of the administrative regions the recently proposed NUTSx aggregation (Renetzeder et al., 2008) was used. The spatial extent of the SRRF covers the European Union and also Norway and Switzerland.

Environmental (climate, topography, bedrock and land cover data), and socio-economic data (including population density, population change rate, activity rate, gross domestic product (GDP), unemployment rate and functional urban areas were extracted from the European Spatial Planning Observation Network (ESPON, 2006a), and Eurostat (European Statistical Office) databases, and LANMAP2 (section 2.2; Mücher et al., 2010). *K*-Means cluster analysis using Euclidean distance was performed separately for environmental and socio-economic variables. Each NUTSx region was assigned to an environmental and a socio-economic cluster on the basis of similar cluster distances and expert knowledge. The final SRRF regions were constructed by merging NUTSx regions based on similarity in cluster distances. The classification procedure is described in detail by Renetzeder et al. (2008).

The SRRF comprises 27 regions, based on 25 environmental clusters and 20 socio-economic clusters. Climate and land cover were the main discriminators, while topography, parent material, population density, and GDP (Gross Domestic Product) played an important role in differentiation between the major climate zones. The largest regions cover more than 500,000 km^2, while the smallest region covers only 22,000 km^2. Several SRRF regions cover areas in many European countries.

2.3.3. Robustness

The analysis of the environmental gradient showed that climate is the main discriminator followed by regional differences in soil properties, which reflect the principal abiotic ecological conditions (cf. Klijn and De Haes, 1994; Metzger et al., 2005a). Because both climate and parent material can be seen as fairly stable parameters, the environmental clusters defining the SRRF regions will be robust. Conversely, socio-economic conditions can change rapidly. Future development, which is dependent on both global trends and national and regional policies, may therefore lead to changes in the clustering results. Furthermore, the borders of the NUTS regions are not stable because they are updated every few years, which requires an equivalent adjustment to the SRRF.

As the EU is divided into 27 SRRF regions, each region will still contain variations in biophysical and socio-economic characteristics. For fine-scaled analysis at the more local level, gradients in biophysical and socio-economic variables need to be considered, with additional datasets added to refine the classification.

2.3.4. Applications

The SRRF regions have been used to reflect biophysical and socio-economic variation within the EU, for the assessment of Land Use Functions (cf. De Groot, 2006). These functions were linked to the sustainability impact indicators developed in SENSOR and weighed within each of the SRRF regions (Pérez-Soba et al., 2008). Then, the final sustainability performance of the Land Use Functions is assessed if:

(1) the pressure actually does affect the SRRF region,
(2) we are likely to see an impact within the region,
(3) it does affect the sustainability within the region.

For more information on this procedure see Pérez-Soba et al. (2008). The SRRF regions, defined by combined socio-economic and environmental clusters, have a clear added value in the sustainability impact assessment.

2.4. The agri-environmental zones (SEAMzones)

2.4.1. Objectives and background

The agri-environmental zones (SEAMzones) were developed as the smallest building block in the spatial framework of the SEAMLESS (System for Environmental and Agricultural Modelling; Linking European Science and Society) project (Hazeu et al., 2006). The aim was to develop a spatial framework that could be used to integrate agricultural sector modeling, bio-economic farm modeling and crop modeling (Van Ittersum et al., 2008). The challenge was to provide a framework that on the one hand represents the diversity in biophysical conditions for farming across the EU, and on the other hand could be linked to agricultural regions defined by administrative borders.

2.4.2. Construction

The SEAMzones were constructed by intersecting agricultural regions, EnZs and a soil classification. The most detailed spatial resolution, of the soil classification, is 1 km^2. The spatial extent covers the EU27, Norway and Switzerland.

The agricultural regions were derived from the agricultural sector model CAPRI (Britz et al., 2007), which determines supply of agricultural products for 242 administrative regions – in most cases at the so-called NUTS2 level (NUTS – Official Journal of the European Union, 2003). The twelve European EnZs (section 2.1, Metzger et al., 2005a) formed a first delineation of regions with similar farming conditions across the EU. Combining the agricultural regions with the EnZs results in 555 *climate zones*, with homogenous climatic conditions. An additional soil layer was added to the dataset to incorporate greater regional diversity in the biophysical conditions for farming. This layer consists of six classes based on the soil organic carbon content in the topsoil. These classes were derived from a 1 km^2 spatial dataset (Jones et al., 2004, 2005) that explained most of the variation in available soils datasets (Hazeu et al., 2010). The threshold values to differentiate the soil classes were defined in order to achieve a homogeneous area coverage of the different soil types within the EU. The construction of the dataset is described in detail by Hazeu et al. (2010).

The final spatial framework delineates 3287 SEAMzones, with an average size of 1400 km^2, ranging from a few km^2 up to almost 80,000 km^2. Fig. 1 shows an example of the SEAMzones for the Iberian Peninsula. The black lines show the borders of the NUTS region, the red lines show the borders of the environmental zones and the colours show the soil types. An area with one colour within any border, red or black, belongs to one SEAMzone.

2.4.3. Robustness

The robustness of the different layers used to define the SEAMzones varies. The layer on agricultural regions depends on the stability of the borders in the administrative regions of the different countries. Changes in these structures can be expected in the future, which will require updates of the spatial framework every few years, depending on the rate of change. The two other layers defining the SEAMzones are more robust. Hazeu et al. (2010), have qualitatively compared the climate variation observed in the climate zones with the original 50 km^2 grid data from the MARS (Monitoring Agriculture through Remote Sensing) system (Micale and Genovese, 2004). It was concluded that the climate zones accurately reflect the long term variations in annual temperature averages and in averages of annual rainfall. However, in some of the Nordic and Baltic countries it was found that the climate zones are too large to fully reflect such variations. The map of the carbon content in the topsoil; used as the third layer to delineate the SEAMzones; is currently the best available option to identify the variation in soil conditions across the EU. However, it is likely that new improved versions of the topsoil carbon content will become available, enabling an even better delineation.

2.4.4. Applications

The SEAMzones, the climate zones and the NUTS2 regions have been used in the SEAMLESS project as a hierarchical spatial framework for all data in the SEAMLESS database (Janssen et al., 2009). This includes issues such as:

- Providing one set of soil data per SEAMzone.
- Spatially allocating farm types to SEAMzones.
- Providing time series of daily climate data per climate zone.
- Linking statistical information on farm management to NUTS regions.
- Selection of sample regions for additional data on farm management.
- Providing contextual information on regions for integrated assessments.

The SEAMLESS database, and thus the spatial framework, has proved to be useful for integrated crop, bio-economic, and agricultural sector modeling (see for example Van Ittersum et al., 2008).

2.5. The FARO-EU rural typology

2.5.1. Objectives and background

There is a policy need for new rural typologies which derive from an approach which proposes that the focus should be on *places* rather than on economic sectors (OECD, 2006; Copus et al., 2007; EC, 2007, 2008). Current rural typologies (OECD, 1994, 2006; ESPON, 2006b) take a site-based approach, but they do not use European averages as standard when studying variations in geographical conditions.

Therefore, in order to provide a further step in the site description of rural types, the EU FP6 Specific Targeted Research Project Foresight Analysis for Rural Areas Of Europe (FARO-EU), has developed a new rural typology whose main objectives are (1) to include the broad geographic differences in Europe (e.g., between northern Europe and the Mediterranean); (2) to select the most appropriate indicators to reflect the site heterogeneity; and (3) to use a high spatial resolution that will allow flexible spatial aggregation to suit a wide range of applications. This new typology considers urban areas and three main types of rural areas, i.e., peri-urban, rural and deep rural. It provides European rural policy-making with a flexible and transparent framework for analysing current trends, as well as future projections, and for supporting flexible policy development.

2.5.2. Construction

The FARO-EU rural typology is based on a matrix of drivers of rurality, nested within the EnZs (section 2.1, Metzger et al., 2005a) to account for geographic differences between rural types. The dataset has a 1 km^2 resolution, and covers the EU27.

An initial multivariate screening of 32 variables from the ESPON database (at NUTS3 level) identified the main axes defining rural regions, i.e., artificial land use, accessibility, population density and GDP. Two datasets with a 1 km^2 resolution were identified to represent these axes in the typology: an economic density indicator, based on GDP per capita and population density and land use, and an accessibility indicator based on travel distances to urban centres. For both indicators three classes were defined within each EnZ to provide a geographic context to the typology. An overlay of the classified maps of the economic density and accessibility indicators resulted in a combined data layer with 3×3 possible rural classes (see for example the Iberian Peninsula in Fig. 1). These nine classes were finally thematically aggregated into three rural classes, i.e., peri-urban, rural, and deep rural.

This FARO-EU rural typology forms a flexible dataset that can be used at various spatial and thematic aggregation levels. The three rural types provide a convenient summary for stakeholders and policymakers, and correspond most directly with existing regional and international rural typologies (OECD, 2005; ESPON, 2006b). However, there is always the possibility to analyse the assumption for the class definition using the underlying 3×3 classes. Spatially, the dataset can be aggregated to NUTS administrative regions for comparison with EU census statistics, or it can be presented at the full 1 km^2 resolution.

2.5.3. Robustness

The rural typology has been tested in nine case studies distributed over five geographical regions, i.e., Alpine, Atlantic, Continental, Mediterranean and North, which are aggregations of the 13 EnZ's. When compared with the national or regional rural classifications available in these case study areas, a strong correspondence was found. The results showed that the typology reflects the geographic and socio-economic variations well. For example, the peri-urban areas are restricted to the areas surrounding the main cities and the principal transport axes. The deep rural areas include remote mountains and moorlands, and contain municipalities with fewer than 5000 inhabitants.

2.5.4. Applications

Since 2008, the results have been applied as a rural framework for thematic analysis by the European Topic Centre Land Use and Spatial Information (ETC-LUSI) (which is an international consortium assisting the European Environment Agency) in two thematic projects on *Environmental Aspects of EU Territorial & Cohesion Policy* and *Regional and Territorial Development of Mountain Areas*.

3. Discussion

3.1. Comparing the stratifications

All five stratifications have a common underlying objective in that they have been developed to divide environmental gradients into convenient units. They have nevertheless been constructed for a range of different specific objects. The following discussion focuses on the similarities and differences in classification methods, and their implications for the results. However, the observations are also relevant to other existing or future studies.

Climate is the primary environmental factor determining environmental differences at a continental scale (Klijn and De Haes, 1994; Metzger et al., 2005a), and explains the principal European patterns of soil, vegetation, species, and landscapes. It is therefore not surprising that climate is the major discriminator in each of the five classifications (Table 1). Although projected climate change will probably impact on many aspects of the environment (IPCC, 2007), the present climate is likely to remain an important independent factor in defining variations in the European environment. The EnS is based primarily on climate; providing broad strata for statistical sampling and analysis of dependant variables such as habitats (Bunce et al., 2008). However, these strata are not designed to reflect local variation, which is often required in regional studies. The climate data used in the EnS is part of the other classifications.

More detailed patterns can be identified when variables with greater regional variation are used to intersect the 13 EnZs. For the SEAMzones this was done by intersecting the EnZs with soil data, while in the FARO-EU Rural Typology detailed patterns were derived from the accessibility and economic density maps. In LANMAP, the segmentation of altitude, parent material and land cover provided landscape classes that were intersected with the climatically defined zones. Fig. 1 illustrates the added regional detail of these approaches for the Iberian Peninsula.

There is also an important difference in the underlying data structure of the different datasets. The EnS, LANMAP, and SRRF were constructed using multivariate classification or segmentation techniques, resulting in a predetermined number of strata that are relatively homogeneous for the combined input variables. The result is a map of uniquely defined polygons or objects. Conversely, the SEAMzones and the FARO-EU Rural Typology were constructed by combining univariate maps of continuous variables, thus forming a database-oriented product with more than one dimension. However, the final typologies were produced by classifying each of the variables separately.

The incorporation of socio-economic variables into the classifications poses a significant challenge, since such data are collected for administrative regions which are often heterogeneous, both in ecological criteria and from the associated socio-economic perspective. For example, NUTS3 regions around the Mediterranean coast often comprise both rural areas in the process of abandonment and intensive coastal tourist development. Other NUTS3 units, especially in mountainous areas, contain major ecological and management gradients. Within the FARO-EU Rural Typology, this limitation was partly overcome by selecting socio-economic variables that could be translated to a 1 km^2 spatial grid. In the case of the SRRF, data availability meant that the administrative level had to be maintained.

3.2. Assessing the robustness of environmental stratifications

Assessing the quality, usefulness or robustness of the environmental stratifications and typologies is not straightforward. In most cases the classifications cut across continuous gradients and the exact location of boundaries will therefore be arbitrary (Metzger et al., 2005a). A primary requirement, however, is that any classification should be constructed within a conceptual framework that is imbedded in scientific theory. This facilitates the identification of the most important gradients to be stratified. Furthermore, the datasets should be created using statistical rules, so that their construction is reproducible and boundaries between strata are not influenced by personal bias. The stratifications presented here meet these requirements. In LANMAP all identified variables were subjected to object-oriented segmentation, while statistical screening was used to select the most relevant input variables for EnS, SRRF, SEAMzones, and the FARO-EU Rural Typology. The strata were then defined by multivariate statistical clustering (EnS, SRRF) or univariate classification (SEAMzones, FARO).

Other factors affecting the quality of the datasets relate to the input data. Although the present discussion does not consider in detail the quality of European environmental datasets, it is important to highlight some sources of uncertainty between these sets. While primary variables (e.g., climate parameters, and those derived from DEMs) are recorded consistently and with a high degree of accuracy across Europe, other datasets are an amalgamation of national datasets. Although considerable effort has been put into the homogenization of the European soils map, the accuracy of derived datasets; such as the data used in the SEAMzones; still have varying degrees of reliability and should be treated with some care (Jones et al., 2005). There are similar issues with the CORINE land cover map, where certain classes are not interpreted consistently between countries. Finally, there are the issues associated with data collected for administrative regions as discussed above.

One way to test the reliability of the patterns derived through the stratifications is by comparing them to other datasets. This is not always straightforward, because comparable datasets may not exist or have been created in a more subjective manner. Differences between datasets often reflect differences in methodology and objectives rather than illustrating the strength or weakness of any new classification. Nevertheless, EnS, LANMAP and the FARO-EU Rural Typology have been compared with existing European and national datasets. Whilst quantitative correlation analyses were only possible for the EnS (Metzger et al., 2005b), comparison with national landscape maps and rural typologies has shown that meaningful regional patterns can be discerned by both LANMAP (Kindler, 2005) and the FARO-EU Rural Typology.

It is important to realize that there are compromises between greater spatial resolution and thematic detail in the stratification and its complexity and robustness. Greater thematic detail is associated with an increase in both the number of data layers, each with inherent uncertainties, and an increase in the choices that need to be made for weighting or classifying the different dimensions. Spatial detail can help to reduce heterogeneity within the strata, but often high-resolution datasets are also based on disaggregation techniques which introduce thematic errors (e.g., for economic density in the FARO-EU Rural Typology). It is important to be aware of these compromises when deciding on the most appropriate stratification, and this will ultimately depend on objectives.

4. Conclusions

As illustrated in this paper, European environmental stratifications and typologies have been constructed for a range of objectives using several classification methods. The current selection was not intended as a complete review of existing classifications, and several recent approaches have not been included, e.g., the Homogeneous Spatial Mapping Units (HSMUs) described elsewhere in this issue (Kempen et al., 2005), and the LTER-Europe socio-ecological regions (Metzger and Mirtl, 2008). However, the five stratifications and typologies presented here give an overview of different research objectives, as well as illustrating the most up to date methods, and the limitations and challenges in classifying the European environment. Furthermore, they provide a sound basis for discussing the factors affecting the robustness of the results. Such a discussion is particularly relevant, since further projects needing European environmental assessment will require new classifications which will be able to use advances in data availability and analysis techniques.

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References

Bakkestuen, V., Erikstad, L., Halvorsen, R., 2008. Step-less models for regional environmental variation in Norway. Journal of Biogeography 35, 1906–1922.
Bartholomé, E., Belward, A.S., 2005. GLC2000: a new approach to global land cover mapping from earth observation data. Internationa Journal of Remote Sensing 26 (9), 1959–1977.
Bohn, U., Gollub, G., Hettwer, C., 2000. Karte der natürlichen Vegetation Europas: Maßstab 1:2.500.000. Bundesamt für Naturschutz, Bonn-Bad Godesberg.
Britz, W., Pérez, I., Zimmerman, A., Heckelei, T, 2007. Definition of the CAPRI Core Modelling System and Interfaces with other Components of SEAMLESS-IF. SEAMLESS Report No.26, SEAMLESS integrated project, EU 6th Framework Programme, contract no. 010036-2, www.SEAMLESS-IP.org, 116 pp.
Bunce, R.G.H., Barr, C.J., Clarke, R.T., Howard, D.C., Lane, A.M.J., 1996a. Land classification for strategic ecological survey. Journal of Environmental Management 47, 37–60.
Bunce, R.G.H., Barr, C.J., Gillespie, M.K., Howard, D.C., 1996b. The ITE land classification: providing an environmental stratification of Great Britain. Environmental Monitoring and Assessment 39, 39–46.
Bunce, R.G.H., Watkins, J.W., Brignall, P., Orr, J., 1996c. A comparison of the environmental variability within the European Union. In: Jongman, R.G.H. (Ed.), Ecological and Landscape Consequences of Land Use Change in Europe. European Centre for Nature Conservation, Tilburg, the Netherlands, pp. 82–90.
Bunce, R.G.H., Carey, P.D., Elena-Rosselló, R., Orr, J., Watkins, J.W., Fuller, R., 2002. A comparison of different biogeographical classifications of Europe, Great Britain and Spain. Journal of Environmental Management 65, 121–134.
Bunce, R.G.H., Metzger, M.J., Jongman, R.H.G., Brandt, J., De Blust, G., Elena-Rossello, R., Groom, G.B., Halada, L., Hofer, G., Howard, D.C., Kovar, P., Mücher, C.A., Padoa-Schioppa, E., Palinckx, D., Palo, A., Perez-Soba, M., Ramos, I.L., Roche, P., Skånes, H., Wrbka, T., 2008. A Standardized procedure for surveillance and monitoring of European habitats and provision of spatial data. Landscape Ecology 23, 11–25.
CEC, 1985. Soil map of the European Communities 1:100.0000 (Tavernier cs) Commission of the European Communities, Luxembourg, 124 pp.
CEC, 1994. CORINE Land Cover. Technical Guide. Office for Official Publications of European Communities, Luxembourg.
CEC, 2007. Progress Report on the Sustainable Development Strategy 2007. COM(2007) 642 final. Commission of the European Communities, Luxembourg.
Copus, A., Psaltopoulod, D, Skuras, D, Terluin, I, Weingarten, P., 2007. Common features of diverse european rural areas: review of approaches to rural typology. Final Report (v 1.2) of EC contract 150669-2007 F1SCUK. UHI Millennium Institute, Inverness, UK.
Council of Europe, UNEP, ECNC, 1996. The Pan-European Biological and Landscape Diversity Strategy: A Vision for Europe's Natural Heritage. Council of Europe Publishing, Strasbourg.
De Groot, R., 2006. Function analysis and valuation as a tool to assess land use conflicts in planning for sustainable, multifunctional landscapes. In: Potschin, M., Haines-Young, R.H. (Eds.), Landscapes and Sustainability. Landscape and Urban Planning, vol. 75, pp. 175–186.
De Wit, A., Mücher, C.A., 2009. Satellite-derived trends in phenology over Europe: real trends or algorithmic effects. Geophysical Research Abstracts, vol. 11, EGU2009-4837, 2009. EGU General Assembly 2009 from 19 to 24 April 2009, Vienna, Austria.
Di Filippo, A., Biondi, F., Čufar, K., De Luis, M., Grabner, M., Maugeri, M., Presutti Saba, E., Schirone, B., Piovesan, G., 2007. Bioclimatology of beech (*Fagus sylvatica* L.) in the Eastern Alps: spatial and altitudinal climatic signals identified through a tree-ring network. Journal of Biogeography 34, 1873–1892.
Duckworth, J.C., Bunce, R.G.H., Malloch, A.J.C., 2000. Vegetation gradient in Atlantic Europe: the use of existing phytosociological data in preliminary investigations on potential effects of climate change on British vegetation. Global Ecology and Biogeography 9, 197–199.
EC, 2007. Growing regions, growing Europe. Fourth report on economic and social cohesion. Communication from the Commission May ISBN 92-79r-r05704-5.
EC, 2008. Green paper on territorial cohesion. Turning territorial diversity into strength. Communication from the Commission October (SEC 2550).
EEA, 2007. Estimating the Environmentally Compatible Bioenergy Potential from Agriculture. EEA Technical Report 12. European Environment Agency, Copenhagen.
Elena-Rosselló, R., 1997. Clasificatión Biogeoclimática de España Peninsular y Balear. Ministerio de Agricultura, Pesca y Alimentación, Madrid.
ESPON, 2006a. Territory matters for competitiveness and cohesion. Synthesis Report III. URL: http://www.espon.eu/mmp/online/website/content/publications/98/1229/file_2471/final-synthesis-reportiii_web.pdf.
ESPON, 2006b. ESPON Project 3.1 – ESPON Atlas. Ed. Bundesamt für Bauwesen und Raumordnung, Bonn, Germany.
Ewert, F., Rounsevell, M.D.A., Reginster, I., Metzger, M.J., Leemans, R., 2005. Future scenarios of European agricultural land use. I: Estimating changes in crop productivity. Agriculture Ecosystems and Environment 107, 101–116.
FAO, 1991. The Digitized Soil Map of the World (Release 1.0), Rep. No. 67/1. Food and Agriculture Organization of the United Nations, Rome.
Grasland, C., Mathian, H., Vincent, J.-M., 2000. Multiscalar analysis and map generalization of discrete social phenomena: statistical problems and political consequences. Statistical Journal of the United Nations ECE 17, 157–188.
Hazeu, G.W., Elbersen, B.S., van Diepen, C.A., Baruth, B., Metzger, M.J., 2006. Regional typologies of ecological and biophysical context. SEAMLESS Report No.14, SEAMLESS integrated project, EU 6th Framework Programme, contract no. 010036-2, www.SEAMLESS-IP.org, 55 pp.
Hazeu, G., Elbersen, B., Andersen, E., Baruth, B., van Diepen, K., Metzger, M., 2010. A biophysical typology for a spatially-explicit agri-environmental modeling framework. In: Brouwer, F., Van Ittersum, M.K. (Eds.), Environmental and Agricultural Modeling: Integrated Approaches For Policy Impact Assessment. Springer, The Netherlands.
Helming, K., Pérez-Soba, M., Tabbush, P. (Eds.), 2008. Sustainability Impact Assessment of Land Use Change. Springer-Verlag, Berlin, Heidelberg, Germany.
Holland, E.P., Burrow, J.F., Dytham, C., Aegerter, J.N., 2009. Modeling with uncertainty: introducing a probabilistic framework to predict animal population dynamics. Ecological Modeling 220, 1203–1217.
IPCC, 2007. Working group II contribution to the intergovernmental panel on climate change fourth assessment report, summary for policymakers. http://www.ipcc.ch/SPM13apr07.pdf.
Janssen, S., Andersen, E., Athanasiadis, I., Van Ittersum, M.K., 2009. A database for integrated assessment of European agricultural systems. Environmental Science & Policy 12 (5), 573–587.
Jones, H.E., Bunce, R.G.H., 1985. A preliminary classification of the climate of Europe from temperature and precipitation records. Journal of Environmental Management 20, 17–29.
Jones, R.J.A., Hiederer, R., Rusco, E., Loveland, P.J., Montanarella, L., 2004. The map of organic carbon in topsoils in Europe, Version 1.2, September 2003: Explanation of Special Publication Ispra 2004 No. 72 (S.P.I.04.72). European Soil Bureau Research Report No. 17, EUR 21209 EN, 26pp. and 1 map in ISO B1 format. Office for Official Publications of the European Communities, Luxembourg.
Jones, R.J.A., Hiederer, R., Rusco, E., Montanarella, L., 2005. Estimating organic carbon in the soils of Europe for policy support. European Journal of Soil Science 56, 655–671.
Jongman, R.H.G., Bunce, R.G.H., 2000. Landscape classification, scales ad biodiversity in Europe. In: Mander, Ü., Jongman, R.H.G. (Eds.), Consequences of Land Use Change in Europe. WIT Press, United Kingdom, pp. 11–38.
Jongman, R.H.G., Bunce, R.G.H., Metzger, M.J., Mücher, C.A., Howard, D.C., Mateus, V.L., 2006. Objectives and applications of a statistical environmental stratification of Europe. Landscape Ecology 21, 409–419.
Kempen, M., Heckelei, T. Britz, W., 2005. A statistical approach for spatial disaggregation of crop production in the EU. In: Arfini, F. (ed.). Modelling Agricultural Policies: State of the Art and New Challenges. Proceedings of the 89th European Seminar of the European Association of Agricultural Economists (EAAE). Parma, Italy, February 3–5, 2005, pp. 810–830.
Kindler, A., 2005. Geo-spatial cross-analysis of LANMAP and national approaches, in: Wascher, D.M. (Ed.), European Landscape Character Areas—Typology, Cartography and Indicators for the Assessment of Sustainable Landscapes. Final ELCAI project report, Landscape Europe, pp. 46–87.
Klijn, F., De Haes, H.A.U., 1994. A hierarchical approach to ecosystems and its implications for ecological land classification. Landscape Ecology 9, 89–104.
Klijn, J.A., 2000. Developments in European landscape assessment. In: Wascher, D.M. (Ed.), Landscapes and suitability, Proceedings of the European Workshop On Landscape Assessment As a Policy Tool, 25th–26th March'99. Strasbourg, France. Tilburg, ECNC pp. 58–61.
Köppen, W., 1900. Versuch einer Klassification der Klima, Vorsuchsweise nach ihren Beziehungen zur Pflanzenwelt. Geographische Zeitschrift 6 (593–611), 657–679.
Leathwick, J.R., Overton, J.M., McLeod, M., 2003. An environmental domain classification of New Zealand and its use as a tool for biodiversity management. Conservation Biology 17, 1612–1623.
Meeus, J.H.A., 1995. Pan-European landscapes. Landscape Urban Planning 31 (1–3), 57–79.
Metzger, M.J., Bunce, R.G.H., Jongman, R.H.G., Mücher, C.A., Watkins, J.W., 2005a. A climatic stratification of the environment of Europe. Global Ecology and Biogeography 14, 549–563.
Metzger, M.J., Leemans, R., Schröter, D.S., 2005b. A multidisciplinary multi-scale framework for assessing vulnerability to global change. International Journal of Applied Geo-information and Earth Observation 7, 253–267.
Metzger, M.J., Schröter, D., Leemans, R., Cramer, W., 2008a. A spatially explicit and quantitative vulnerability assessment of environmental change in Europe. Regional Environmental Change 8, 91–107.
Metzger, M.J., Bunce, R.G.H., Leemans, R., Viner, D., 2008b. Projected environmental shifts under climate change: European trends and regional impacts. Environmental Conservation 35, 64–75.
Metzger, M.J., Mirtl, M., 2008. LTER Socio-ecological regions (LTER-SER)–represenativeness of European LTER facilities—current state of affairs. ALTER-Net report I3051v06.
Micale, F., Genovese, G. (Eds.), 2004. Methodology of the MARS Crop Yield Forecasting System (MCYFS) Vol. 1, Meteorological Data Collection, Processing

and Analysis. EUR 21291 EN/1. Office for Official Publications of the European Communities, Luxembourg, 100pp.

Milanova, E.V., Kushlin, A.V. (Eds.), 1993. World Map of Present Day Landscapes. An Explanatory Note. Department of World Physical Geography and Geoecology, Moscow State University (in collaboration with UNEP, 25 pp. plus annexes).

Mitchell, T.D., Carter, T.R., Jones, P.D., Hulme, M., New, M., 2004. A Comprehensive Set of High-resolution Grids of Monthly Climate for Europe and the Globe: The Observed Record (1901–2000) and 16 Scenarios (2001–2100), Tyndall Centre Working Paper no. 55. Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, UK.

Monserud, R.A., Leemans, R., 1992. The comparison of global vegetation maps. Ecological Modelling 62, 275–293.

Mücher, C.A., Steinnocher, K.T., Kressler, F.P., Heunks, C., 2000. Land cover characterization and change detection for environmental monitoring of Pan-Europe. International Journal Remote Sensing 21 (6/7), 1159–1181.

Mücher, C.A., Champeaux, J.L., Steinnocher, K.T., Griguolo, S., Wester, K., Heunks, C., Winiwater, W., Kressler, F.P., Goutorbe, J.P., ten Brink, B., van Katwijk, V.F., Furberg, O., Perdigao, V., Nieuwenhuis, G.J.A., 2001. Development of a consistent methodology to derive land cover information on a European scale from remote sensing for environmental monitoring; the PELCOM report. Alterra-rapport 178/CGI-report 6, Alterra, Wageningen, the Netherlands, 178 pp.

Mücher, C.A., Wascher, D.M., Klijn, J.A., Koomen, A.J.M., Jongman, R.H.G., 2006. A new European Landscape Map as an integrative framework for landscape character assessment. In: Bunce, R.G.H., Jongman, R.H.G. (Eds.), Landscape Ecology in the Mediterranean: Inside and Outside Approaches, Proceedings of the European IALE Conference. 29 March–2 April 2005, Faro, Portugal. IALE Publication Series 3, pp. 233–243.

Mücher, C.A., Hazeu, G.W., Swetnam, R., Pino, J., Halada, L., Gerard, F., 2008a. Historic land cover changes at Natura 2000 sites and their associated landscapes across Europe. In: Proceedings 28th EARSeL Symposium: Remote Sensing for a Changing Europe. Istanbul, Turkey, 2–7 June 2008, Istanbul, Turkey pp. 226–231.

Mücher, C.A., Vos, C., Kiers, M., Renetzeder, C., Wrbka, T., van Eupen, M., 2008b. The use of satellite imagery to identify landscape permeability through observed landscape structure and land cover. In: International Conference "Impact Assessment of Land Use Changes". IALUC 2008, 6–9 April 2008, Humboldt University Unter den Linden, Berlin, Germany pp. 57.

Mücher, C.A., Klijn, J.A., Wascher, D.M., Schaminée, J.H.J., 2010. A new European Landscape Classification (LANMAP): a transparent, flexible and user-oriented methodology to distinguish landscapes. Ecological Indicator 10, 87–103.

OECD, 1994. Creating Rural Indicators for Shaping Territorial Policy. OECD Publications, Paris.

OECD, 2005. Regions at a Glance. OECD Publications, Paris.

OECD, 2006. The New Rural Paradigm. OECD Rural Policy Reviews, Paris.

Official Journal of the European Union, 2003. Regulation (EC) No 1059/2003 of the European Parliament and of the Council 26 May 2003 on the establishment of a common classification of territorial units for statistics (NUTS).

Olson, D.M., Dinerstein, E., Wikramanayake, E.D., Burgess, N.D., Powell, G.V.N., Underwood, E.C., d'Amico, J.A., Itoua, I., Strand, H.E., Morrison, J.C., Loucks, C.J., Allnutt, T.F., Ricketts, T.H., Kura, Y., Lamoreux, J.F., Wettengel, W.W., Hedao, P., Kassem, K.R., 2001. Terrestrial ecoregions of the world: a new map of life on Earth. BioScience 51, 933–938.

Paracchini, M.L., Petersen, J.-E., Hoogeveen, Y., Bamps, C., Burfiled, I., Van Swaay, C., 2008. High nature value farmland in Europe, an estimate of the distribution pattern on the basis of land cover and biodiversity data. In: JRC Scientific and Technical Report EUR 23480, Ispra, Italy.

Pérez-Soba, M., Petit, S., Jones, L., Bertrand, N., Briquel, V., Omodei-Zorini, L., Contini, C., Helming, K., Farrington, J., Tinacci Mossello, M., Wascher, D., Kienast, F., De Groot, R., 2008. Land use functions—a multifunctionality approach to assess the impact of land use change on land use sustainability. In: Helming, K., Pérez-Soba, M., Tabbush, P. (Eds.), Sustainability Impact Assessment of Land Use Change. Springer-Verlag, Berlin, Heidelberg, Germany, pp. 375–404.

Peterseil, J., Wrbka, T., Plutzar, C., Schmitzberger, I., Kiss, A., Szerencsits, E., Reiter, K., Schneider, W., Suppan, F., Beissmann, H., 2004. Evaluating the ecological sustainability of Austrian agricultural landscapes: the SINUS approach. Land Use Policy 21, 307–320.

Petit, S., Firbank, R., Wyatt, B., Howard, D., 2001. MIRABEL: models for integrated review and assessment of biodiversity in European landscapes. Ambio 30, 81–88.

Pizzoli, E., Gong, X., 2007. How to Best Classify Rural and Urban? [online] URL: http://www.stats.gov.cn/english/icas/papers/P020071114325747190208.pdf.

Prentice, I.C., Cramer, W., Harrison, S.P., Leemans, R., Monserud, R.A., Solomon, A.M., 1992. A global biome model based on plant physiology and dominance, soil properties and climate. Journal of Biogeography 19, 117–134.

Renetzeder, C., van Eupen, M., Mücher, C.A., Wrbka, T., 2008. A spatial regional reference framework for sustainability assessment in Europe. In: Helming, K., Perez-Soba, M., Tabbush, P. (Eds.), Sustainability Impact Assessment of Land Use Changes. Springer, Berlin, Heidelberg, Germany, pp. 249–268.

Roekaerts, M., 2002. The biogeographical regions map of Europe. In: Basic Principles of Its Creation and Overview of its Development, European Environment Agency, Copenhagen.

Smit, H.J., Metzger, M.J., Ewert, F., 2008. Spatial distribution of grassland productivity and land use in Europe. Agricultural Systems 98, 208–219.

Thuiller, W., Lavorel, S., Araújo, M.B., Sykes, M., Colin Prentice, I., 2005. Climate change threats to plant diversity in Europe. Proceedings of the National Academy of Sciences of the United States of America 102, 8245–8250.

Tol, R.S.J., Vellinga, P., 1998. The European forum on integrated environmental assessment. Environmental Modeling and Assessment 3, 181–191.

Van Ittersum, M.K., Ewert, F., Heckelei, T., Wery, J., Alkan Olsson, J., Andersen, E., Bezlepkina, I., Brouwer, F., Donatelli, M., Flichman, G., Olsson, L., Rizzoli, A., van der Wal, T., Wien, J.-E., Wolf, J., 2008. Integrated assessment of agricultural systems—a component based framework for the European Union (SEAMLESS). Agricultural Systems 96, 150–165.

Verboom, J., Alkemade, L.R.M., Klijn, J., Metzger, M.J., Reijnen, R., 2007. Combining biodiversity modeling with political and economic development scenarios for 25 EU countries. Ecological Economics 62, 267–276.

Vervloet, J.A., Spek, T., 2003. Towards a Pan-European landscape map—a midterm review. European landscapes: from mountain to sea, Tallinn (Estonia). Huma 9–19.

Wascher, D.M. (Ed.), 2000. "The Face of Europe – Policy Perspectives for European Landscapes". Report on the implementation of the PEBLDS Action Theme 4 on European Landscapes, published under the auspices of the Council of Europe. ECNC, Tilburg, 60 pp.

Wascher, D.M. (Ed.), 2005. European Landscape Character Areas – Typologies, Cartography and Indicators for the Assessment of Sustainable Landscapes. Final ELCAI project report, Landscape Europe, 160 pp. Alterra rapport 1254. Alterra, Wageningen.

Wrbka, T., Erb, K.H., Schulz, N., Peterseil, J., Hahn, C., Haberl, H., 2004. Linking pattern and process in cultural landscapes. An empirical study based on spatially explicit indicators, in: Haberl, H., Wackernagel, W., Wrbka, T. (Eds.), Land Use and Sustainability Indicators. Land Use Policy 21, 28–306.

Article 3

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Title (max 15 words)

Biophysical regionalisation and comparative landscape structure analysis of the European Green Belt

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Abstract (max. 300 words)

The European Green Belt (EGB) presents a unique example of a transcontinental bottom-up conservation network with a broad diversity of landscapes. Regionalisation gives the necessary basis for the assessment and comparison of biodiversity and nature conservation issues and for investigating socio-economic and ecological processes. In this paper, we define biophysical regions along the EGB, compare these regions in terms of their landscape structure, and test, if historical differences in land management between East and West are visible in the EGB's landscape structure. The regionalisation was based on clustering the variables of climate, topography, latitude, and coastal influence. Nine regions resulted, three coastal regions (Boreal-Nemoral, Continental-Baltic, and Mediterranean-Black Sea Coast) differentiated from six inland regions (Arctic, Boreal Baltic Inland, Continental Lowlands, South Eastern European Lowlands, Low and High Mountain Ranges, and Mediterranean Mountains and Inland). The northern regions were spatially more coherent whereas in Central and Southern Europe, the clusters showed a patchier picture. Landscape structure analysis, done by calculating landscape metrics for land cover maps, revealed that Mediterranean regions showed the highest Simpsons' diversity values. Patch metrics showed particularly irregular shape for pastures in the Continental Baltic Coast region.

Arable land had maximum values of connectivity in the Continental Lowlands. Forests showed highest connectivity in the Boreal Baltic Inland region. The East-West comparison exposed differences in proportion and size of arable land patches in Low and High Mountain Ranges and Continental Lowlands. Although approximation towards western land use practices occurred in Eastern Europe during the last 20 years, differences in the landscapes east and west of the border were still visible. The differences in landscape diversity are mainly based on the heterogeneity of the cultural landscapes in South-Eastern Europe that are particularly rich in biodiversity. Therefore heterogeneity, extensive land use, and traditional life style should be maintained.

Introduction

The European Green Belt (EGB) is an international nature conservation initiative that aims at preserving the landscapes along the former Iron Curtain and sustainably safeguarding their natural and cultural assets (Ricken et al., this issue; Terry et al., 2006). The EGB is diverse in landscapes and a unique example of a transcontinental bottom-up conservation network containing a high share of Nature 2000 sites and many cross-boarder reserves (Schlumprecht, this issue; Schlumprecht et al., 2009). This mosaic of reserves, embedded mostly in variegated cultural landscapes, represents the backbone of a transcontinental habitat network and supports the concept of green infrastructure in land use planning (Terry et al., 2006, Zmelik et al. this issue).

In order to identify the state, trends and threats of landscapes, it is essential to categorize and delineate spatial units, which are homogenous in their underlying characteristics. These spatial stratifications can be used as a framework for stratified random sampling and subsequent up-scaling or modeling approaches (Metzger et al., 2005). Consistent regionalisations are therefore important tools to enable comparison among different regions. Statistical approaches of environmental stratifications for European (Metzger et al., 2005; Renetzeder et al., 2008; Mücher et al., 2010) and national needs (Bunce et al., 1996; Peterseil et al., 2004) have evolved only in the last decades, and resulted in a wide range of different regionalisation approaches. The underlying objectives for the stratification strongly influence the choice of input variables and data sets (Hazeu et al., 2010). For the landscapes of the EGB, no such regionalisation has been undertaken yet. It is the necessary basis for the assessment and comparison of biodiversity and nature conservation issues and for the investigation of socio-economic and ecological processes on both sides of the borders and their resulting landscape structure.

The composition and configuration of landscapes (i.e. the landscape structure) reflects not only the natural settings of the landscape but also its history and the impact of mankind throughout the centuries (Antrop, 2005; Ernoult et al., 2006). This “pattern and process” paradigm is a key concept in modern landscape ecology (Turner et al., 2001). It relates to the spatial and functional relationship between individual local ecosystems in terms of the distribution of energy, resources and species. Many European landscapes developed their own regionally distinct pattern of landscape elements (Antrop, 2005). Thus, the present structure of the EGB is a result of former activities and processes which shaped the landscape particularly since the construction of the iron curtain in the 1950s. As the political history of the EGB is such an exceptional one, its landscapes are of particular interest for the application of landscape ecological approaches, which can provide an efficient tool for nature and biodiversity management (Gillespie et al. 2008; Kati et al., 2010; Schindler et al., 2010).

It has been shown, that a change in landscape structure has effects on ecological values (Millennium Ecosystem Assessment, 2003; Peterseil et al., 2004; Zebisch et al., 2004) and biodiversity (Moser et al., 2002; Zechmeister et al., 2003). A common tool to assess these relations is the application of landscape metrics (Turner et al., 2001; Schindler et al. 2009; Uuema et al., 2009). Numerous metrics are available (e.g. McGarigal et al., 2002; Schindler et al., 2008), and their use increased over the last decade as remote sensing and GIS became standard data sources within biogeography and biodiversity research (Gaston, 2000; Gillespie et al., 2008).

In this paper, we (1) define biophysical regions along the EGB, (2) compare these regions in terms of their landscape structure, and (3) test, if historical differences in land management between East and West are visible in the EGB's landscape structure.

Methods

The Green Belt boarder is a strip extending over a length of 12 500 km across 24 European countries (Schlumprecht, this issue; Schlumprecht et al., 2009). In this study, we used a 50 km buffer east and west of the EGB, serving as an input mask for the regionalisation process and the subsequent investigations on composition and configuration of the regions.

Regionalisation of the European Green Belt

For the stratification of the regions along the EGB, the major input variables were climate, topography, latitude, and coastal influence. The first two variables were derived from LANMAP (Mücher et al., 2010). LANMAP is a European landscape classification with the four determinant factors climate, altitude, parent material and land use with a spatial resolution of 1 km. Additionally, we attributed the polygons with the information on latitude to enhance the spatial coherence of the regions. Since it is generally assumed that coastal influence is important (see e.g. the Integrated Coastal Zone Management of the EU (http://ec.europa.eu/environment/iczm/home.htm)); we declared all polygons within a 25 km buffer along the coastline as "coastal".

The four variables served as input for a cluster analysis that we computed in R2.7.1. (R development Core Team, 2008). The regions were defined using Ward's method with hierarchical agglomerative cluster analysis. The distance matrix for the cluster analysis was calculated with the 'daisy' algorithm using Gower's coefficient (Kaufman and Rousseeuw, 1990) implemented in the R package 'cluster' (Maechler et al., 2005). The variable 'coast' was treated as a symmetric binary character (coast or no coast), whereas the others as interval-scaled characters. The amount of clusters was determined by cutting the dendrogram at a level of nine groups. This number was considered as optimal, because more groups resulted in regions being too small and scattered.

Landscape structure analysis and land cover assessment

Land cover information of LANMAP (Mücher et al., 2010) was also used for the comparative landscape structure analysis of the previously defined EGB-Regions. Based on LANMAP, information on ten land cover types ([1] artificial surfaces, [2] arable land, [3] permanent crops, [4] pastures, [5] heterogeneous agricultural areas, [6] forest, [7] shrubs and herbaceous vegetation, [8] open spaces, [9] wetlands, [10] water bodies) were clipped for each single region in *ArcGIS 9.3*. The land cover maps were used for the landscape structure analysis, landscape-, class- and patch metrics were calculated (Table 1) in *Fragstats 3.3*. (McGarigal et al., 2002).

The selection of the landscape metrics was driven by three main motivations: (1) to use metrics with clear ecological meaning and to keep the interpretation of the calculated indices simple, (2) to avoid redundancy in the metrics' information and (3) to grasp differences in landscape structure and land cover despite the coarse-grained dataset. On the regions' landscape level, we calculated the diversity metrics *Simpson's diversity index* (SIDI) and *Modified Simpson's evenness index* (MSIEI). However, as these metrics correlated (Schindler et al., 2008) and resulted in the same pattern, we finally omitted MSIEI from results and discussion. Further metrics that we used at landscape level (i.e. averaging across all land use classes) were *Patch area* (AREA), *Patch shape* (SHAPE), *Edge contrast index* (ECON) and *Proximity index* (PROX). These metrics were computed at patch level (McGarigal and Marks, 1995) and then summarised for the regions in box plots. For each landcover class (i.e. at class level), we further computed *Percentage of landscape* (PLAND), *Number of patches* (NP), *Largest patch index* (LPI), AREA, SHAPE, ECON and PROX.

Comparison among the eastern and western sub regions of the Green Belt

For the comparison of land-use patterns and the spatial distribution of different land cover types East and West of the EGB, we only used regions, which were spatially homogeneous (i.e. not scattered over a large area) and with terrestrial surface on both sides. For these selected regions, we calculated the metrics *Mean Patch Area* (AREA_MN), PLAND and LPI for all land cover classes on both sides.

Finally, to point out the main disparities between the sub regions, combined scatter plots containing east and west values of all land cover classes were generated.

Table 1

Results

Regionalisation of the European Green Belt

Cluster analysis resulted in nine Green Belt regions (Figure 1, Appendix A). Basically, the northern regions were spatially more coherent whereas in Central and Southern Europe, the clusters showed a patchier picture. Three regions were characterised by their coasts, Boreal Nemoral Coast (BNC), Continental Baltic Coast (CBC) and Mediterranean-Black Sea Coast (MBC). An arctic region (ARC) was delineated, mainly determined by climate; the Boreal Baltic inland (BBI) region differentiated from BNC. Further terrestrial regions were Continental Lowlands (CL) and South Eastern European Lowlands (SEL). Low and High Mountain Ranges (LHM) as well as Mediterranean Mountains and Inland (MMI) completed the set of nine Green Belt regions.

Figure 1

ARC was the smallest region in size (6 078 km^2) and number of patches (N = 337), covered mostly by shrubs (45 %) and forests (39 %) as well as a notable share of open spaces, wetlands and water bodies. Agricultural areas were missing almost completely. The same was true for BBI, which was mostly covered by forests (77 %) and water bodies (10 %). Having a large area (101 568 km^2) and rather few patches, the mean patch size of BBI was notably high. BNC had smaller patches, was also mostly covered by forest, but already with a remarkable proportion of arable land (Table 2).

The second smallest region was CBC (24 411 km^2). Agricultural areas were the most prominent land cover classes, with a particularly high share of pastures (9 %); forests were only remnants in small patches. CL showed an average number of patches and average size, covered mostly by arable land (54 %). Artificial surfaces had the highest value in this region (5.4 %). Agricultural land cover also dominated LHM, being the largest region (122 453 km^2). Together with SEL, MMI and MBC, heterogeneous agricultural areas played an important role in the distribution of land cover classes. SEL was one of the biggest regions with a high proportion of agricultural areas (55 %). In MMI, the share of semi-natural and natural land cover classes increased in comparison to the central European regions, but agriculture still dominated land cover. A similar distribution of land cover classes was presented in MBC, although permanent crops obtained the highest share (2 %) in this coastal region (Table 2).

Table 2

<u>Landscape structure of EGB regions</u>

The MMC and MMI regions, which also were most incoherent after the regionalisation process (Figure 1), showed the highest SIDI values. The LHM-region ranked third in landscape diversity, while the northern regions CL, CBC and BNC showed lower values, followed by the BBI region placed at the lower end of the landscape diversity gradient (Table 2).

Regarding the patches of arable land, mean patch size was similar in all regions (except ARC and BBI), as was the variance in shape complexity (Figure 2). In the CL region, mean and maximum values of PROX for arable land were several times higher than in the other regions. Together with a moderate level of edge contrast, this indicates a high degree of connectivity of the arable land matrix. Regarding the patches of pastures, SHAPE was highest in the CBC region, thus indicating a particularly irregular shape. The PROX values for pastures in this region also ranked highest, while the ECON values turned out under average, all indicating comparatively wide pastoral use and well connected patches. The expanse of permanent crop patches varied widely along the EGB, but normally they covered only a small proportion of land (Table 2). Only in the MBC region did permanent crop patches reach up to the mean area sizes resulting also in higher shape complexity (Figure 2). In addition, PROX as well as ECON levels for this land cover class ranged higher than in the other EGB-regions. Therefore permanent crop fields played a relatively important role in the MBC region, where they contributed to the small scaled landscape mosaic of this region. The AREA- and SHAPE-values for the land cover class forest performed rather similar in all regions. But the PROX value range of forests evidently showed a far higher connectivity of forests in the BBI region than in the others.

Figure 2

Comparison among the Eastern and Western sub regions of the Green Belt

Finally, only three regions were homogenous enough to permit a valid comparison East – West: Boreal Baltic Inland (BBI), Continental-Lowlands (CL) and Low and High Mountain Region (LHM). Eastern parts generally showed larger mean patch sizes and lower SIDI values than the western parts, with the exception of the LHM region, where patch size was slightly higher west of the border (Table 3).

Table 3

In BBI, most notably the forest patches mean size was two times higher in the eastern than in the western part of the region, whereas the proportion of forest cover was similar on both sides of the border. Differences in composition of utilised agricultural areas appeared in CL. The mean patch size and the total land cover of arable land patches were higher east of the border, while the abundance of heterogeneous agricultural areas only amounted to one third in comparison to the western part.

An even more distinctive land cover distribution was recognisable in LHM (Figure 3). The land cover proportion for arable land was twice as high in the eastern part, while the other agriculturally used land cover types were prevalent in the west. The mean patch area for arable land patches was three times lower in the western part, but the values for permanent crops, pastures and heterogeneous agricultural areas were two to eight times higher, representing a more diverse and fragmented agricultural matrix in the west.

Figure 3

Discussion

Despite recognition of the great benefits to be gained from a Europe-wide approach to conservation planning and implementation, the conservation biology literature remains lacking in studies at this scale, beyond those concerned with issues of climate change (Gaston et al., 2008). In this study we tried to cover the landscape of the whole European Green Belt, from the Barents Sea southwards until the Adriatic and the Black Sea. Therefore, we used a land cover data set that covered the entire study area, but was limited by the minimal mapping unit size of 1 km². Though this should not have had a major impact on the results but the rather coarse scale has to be considered in the interpretation of the results. For instance, a landscape assessed as diverse with a resolution of 1 km² means that it changes from time to time at the kilometre scale, but it can be theoretically rather homogeneous at finer scales (i.e. inside the 1 km grids). Furthermore, the coarse resolution can have biased the less abundant land cover classes such as water bodies, at least where they mainly occurred in very small patches.

The landscapes along the EGB are of particular interest, as they are specific European border regions and thus “hot-spots” of land use change, as concluded by Bicik and Kabrda (2007). Border regions show a different landscape structure when compared to the interior, because political divide can influence the surrounding landscape directly, always depending on the distinct geopolitical and geo-economic orientation of a country. The proximity to political borders can act as “driving forces” for local land use change. Border regions are commonly exposed to a weaker anthropogenic impact, contain less arable land and artificial surfaces, but more forested areas, pastures and abandoned or natural land (Bicik and Kabrda, 2007). They should exhibit a fast extensification especially in times of radical political influences (e.g. after the construction and after the fall of the iron curtain). Other factors that could affect border regions are less favourable natural conditions (e.g. altitude, slope, climate, soil fertility) and local socio-economic changes (e.g. spatial marginality, areas of expulsion of minorities). Thus, agriculture becomes less and less viable, and some borders regions are completely released from provisional ecosystem services and transformed to satisfy other needs of the modern society, such as nature protection and recreation (Bicik and Kabrda, 2007).

Regionalisation of the EGB

To compare the influence of socio-economic and political conditions on both sides of the border, it is necessary to develop a consistent framework of biophysical conditions. A stratification of environmental conditions (Meeus, 1995; Metzger et al., 2005; Mücher et al., 2010) seems appropriate to this objective. The quality of a regionalisation is strongly dependent on the quality of the input data. LANMAP is a widely accepted stratification and already applied in regionalisation studies (De Wit and Mücher, 2009; Mücher et al., 2008; Renetzeder et al., 2008). Still, the limitations in spatial and thematic detail and accuracy of currently available datasets exist and were not totally solved in LANMAP (Mücher et al., 2010). For the scale of a Pan-European study, LANMAP is still the best available dataset as input. Regarding to regionally scaled studies (e.g. Veteikis et al., this issue), the local variation is not captured, as the limit lies in the spatial resolution of 1 km^2. Hazeu et al. (2010) stress that the stratification should be created using statistical rules, so that their construction is reproducible and boundaries between strata are not influenced by personal bias. We followed this recommendation by applying appropriate multi-variate analysis on the input data. For a future development of the regionalisation, the integration of socio-economic data should be envisaged. Existing interdependencies between landscape character and the socio-economic context in which they reside (Peterseil et al., 2004; Wrbka et al., 2004) have been stressed and first approaches to integrate these different dimensions into one stratification were carried out recently (Renetzeder et al., 2008; Van Eupen et al., in preparation, see http://www.faro-eu.org).

Comparison among regions

The regions can be divided into three groups: the northern regions have a high share of natural and semi natural areas (mainly forests and water bodies), the Central European regions have a high share of heavily impacted areas (agricultural and artificial areas), while the southern Green Belt regions distinguish with their high level of landscape diversity. We detected an increase in landscape diversity from north to south, although the number of habitats listed in the habitats directive did not differ significantly among Northern, Central and South-Eastern reserves (Schlumprecht, this issue). Therefore, the differences in landscape diversity must be based mainly on differences in the heterogeneity of the cultural landscapes that connect the reserves, and to a lesser amount on differences in the reserves themselves.

The northern regions showed the lowest landscape diversity, though they are not densely populated and the land use pressure is rather low (REFERENCE). Consequently the utilized agricultural areas were poorly developed and the dominance of forests lead to the downshift in landscape diversity and rise of unevenness.

Comparison among East and West

Socioeconomic conditions such as political systems and practices, isolation and poverty of the rural population as well as traditional life style have a strong impact on the recent landscape (Helming et al., 2008). Current changes, occurring in Eastern Europe depend mainly on these socio-economic factors, primarily on the economic activity of the residents (Lowicki, 2008). The end of communism was accompanied by dramatic changes in the economies of East-European countries, and the shift from a planned to a market economy was related to temporary recession and massive restructuring of the economy, including agriculture (e.g. Kuskova et al., 2008). Several processes influenced land use change such as the restitution of private property, the partial privatization of state property, increasing environmental awareness among the population, transformation of agricultural co-operatives, increased accessibility of the border regions, and the restitution of the land market (Bicik et al., 2001). The privatization of agriculture triggered a process of structural change. Large areas, especially grasslands were abandoned, and agricultural production in general was extensified (Bicik and Jancak, 2005). However, although significant changes have occurred (Bicik et al., 2001; Kohlheb and Krausmann, 2009; Veteikis et al., this issue), differences in composition and configuration of the landscape east and west of the border were still visible. The differences described for the BBI region attest to the former land use of forests, which had been divided in smaller sections in the western subregion.

Meanwhile fragmentation and disturbance is increasing in East European forests (Kuemmerle et al., 2007). Differences in composition of utilised agricultural areas appeared in CL and LHM. The mean patch size and the total land cover of arable land patches were higher in the eastern subregion. Although cropland abandonment is one of the strongest trends of Eastern European land use change (Kuemmerle et al. 2008, 2009; Lakes et al., 2009), and should lead to increase of heterogeneous agricultural areas, this category was still much higher in the western subregion.

Conclusions for the conservation of biodiversity

Spatial heterogeneity proved to be a driving factor of biodiversity, particularly, in many European ecosystems, with a long history of human impact (Benton et al., 2003; Brotons et al., 2004; Kati et al., 2004, 2010; Schindler et al., 2009; Torras et al., 2008). Our analyses revealed that the south eastern regions of the EGB were of highest heterogeneity. But the landscape structure, often regarded as important background for local biodiversity, underlies rapid changes due to current trends in socio-economic, agri- and silvicultural development (e.g. Rocchini et al., 2006). Their negative impact on local and regional biodiversity has been encountered in several studies (e.g. Kleijn et al., 2009; Scozzafava and De Sanctis, 2006; Zechmeister et al., 2003). Thus, landscape heterogeneity must be maintained, e.g. by maintaining forest openings and promoting traditional life style such as sustainable agriculture and periodical livestock grazing (Nikolov, 2009; Schindler et al., this issue). Also, social and political measures, e.g. against land abandonment, could help the maintenance of biodiversity, if they are targeted thoroughly (Wrbka et al., 2008).

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References

Antrop, M. (2005). Why landscapes of the past are important for the future? *Landscape and Urban Planning, 70*, 21–34.

Benton, T. G., Vickery, J. A., & Wilson, J. D. (2003). Farmland Biodiversity: is habitat heterogeneity the key? *Trends in Ecology and Evolution, 18,* 182-188. DOI: 10.1016/S0169-5347(03)00011-9

Bicik, I., Jelecek, L., & Stepanek, V. (2001). Land-use changes and their social driving forces in Czechia in the 19th and 20th centuries. *Land Use Policy, 18,* 65–73.

Bicik, I., & Jancak, V. (2005). *Transformacní procesy v ceském zemedelství po roce 1990.* Univerzita Karlova, Praha.

Brotons, L., Herrando, S., & Marin, J. L. (2004). Bird assemblages in forest fragments within Mediterranean mosaics created by wild fires. *Landscape Ecology, 19,* 663-675.

Bunce, R. G. H., Barr, C. J., Gillespie, M. K., & Howard, D. C. (1996). The ITE Land Classification: providing an environmental stratification of Great Britain. *Environmental Monitoring and Assessment, 39,* 39–46.

De Wit, A., & Mücher, C. A. (2009). Satellite-derived trends in phenology over Europe: real trends or algorithmic effects. *Geophysical Research Abstracts, Vol. 11, EGU2009-4837, 2009. EGU General Assembly 2009 from 19 – 24 April 2009, Vienna, Austria.*

Ernoult, A., Freiré-Diaz, S., Langlois, E., & Alard, D. (2006). Are similar landscapes the result of similar histories? *Landscape Ecology, 21,* 631–639. doi:10.1007/s10980-005-5321-1.

Gaston, K. J. (2000). Global patterns in biodiversity. *Nature, 405*, 220–227.

Gaston, K. J., Jackson, S. F., Cantú-Salazar, L. & Cruz-Piñón, G. (2008). The Ecological Performance of Protected Areas. *Annual Review of Ecology, Evolution, and Systematics,* 39, 93–113.

Gillespie, T. W., Foody, G. M., Rocchini, D., Giorgi, A. P. & Saatchi, S. (2008). Measuring and modeling biodiversity from space. *Progress in Physical Geography, 32*, 203-221.

Gustafson, E. J., & Parker, G. R. (1992). Relationships between landcover proportion and indices of landscape spatial pattern. *Landscape Ecology, 7,* 101-l10.

Hazeu, G. W., Metzger, M. J., Mücher, C. A., Perez-Soba, M., Renetzeder, C., & Andersen, E. (2010) European environmental stratifications and typologies: an overview. *Agriculture, Ecosystems and Environment*, in press, doi: 10.1016/j.agee.2010.01.009

Helming, K., Pérez-Soba, M., & Tabbush, P. (2008). *Sustainability Impact Assessment of Land Use Change*. Berlin, Heidelberg, Germany: Springer.

Integrated Coastal Zone Management of the EU: http://ec.europa.eu/environment/iczm/home.htm (last accessed 01 January 2010)

Kati, V., Devillers, P., Dufrêne, M., Legakis, A., Vokou, D., & Lebrun, P. (2004). Testing the value of six taxonomic groups as biodiversity indicators at a local scale. *Conservation Biology,* 18, 667–675.

Kati, V., Poirazidis, K., Dufrêne, M., Halley, J. M., Korakis, G., Schindler, S., & Dimopoulos, P. (2010). Toward the use of ecological heterogeneity to design reserve networks: a case study from Dadia National Park, Greece. *Biodiversity and Conservation*, in press, DOI 10.1007/s10531-010-9788-y

Kaufman, L., & Rousseeuw, P.J. (1990). *Finding Groups In Data: An Introduction To Cluster Analysis.* New York: Wiley.

Kleijn, D., Kohler, F., Báldi, A., Batáry, P., Concepción, E. D., Clough, Y., Díaz, M., Gabriel, G., Holzschuh, A., Knop, E., Kovács, A., Marshall, E. J. P, Tscharntke, T., & Verhulst, J. (2009). On the relationship between farmland biodiversity and land-use intensity in Europe. *Proceedings of the Royal Society B,* 276, 903–909.

Kohlheb, N., & Krausmann, F. (2009). Land use change, biomass production and HANPP: The case of Hungary 1961-2005. *Ecological Economics, 69,* 292–300. doi: 10.1016/j.ecolecon.2009.07.010

Kuemmerle, T., Hostert, P., Radeloff, V. C., Perzanowski, K., & Kruhlov, I. (2007). Post-socialist forest disturbance in the Carpathian border region of Poland, Slovakia, and Ukraine. *Ecological Applications, 17,* 1279-1295.

Kuemmerle, T., Hostert, P., Radeloff. V, Van der Linden, S., Perzanowski, K., & Kruhlov, I. (2008). Cross-border comparison of post-socialist farmland abandonment in the Carpathians. *Ecosystems, 11,* 614-628.

Kuemmerle, T., Müller, D., Griffiths, P., & Rusu, M. (2009). Land use change in Southern Romania after the collapse of socialism. *Regional Environmental Change, 9,* 1–12.

Kuskova, P., Gingrich, S., & Krausmann, F. (2008). Long term changes in social metabolism and land use in Czechoslovakia, 1830–2000: an energy transition under changing political regimes. *Ecological Economics, 68,* 394–407.

Lakes, T., Müller, D., & Krüger, C. (2009). Cropland change in Southern Romania: A comparison of logistic regressions and artificial neural networks. *Landscape Ecology, 24,* 1195-1206. doi: 10.1007/s10980-009-9404-2

Łowicki, D. (2008). Land use changes in Poland during transformation. Case study of Wielkopolska region. *Landscape and Urban Planning, 87* , 279-288. doi: 10.1016/j.landurbplan.2008.06.010

Maechler, M., Rousseeuw, P., Struyf, A., & Hubert, M. (2005). *Cluster analysis basics and extensions.* http://www.R-project.org.

McGarigal, K., Cushman, S. A., Neel, M.C., & Ene, E. (2002). *FRAGSTATS: spatial pattern analysis program for categorical maps*, http://www.umass.edu/landeco/research/fragstats/fragstats.html (last accessed 21 June 2005).

Meeus, J.H.A. (1995). Pan-European landscapes. *Landscape and Urban Planning, 31,* 57-79.

Metzger, M. J., Bunce, R. G. H, Jongman, R. H. G, Mücher, C. A., & Watkins, J. W. (2005). A climatic stratification of the environment of Europe. *Global Ecology and Biogeography, 14,* 549-563.

Millennium Ecosystem Assessment (2003). *Ecosystems and Human Well-being: A Framework for Assessment.* Washington: Island Press.

Moser, D., Zechmeister, H. G., Plutzar, C., Sauberer, N., Wrbka, T., & Grabherr, G. (2002). Landscape patch shape complexity as an effective measure for plant species richness in rural landscapes. *Landscape Ecology, 17,* 657–669. doi:10.1023/A:1021513729205

Mücher, C. A., Hazeu, G. W., Swetnam, R., Pino, J., Halada, L., & Gerard, F. (2008). Historic land cover changes at Natura 2000 sites and their associated landscapes across Europe. *Proceedings 28th EARSeL Symposium: Remote Sensing for a Changing Europe, Istanbul, Turkey, 2 - 7 June 2008, Istanbul, Turkey* pp. 226-231.

Mücher, C. A., Klijn, J. A., Wascher, D. M., & Schaminée, J. H. J. (2010). A new European Landscape Classification (LANMAP): A transparent, flexible and user-oriented methodology to distinguish landscapes. *Ecological Indicators, 10,* 87–103.

Nikolov, S. C. (2009). Effects of land abandonment and changing habitat structure on avian assemblages in upland pastures of Bulgaria. *Bird Conservation International*, in press, doi: 10.1017/S0959270909990244

Peterseil, J., Wrbka, T., Plutzar, C., Schmitzberger, I., Kiss, A., Szerencsits, E., Reiter, K., Schneider, W., Suppan, F., & Beissmann, H. (2004). Evaluating the ecological sustainability of Austrian agricultural landscapes: the SINUS approach. *Land Use Policy, 21,* 307-320.

R Development Core Team (2008). *R: A language and environment for statistical computing.* R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Renetzeder, C., van Eupen, M., Mücher, C. A., & Wrbka, T. (2008). A Spatial Regional Reference Framework for Sustainability Assessment in Europe. In: K. Helming, M. Perez-Soba, & P. Tabbush (Eds.), *Sustainability Impact Assessment of Land Use Changes* pp. 249– 268. Berlin Heidelberg New York: Springer.

Ricken et al., this issue

Rocchini, D., Perry, G.L.W., Salerno, M., Macherini, S., & Chiarucci, A. (2006). Landscape change and the dynamics of open formations in a natural reserve. *Landscape and Urban Planning, 77*, 167–177.

Schindler ,S., Poirazidis, K., & Wrbka, T. (2008). Towards a core set of landscape metrics for biodiversity assessments: A case study from Dadia National Park, Greece. *Ecological Indicators, 8,* 502-514.

Schindler, S., Kati, V., von Wehrden, H., Wrbka, T., & Poirazidis, K. (2009). Landscape metrics as biodiversity indicators for plants, insects and vertebrates at multiple scales. In: J. Breuste, M. Kozová & M. Finka (Eds.), *European Landscapes in Transformation: Challenges for Landscape Ecology and Management. European IALE Conference 2009* pp. 228–231. Salzburg & Bratislava: University of Salzburg, Slovak University of Technology, and Comenius University Bratislava.

Schindler, S., Poirazidis, K., Papageorgiou, A.C., Kalivas, D., von Wehrden, H., & Kati, V. (2010). Landscape approaches and GIS for biodiversity management. In: J. Andel, I. Bicik, P. Dostal, Z. Lipsky, & S.G. Shahneshin (Eds.), *Landscape modelling: geographical space, transformation and future scenarios*, pp. 207-220. Urban and Landscape Perspectives Series, Vol. 8, Berlin Heidelberg New York: Springer.

Schindler et al., this issue

Schlumprecht, H., Kreutz, M., & Lang, A. (2009). Landscapes of conservation value along the Green Belt – A pan-European overview as foundation for cross-border management and action. *Natur und Landschaft,* 84, 409-414.

Schlumprecht, this issue

Scozzafava, S., & De Sanctis, A. (2006). Exploring the effects of land abandonment on habitat structures and on habitat suitability for three passerine species in a highland area of central Italy. *Landscape and Urban Planning, 75*, 23–33.

Terry, A., Ullrich, K., & Riecken, U. (2006). *The Green Belt of Europe: From Vision to Reality.* Gland, Switzerland and Cambridge, UK: IUCN.

Torras, O., Gil-Tena, A., & Saura, S. (2008). How does forest landscape structure explain tree species richness in a Mediterranean context? *Biodiversity Conservervation, 17*, 1227-1240.

Turner, M.G., Gardner, R.H., & O'Neill, R.V. (2001). *Landscape Ecology in Theory and Practice, Pattern and Process.* Berlin Heidelberg New York: Springer.

Uuemaa, E., Antrop, M., Roosaare, J., Riho, M., & Mander Ü. (2009). Landscape metrics and indices: An overview of their use in landscape research. *Living Reviews in Landscape Research, 3*, 1 (http://landscaperesearch.livingreviews.org/Articles/lrlr-2009-1/)

Veteikis et al., this issue

Wrbka, T., Erb, K. H., Schulz, N., Peterseil, J., Hahn, C., & Haberl, H. (2004). Linking pattern and process in cultural landscapes. An empirical study based on spatially explicit indicators. *Land Use Policy, 21,* 28-306.

Wrbka, T., Schindler, S., Pollheimer, M., Schmitzberger, I., & Peterseil, J. (2008). Impact of the Austrian Agri-Environmental Scheme on diversity of landscape, plants and birds. *Community Ecology, 9,* 217–227. doi:10.15556/ComEc.9.2008.2.x.

Zebisch, M., Wechsung, F., & Kenneweg, H. (2004). Landscape response functions for biodiversity – assessing the impact of land use changes at the county level. *Landscape and Urban Planning, 67,* 157–172.

Zechmeister, H. G., Schmitzberger, I., Steurer, B., Peterseil, J., & Wrbka, T. (2003). The influence of land use practices and economics on plant species richness in meadows. *Biodiversity and Conservation, 114,* 165-177. doi:10.1016/S0006-3207(03)00020-X.

Appendix A

Percentages of area in the nine resulting Green Belt regions for the three variables 'coast/no coast', 'climate' and 'altitudinal class'. ARC – Arctic; BBI – Boreal Baltic inland; BNC – Boreal Nemoral Coast; CBC – Continental Baltic Coast; CL – Continental Lowlands; LHM – Low and High Mountain Ranges; MBC – Mediterranean-Black Sea Coast; MMI – Mediterranean Mountains and Inland; SEL – South Eastern European Lowlands

	ARC	BNC	BBI	CBC	CL	LHM	SEL	MMI	MBC
Cluster	1	2	3	4	5	6	7	8	9
coast/no coast									
coast	50	100		100					100
climate									
Alpine North			6						
Boreal		56	92						
Nemoral		41	1						
Atlantic North		3			15				
Alpine South						21			1
Continental				100	85	79			8
Atlantic Central									
Pannonian							100		32
Mediterranean Mountains								27	9
Mediterranean North								72	49
Mediterranean South								1	1
Arctic	100								
Altitudinal class									
<0 m a.s.l.									1
0-5 m a.s.l.		3		19	2			5	4
5-10 m a.s.l.		5		1				15	
10-20 m a.s.l.		26		16	5			2	
20-50 m a.s.l.		21	2	37	18			2	3
50-100 m a.s.l.		30	35	20	28	1	19	2	13

100-200 m a.s.l.	26	12	43	7	41	4	46	29	24
200-300 m a.s.l.	74	2	13		6	12	20	4	14
300-500 m a.s.l.			6		1	38	12	22	13
500-700 m a.s.l.						19	1	8	18
700-900 m a.s.l.						7	1	3	3
900-1100 m a.s.l.						8		1	3
1100-1500 m a.s.l.						6		7	3
1500-2000 m a.s.l.						4			
2000-2500 m a.s.l.						1			

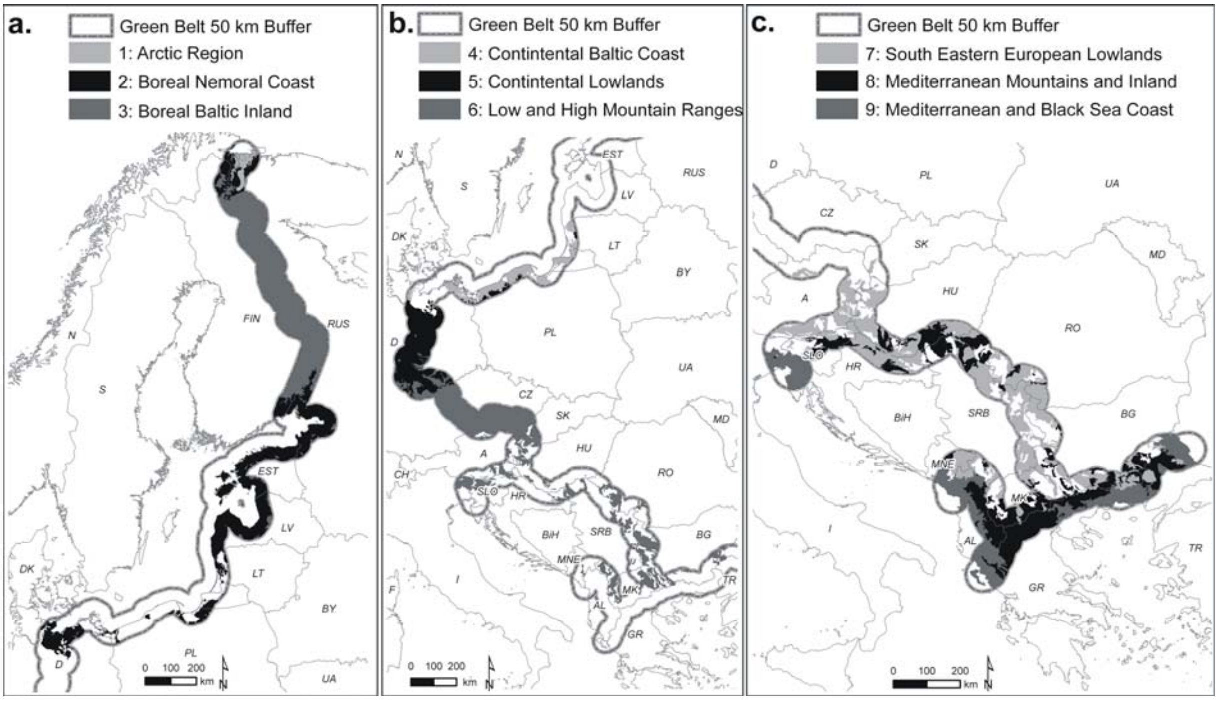
Figure legends

Figure 1: Nine Green Belt regions resulted from cluster analysis. a. three northern regions, b. three central regions, c. three southern regions.

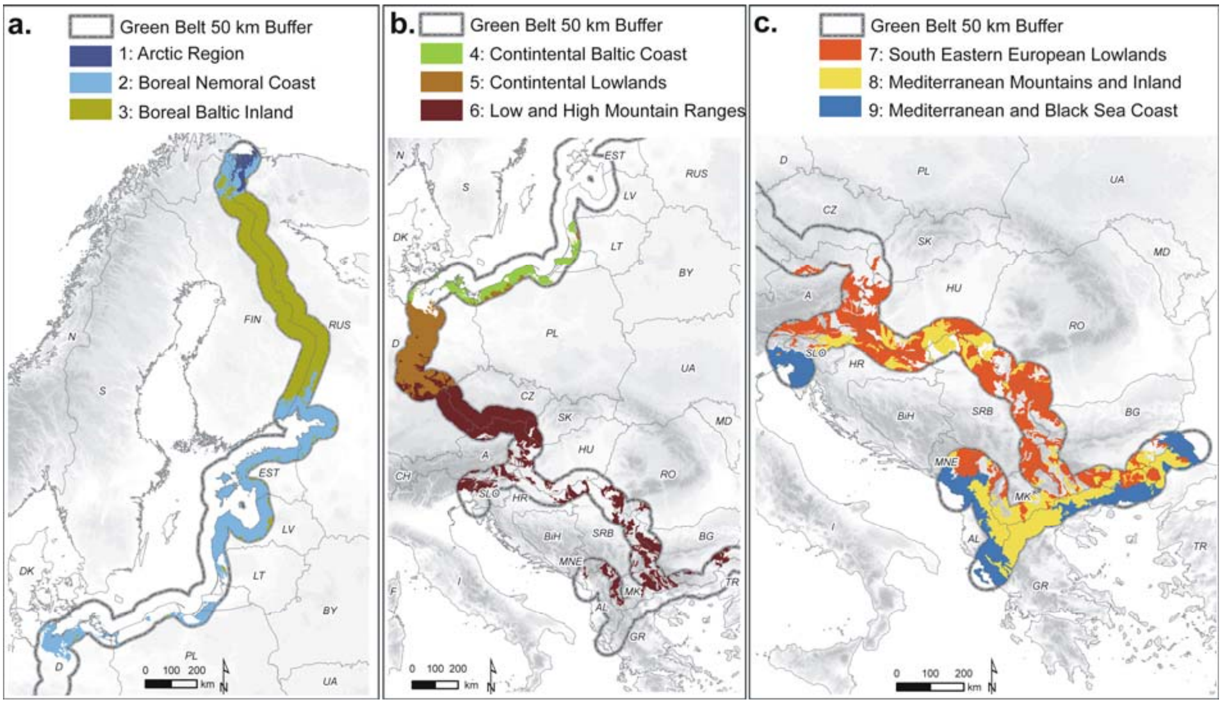
Figure 2: Comparison of Proximity index, Shape index and Edge Contrast of the land cover classes arable land, pastures and permanent crops in the nine GBE regions; the box is presenting the quartiles below and above the median, whiskers delimitate 1.5 interquartile range (IQR) of the lower and the upper quartile; the notches give roughly a 95% confidence interval for the difference in two medians. If the notches of two plots do not overlap then the medians are significantly different at the 5 percent level. Some notches may lie outside the box. Outliers are not shown in the figure.
ARC – Arctic; BBI – Boreal Baltic inland; BNC – Boreal Nemoral Coast; CBC – Continental Baltic Coast; CL – Continental Lowlands; LHM – Low and High Mountain Ranges; MBC – Mediterranean-Black Sea Coast; MMI – Mediterranean Mountains and Inland; SEL – South Eastern European Lowlands

Figure 3. Scatter plots showing the distribution of the mean patch size and the percentage of land cover on a logarithmic scale east and west of the border for the three regions BBI, CL, and LHM (abbreviations cf. figure 2).

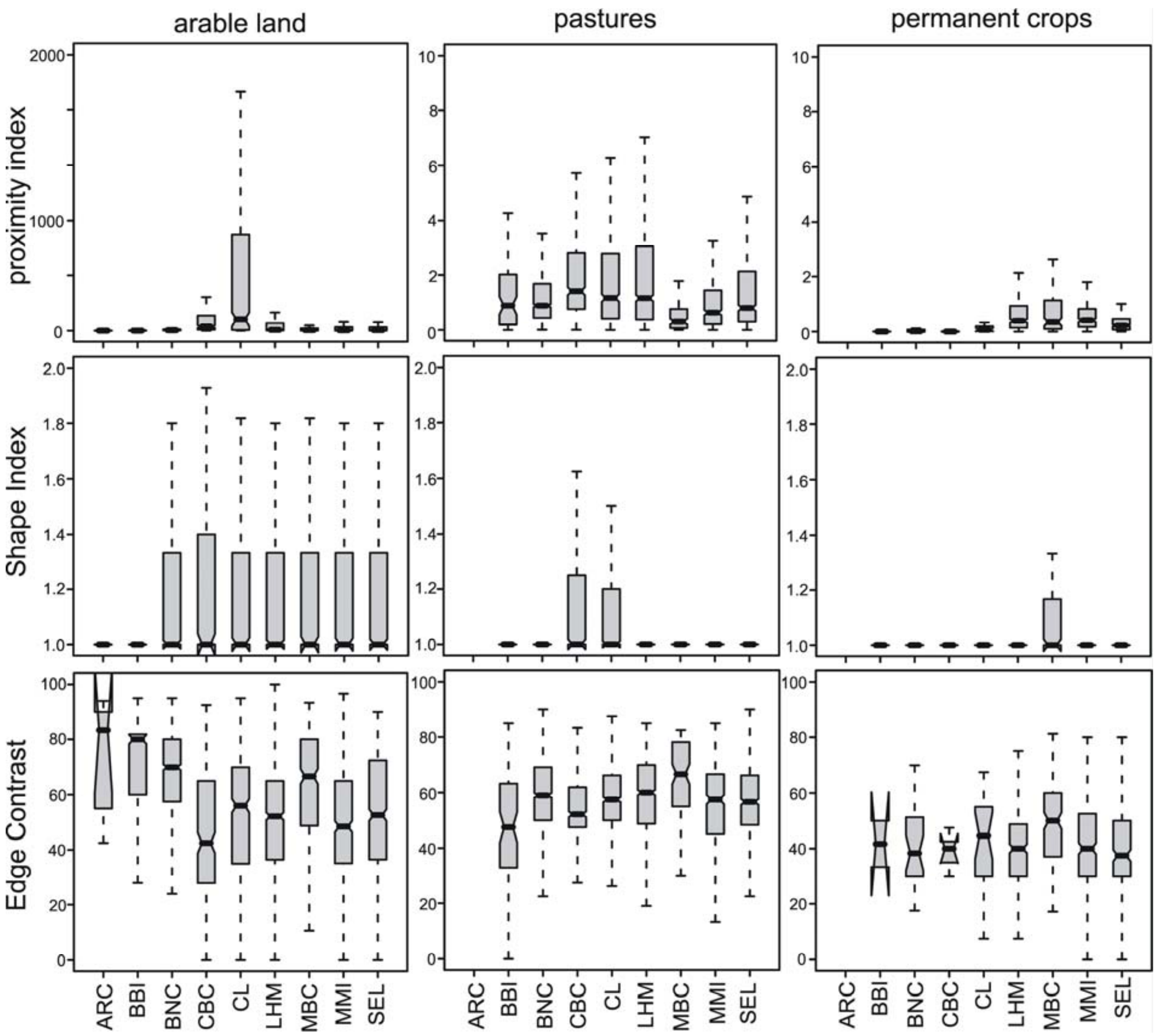
Figures



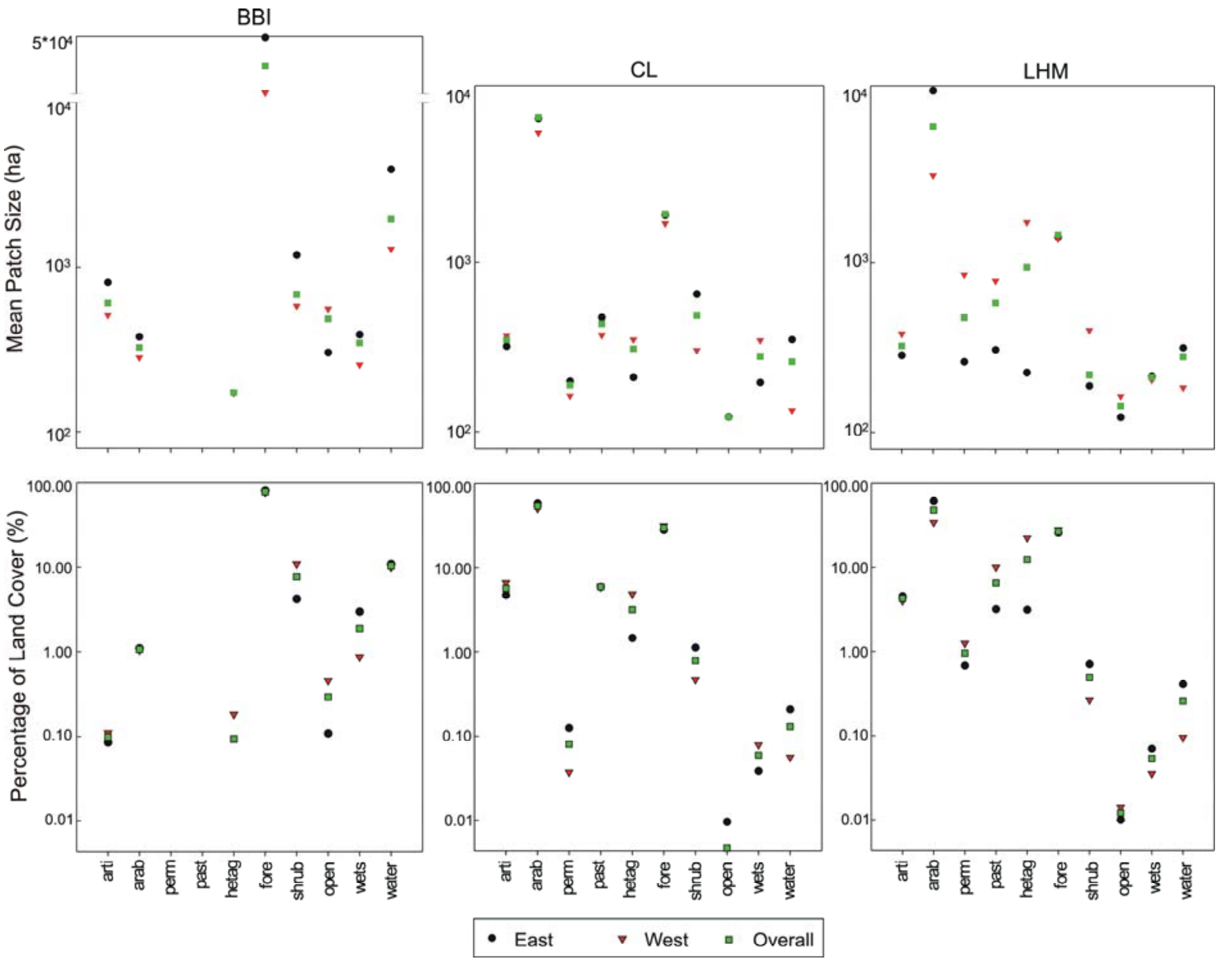
Renetzeder_Figure 1



Renetzeder_Figure 1 colour



Renetzeder_Figure 2



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668 Renetzeder_Figure 3

Tables

Table 1. Computed landscape metrics grouped by its general meaning, followed by the acronym, the name and a short description (DSt…distribution statistics); for more detailed information see (McGarigal et al., 2002)

Group	Acronym	Metric name	Description
Group I. Patch size			
	AREA	Patch Area	DSt; size of the patches
	NP	Number of Patches	Number of patches per land cover class
	LPI	Largest Patch Index	Percentage of total area occupied by the largest patch
	PLAND	Percentage of Landscape	Percentage of area occupied by certain land cover class
Group II. Shape, edge & contrast			
	SHAPE	Shape Index	DSt; equals 1 when all patches are circular; increases with complexity of patch shapes; independent of patch size
	ECON	Edge Contrast Index	DSt; ratio of the contrast weighted to the not-contrast weighted edge length per patch
Group III. Isolation, proximity & connectedness			
	PROX	Proximity Index	DSt; considers size and proximity of all patches with the same land cover type inside a specified search radius
Group IV. Diversity			
	SIDI	Simpson's Diversity Index	Diversity measure, which equals 1 minus the sum of the squared proportional abundance of each patch type
	MSIEI	Modified Simpson's Evenness Index	Diversity measure, which considers only evenness of patch sizes, not the number of patches

Table 2. Summary of index-values used for the description of landscape composition and diversity; NP: Number of Patches; PLAND: Percentage of landscape; SIDI: Simpson's diversity index; (arti): artificial surfaces; (arab): arable land; (perm): permanent crops; (past): pastures; (hetag): heterogeneous agricultural areas; (fore): forest; (shrub): shrubs and herbaceous vegetation; (open): open spaces; (wets): wetlands; (water): waterbodies; ARC – Arctic; BBI – Boreal Baltic inland; BNC – Boreal Nemoral Coast; CBC – Continental Baltic Coast; CL – Continental Lowlands; LHM – Low and High Mountain Ranges; MBC – Mediterranean-Black Sea Coast; MMI – Mediterranean Mountains and Inland; SEL – South Eastern European Lowlands

				PLAND of each landcover class (in %)									
region	NP	AREA [km^2]	SIDI	(arti)	(arab)	(perm)	(past)	(hetag)	(fore)	(shrub)	(open)	(wets)	(water)
ARC	337	6 078	0.62	0.6	0.3	NA	NA	NA	39.2	45.4	5.4	3.8	3.9
BBI	3 316	101 568	0.39	0.2	2.0	0.0	0.2	0.3	77.1	7.5	0.3	1.9	10.3
BNC	7 248	98 639	0.65	2.4	26.1	0.1	3.6	5.7	51.5	6.0	0.4	2.0	1.6
CBC	1 770	24 411	0.57	3.4	60.8	0.1	9.4	2.4	20.7	0.4	0.0	0.4	1.7
CL	3 753	54 989	0.61	5.4	54.2	0.2	5.8	3.2	30.3	0.8	0.0	0.1	0.1
LHM	9 262	122 454	0.71	3.5	39.9	1.0	5.2	12.7	32.8	4.3	0.3	0.1	0.3
SEL	6 053	94 790	0.69	2.7	41.7	0.6	3.6	9.4	35.6	5.2	0.4	0.2	0.6
MMI	4 683	68 354	0.75	2.0	33.5	1.4	1.8	12.2	31.1	15.8	0.5	0.1	1.5
MBC	3 092	46 488	0.75	1.3	22.2	2.0	0.5	12.1	36.4	22.2	1.5	0.1	1.3
Sum	39 514	617 771											

Table 3. Comparison of SIDI and AREA_MN [ha] values for the landscapes of the eastern and western parts of the three regions BBI, CL, and LHM (abbreviations cf. figure 2)

	SIDI			AREA_MN [ha]		
	Overall	East	West	Overall	East	West
BBI	0.37	0.34	0.39	3488	5316	2589
CL	0.61	0.58	0.63	1515	1654	1298
LHM	0.67	0.55	0.74	1443	1375	1436

Chapter 2 – Ecological Sustainability

Article 4

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Own contribution:

Study design 70%, implementation 70%, writing 90%

Does landscape structure reveal ecological sustainability?

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1. Introduction

In the last decades, sustainable development has been acknowledged to be of major importance in the European Union for the future and yielded a list of Commission Strategies and Action Plans (amongst others CEC 2001, 2004, 2005a, b, c, 2007). Sustainability Impact Assessment is one option to convert policies into operational approaches. Considerable efforts are made to assess the impact of policy on the three pillars comprised of economic, social and environmental to ensure a holistic benefit for society. Indicators (e.g. EEA 2005) and guidelines have been developed to enable an in-depth analysis of sustainability impact assessment (CEC 2005d). Helming et al. (2008) and Peterseil et al. (2004) showed that changes in a landscape regarding the anthropogenic influence are a highly integrative indicator for sustainability. The structure of landscape is reflecting not only the natural settings of the landscape but also its history and the impact of mankind throughout the centuries (Antrop 2005, Ernoult et al. 2006), so the present spatial patterns are a result of former activities and processes in the landscape. This “pattern and process” paradigm is a key concept in modern landscape ecology (Turner et al. 2001). It relates to the spatial and functional relationship between distinct local ecosystems by describing the distribution of energy, resources and species in relation to size, shape, number and type of ecosystems in a particular landscape. Many European cultural landscapes developed their own regionally distinct pattern of landscape elements which has been the aim of ongoing or recently finalised European research projects.

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Human influence tends to result in a simplification and geometrisation of landscape pattern (Forman 1995, Turner et al. 2001) and impact on ecological values (Millennium Ecosystem Assessment 2003, Peterseil et al. 2004, Zebisch et al. 2004) and biodiversity (Moser et al. 2002, Pino et al. 2000, Schindler et al. 2007, Zechmeister and Moser 2001, Zechmeister et al. 2003) of landscapes have been shown. The removal of small biotopes or changes in the patch size of land-use parcels to larger units can therefore be seen as an unsustainable development, at least in terms of ecological sustainability. Opposite processes, such as the introduction of small biotopes, can be seen as sustainable development in its ecological dimension.

Complex biophysical, historical and political patterns in Europe lead to considerable regional differences in economical, social and environmental situations (Jongman, 2002). In general, the current knowledge about landscape structure and sustainability comes from case studies (Turner and Ruscher 1988, Moser et al. 2002, Wrbka et al. 2004). Consequently, consistent and statistically robust information on structure in the different parts of Europe is still missing. To achieve an accurate spatially explicit sustainability impact assessment, the regional complexities need to be considered and indicator systems are to be adapted to the regional level (Blaschke, 2006). Identifying and delineating spatial units that are relatively homogeneous in both biophysical and socio-economic contexts allow a successful upscaling of the approaches.

To meet these concerns, the Spatial Regional Reference Framework (Renetzeder et al. 2008) was developed within the ongoing FP6-project SENSOR: In this integrated project, the main objective was to develop an ex-ante sustainability impact assessment tool including pan-European databases and spatial reference frameworks for the analysis of land and human resources in the context of European land use policies. This approach is enabling the identification of European regions (EU 27 + Norway and Switzerland) which are to a certain extent similar in terms of their environmental, social and economic situations. Within these regions, thresholds and limits of European sustainability indicators are defined. The spatial unit is NUTS 2/3-regions, because many social and economic data are only available on the administrative level.

In this paper, the process of a consistent European pattern analysis is examined, results of the differences in landscape structure among 10 European regions are presented and the use for sustainability impact assessment of agricultural landscapes is discussed.

2. Material and methods

Important input data for sampling design was the stratum of the Spatial Regional Reference Framework (SRRF - Renetzeder et al. 2008). It covers the EU 27, Norway and Switzerland and delineates 27 SRRF regions and identifies spatial administrative units on basis of statistical clustering of biophysical (climate, topography and bedrock) and socio-economic data (including population density, population change rate, activity rate, gross domestic production, unemployment rate, functional urban areas and land cover data). This product was used in order to have a definition of more or less homogeneous regions and randomly select sampling sites with the condition of representing European biogeographic regions (EEA 2002). Selected SRRF-regions were (first biogeographic region, followed by main land cover class): Boreal Forest (BORF), Central Atlantic Mixed Agricultural Activities (CATM), Continental Forest (CONF), Continental Heterogeneous Agricultural Areas (CONH), Mediterranean Arable Land (MEDA), Mountains Open Spaces (MNTO), North Atlantic Arable Land (NATA), North Atlantic Pastures (NATP), Nemoral Mixed Agricultural Activities (NEMI), Pannonian Arable Land (PANA). Within the selected regions, three satellite images by 50 x 50 km^2 are randomly selected using the official European grid system (Fig. 1).

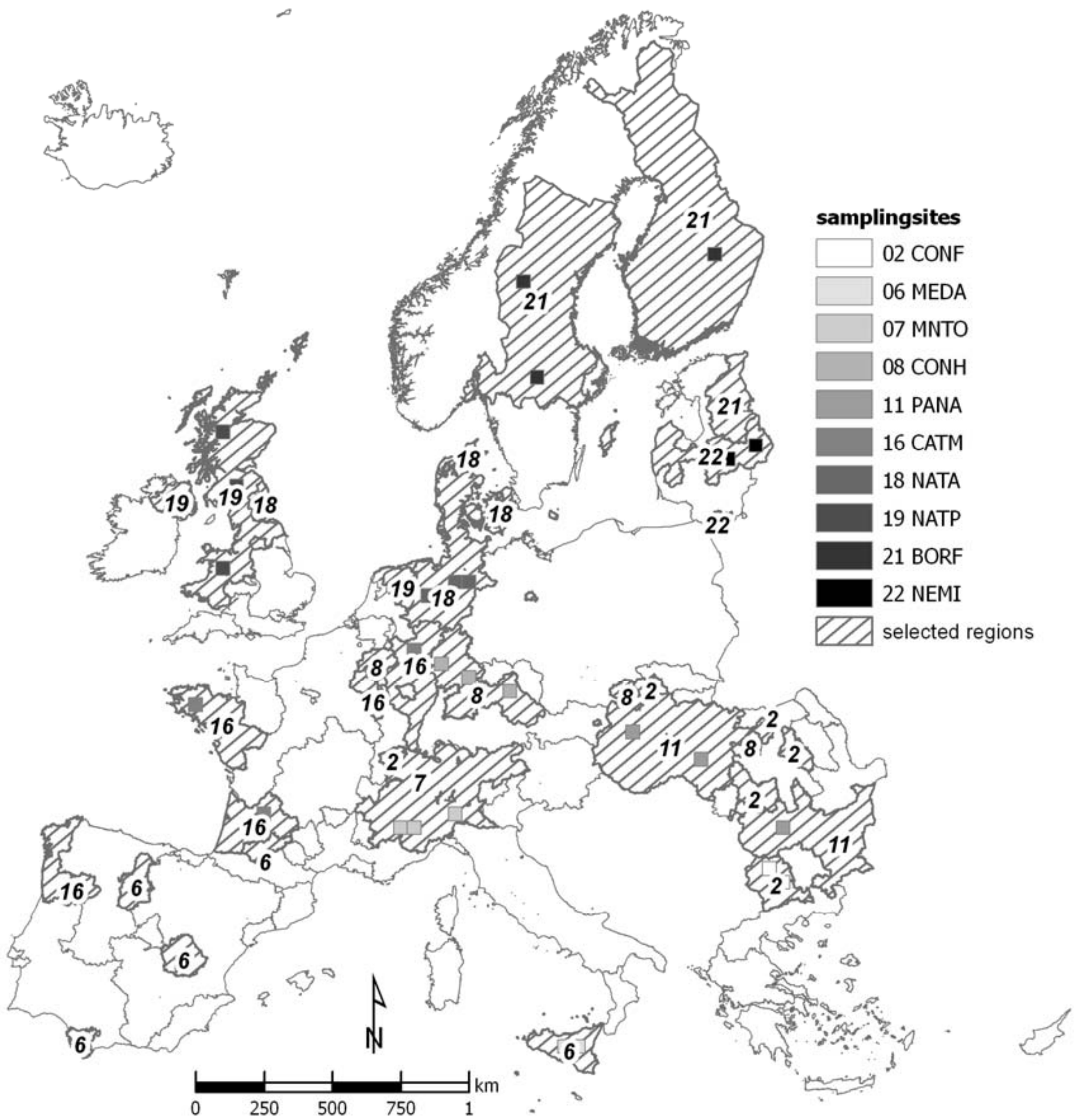

Fig. 1: Ten SRRF regions (Renetzeder et al. 2008) with three sampling sites (50 x 50 km) BORF = Boreal Forest, CATM = Central Atlantic Mixed agricultural activities, CONF = Continental Forest, CONH = Continental Heterogeneous agricultural areas, MEDA = Mediterranean Arable land, MNTO = Mountains Open spaces, NATA = North Atlantic Arable land, NATP = North Atlantic Pastures, NEMI = Nemoral Mixed agricultural activities, PANA = Pannonian Arable

The satellite images (Image2000) are covering most of the European countries. They are provided by the Joint Research Centre (JRC; http://image2000.jrc.it/) and publicly available. They are the main source of information regarding the landscape structure. Segmentation of satellite images was performed with the software package eCognition (© Definiens Inc.) delivering pure structural information. In order to fill this ‘empty’ layer of structural information with thematic one, Corine Land Cover (CLC2000; http://terrestrial.eionet.europa.eu/CLC2000) was used. These land cover data have a minimum mappable unit of 25 ha and a minimum width of 100 m. There are 44 classes in five major groups distinguished. With usual GIS-methods, the structural information was intersected with CLC2000 in ArcGIS (ESRI, Inc., Redlands, CA) appointing a thematical meaning to the individual landscape element. Because of differences in the Minimum Mappable Unit (MMU) and minimum width (MMU segmentation – 0.25 ha, minimum width – 25 m; MMU CLC2000 – 25 ha, minimum width – 100 m) more detailed structural than thematic information is available. The combination of all input data allowed building a consistent data base of landscape structure data.

Calculation of the landscape structure indices was done with V-Late 1.1, Vector-based Landscape Analysis Tools Extension (Lang and Tiede 2003). V-Late is able to calculate landscape metrics on three different levels – the patch level (metrics of every single landscape element), the class level (averages of the metrics of all landscape elements belonging to one land cover) and the landscape level (average over all elements within one landscape no matter which thematic information they possess). We selected five landscape metrics: Patch Size (MPS_ha), Patch Edge (MPE), Shape Index (MSI), Perimeter-Area-Ratio (MPAR), and Fractal Dimension (MFRACT). Focus was given on those land cover classes which are most interesting in agricultural landscapes and which were present in at least nine selected regions with a high percentage in area: non-irrigated arable land, pastures, complex cultivation patterns, agricultural land with natural vegetation, and natural grasslands.

Statistical analysis was performed with R2.6.0 (R Development Core Team, 2006) and Statgraphics 5.0 with the main focus on extracting differences of landscape metrics regarding land cover classes among the regions. Standard statistical procedures were applied testing for normal distribution and variance homogeneity. Mann-Whitney U test, discriminant and factor analysis were performed to detect differences in terms of class level landscape metrics among the regions. In particular, the factor analysis with varimax rotation was carried out to determine the contribution of the individual landscape metrics to the variation in the data at class level (Cumming and Vernier, 2002, Schindler et al. 2008). The quadratic discriminant function analysis (QDA) was performed to test, whether the function with the variables classified according to the existing groups, and thus whether the multivariate set of landscape metrics allows an accurate separation of the data into SRRF-regions.

3. Results

In the different regions, the area of land cover classes varied enormously (Table 1). In all regions, agricultural and forest classes are the dominating land cover. The share of anthropogenic, semi-natural and natural cover is rather low.

Tab. 1 Percentages of land cover classes (label and class number) in the investigated SRRF-regions, numbers >10% are given in italic. Land cover classes chosen for further analysis are marked with *. Boreal Forest (BORF), Central Atlantic Mixed Agricultural Activities (CATM), Continental Forest (CONF), Continental Heterogeneous Agricultural Areas (CONH), Mediterranean Arable land (MEDA), Mountains Open Spaces (MNTO), North Atlantic Arable Land (NATA), North Atlantic Pastures (NATP), Nemoral Mixed Agricultural Activities (NEMI), Pannonian Arable Land (PANA).

Label		BORF	CATM	CONF	CONH	MEDA	MNTO	NATA	NATP	NEMI	PANA
Continuous urban fabric			0.1	0.1	0.1	0.5	0.8	<0.1			<0.1
Discontinuous urban fabric		0.8	6.8	5.2	7.0	0.2	7.9	3.7	0.3	1.0	5.9
Industrial or commercial units		0.2	0.8	1.1	0.9	0.1	2.1	0.2	<0.1	0.2	0.6
Road and rail networks and associated land			0.1	0.1	0.1	<0.1	0.1	<0.1	0.1	<0.1	<0.1
Port areas			<0.1		<0.1						<0.1
Airports		<0.1	0.2	0.1	0.1		0.1	0.1		<0.1	<0.1
Mineral extraction sites		<0.1	0.2	1.3	0.2	0.1	0.1	<0.1	<0.1	<0.1	<0.1
Dump sites			<0.1	0.2	<0.1		<0.1	<0.1			<0.1
Construction sites			0.1		<0.1		<0.1			<0.1	<0.1
Green urban areas		<0.1	0.3	0.2	0.2		0.3	<0.1		<0.1	<0.1
Sport and leisure facilities		<0.1	0.3	0.2	0.3	<0.1	0.2	0.1	0.2	<0.1	0.1
Non-irrigated arable land	*	1.9	*19.7*	*20.1*	*38.6*	*54.6*	*34.8*	*48.4*	1.0	*24.4*	*74.9*
Permanently irrigated land						0.5					
Rice fields							3.3				0.1
Vineyards			1.8	1.5	0.7	0.6	0.3				1.5
Fruit trees and berry plantations			0.6	1.1	0.6	2.8	0.1			0.1	0.2
Olive groves						3.5					
Pastures	*	<0.1	*11.8*	3.3	4.7		2.4	*12.2*	*21.6*	*14.3*	4.7
Annual crops with permanent crops						0.7					
Complex cultivation patterns	*	0.2	*24.9*	4.0	9.6	4.5	4.2	4.5	1.2	*12.0*	1.8
Agricultural land with of natural vegetation	*	2.1	2.4	8.2	1.6	2.7	3.0	3.6	2.2	9.6	1.7
Agro-forestry areas						<0.1	<0.1				
Broad-leaved forest		2.1	*14.7*	*31.2*	13.0	3.9	8.7	1.6	0.9	*13.3*	4.3
Coniferous forest		*43.7*	3.2	5.5	*16.3*	1.6	*10.4*	*20.1*	*13.8*	5.3	0.1
Mixed forest		*13.6*	*10.4*	6.5	4.5	2.5	1.1	2.1	<0.1	12.0	0.2
Natural grasslands	*	0.1	<0.1	2.6	1.0	6.6	8.2	0.4	*20.2*		0.6
Moors and heathland		4.1	0.3	0.5	<0.1	2.1	0.5	1.7	*27.9*		
Sclerophyllous vegetation						7.0					
Transitional woodland-shrub		<0.1	1.0	5.4	0.1	3.7	2.3	0.1	1.9	4.6	1.1
Beaches, dunes, sands				0.1		<0.1	0.2				0.3

Bare rocks	<0.1		0.1		0.1	4.4		0.7		
Sparsely vegetated areas	0.1		0.3	<0.1	0.7	4.1	0.3	5.2		
Burnt areas						<0.1				
Glaciers and perpetual snow						<0.1				
Inland marshes	<0.1	<0.1	0.3	<0.1		<0.1	<0.1	<0.1	0.2	0.4
Peat bogs	5.0		0.2				0.7	0.8	0.7	
Water courses	*14.0*	0.6	1.0	0.5	0.9	0.3	0.1	0.1	2.1	1.6
Water bodies	2.0							1.6		

Significant differences of single landscape structure indices among the regions were detected by box-and-whisker-plots and Mann-Whithney U test. Not every landscape metrics depicted differences where others did, also some variation between the land cover classes were exposed. Interestingly, the structure of natural grassland was least different among the regions and the landscape metrics for non-irrigated arable land show the most differences. The most contrasting regions were continental forests and mountains open spaces. Nearly every metric in all land cover classes differed significantly from each other. The most similar regions were Central Atlantic Mixed Agricultural Activities – North Atlantic Arable Land, Boreal Forest– Nemoral Mixed Agricultural Activities, Central Atlantic Mixed Agricultural Activities – Continental Forest and Mediterranean Arable Land– Nemoral Mixed Agricultural Activities (Fig. 2 as example).

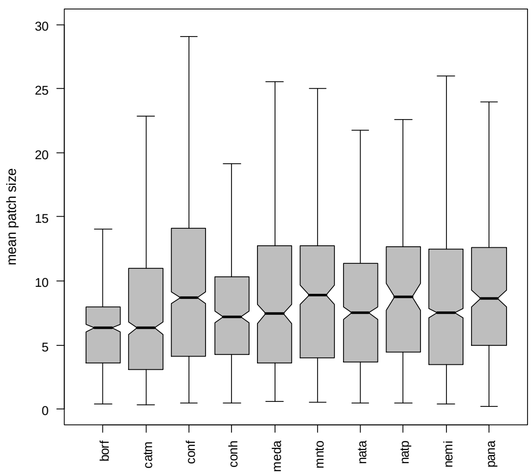

Fig. 2: Boxplot of landscape metric Mean Patch Size (MPS) for the land cover class "agricultural land with natural vegetation"; overlapping notches (confidence interval of the Median) reveal regions which are not significantly different in this structure index.

The factor analysis revealed two different dimensions of landscape pattern, but the loadings were rather different for the individual land cover classes (Table 2). Mean Patch Edge (MPE) had the highest loading for non-irrigated arable land, Mean Patch Size in ha

(MPS_ha) for pastures, Mean Shape Index (MSI) for complex cultivation pattern and agricultural land with natural vegetation and Mean Fractal Dimension (MFRACT) for natural grasslands. The QDA showed that the landscape cover classes could only poorly be predicted by its combination of multivariate landscape metrics among the SRRF regions. In general, the error rate is rather high.

Tab.2: Factor Analysis at the European scale including the five class level metrics for each land cover class; Mean Patch Size in ha (MPS_ha), Mean Patch Edge (MPE), Mean Shape Index (MSI), Mean Perimeter-Area-Ratio (MPAR) and Mean Fractal Dimension (MFRACT).

	Non-irrigated arable land		Pastures		Complex cultivation patterns	
	Factor1	Factor2	Factor1	Factor2	Factor1	Factor2
MPS_ha	0.930	-0.260	0.900	0.336	0.735	-0.630
MPE	0.997		0.822	0.565	0.879	-0.471
MSI	0.905	0.385	0.501	0.844	0.980	
MPAR	-0.380	0.760	-0.762	0.326	0.808	
MFRACT	0.515	0.854	-0.102	0.992	0.869	0.489

	Agricult. land with natural. veg.		Natural grasslands	
	Factor1	Factor2	Factor1	Factor2
MPS_ha	0.778	-0.584	0.933	0.256
MPE	0.916	-0.395	0.879	0.472
MSI	0.984		0.588	0.783
MPAR	0.808		-0.741	0.357
MFRACT	0.826	0.560	0.997	

Spatial visualisation via Geographical Information Sytems (GIS) gives a useful tool for the communication of statistical results. For example, the elements which match certain statistical results (above or below the Median etc.) can be marked accordingly (Fig. 3) and gives a quick overview over a certain area of interest.

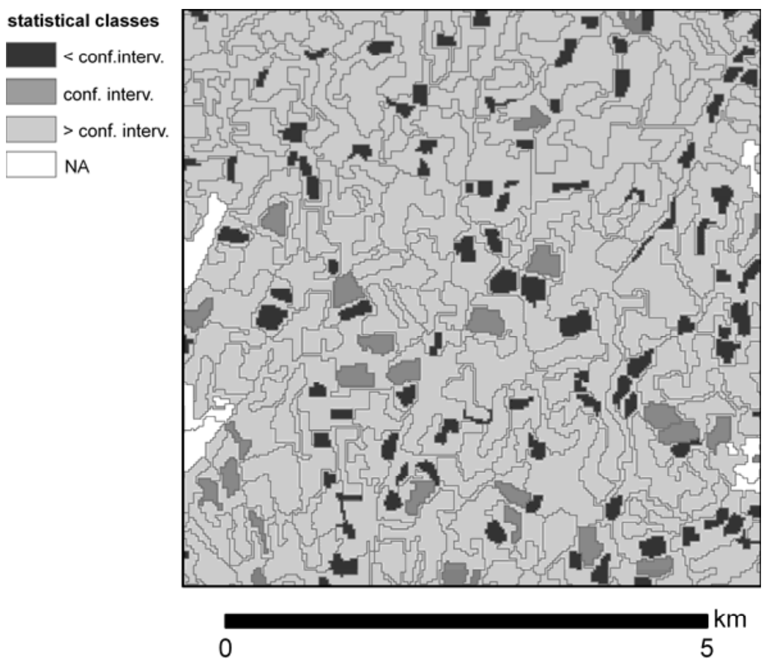

Fig. 3: Detail of the region “North Atlantic Arable Land” showing three statistical classes of the perimeter of land cover class “Arable Land”; below and above the confidence interval of the Median, and the confidence interval.

4. Discussion and Conclusions

Various authors have criticised approaches (Estregueil et al. 2001, Haines-Young and Chopping 1996, Kozak et al. 2008) where land cover information with relatively coarse spatial resolution is used for large scale landscape studies. Corine Land Cover classes reflect only the dominant land use but contain also other land cover types and therefore, important structural features are not captured at this resolution. In contrast, high-resolution images and fine grain habitat and land use maps are used to explain small scale ecological phenomena on the landscape level (Lee et al. 2008, Schindler et al. 2007, 2008). Consequently, large scale and widely used datasets such as Corine Land Cover should be supplemented and combined with an innovative derivation of homogeneous spatial units by segmentation as presented in our study.

Statistical analysis showed contradicting results concerning the differentiation of landscape metrics for the individual SRRF regions. Univariate analysis revealed significant differences between many regions for several land cover classes (Fig. 2), multivariate analysis did not. Overlaying different distributions of the individual landscape metrics may have contributed to blurring of individual differences. The use of administrative units (NUTS 2/3 implemented into the SRRF) has weakened the desirable homogeneity in terms of primary and to some extent also secondary landscape structure, by resulting in lesser meaningful units for ecological assessment as confirmed by the poor performance of the set of metrics in the QDA. Further improvement of results may also be achieved by a higher number of sampling sites per region. Higher spatial resolutions could lead to a better discrimination of size and shape of patches. But at the same time higher resolutions will hamper the analysis for vast areas across Europe.

The use of landscape metrics as indices for Sustainability Impact Assessment is not very common (Graymore et al. 2008) although certain aspects of ecological sustainability like biodiversity (Moser et al. 2002, Schindler et al. 2007) or naturalness (Peterseil et al. 2004) were investigated. Already Odum and Turner have shown in their classical work (1989) how increasing consumption of fossil energy and agrochemicals are coupled with a geometrical simplification of landscapes expressed by a decrease in fractal dimension. We have shown that even at the European scale, single landscape metrics react differently depending on land cover, suggesting that such sensitive indices could be utilized as indicators for ecological sustainability of land-use, when applied together with land cover types in a spatial regional reference. The elaboration of a scientifically sound knowledge-base for any impact assessment requires the establishment of statistical valid relationships between observed pattern and a particular ecological process of interest. This is especially true for biodiversity and sustainability related studies at the landscape level (Bunce et al. 2008) and calls for not only the combined use of geodatasets with different spatial resolution, but also for the inclusion of empirical data derived by representative field observations. As at European level, there is no consistent data available on human impact or hemeroby to correlate with, application of simple rules can be used for assessing trends in sustainability. Intensification of land use generally leads to simpler geometry and configuration of landscape elements (Forman 1995, Turner et al. 2001). A first indication is the deviation of landscape metrics from the average, based on the Austrian 'Concept of Relative Deviance' (Peterseil et al. 2004) and currently applied on the presented European data.

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6. References

Antrop, M. (2005). Why landscapes of the past are important for the future. *Landscape and Urban Planning 70*, pp. 21-34. doi:10.1016/j.landurbplan.2003.10.002

Blaschke, T. (2006). The role of the spatial dimension within the framework of sustainable landscapes and natural capital *Landscape and Urban Planning 75*, pp. 198-226. doi:10.1016/j.landurbplan.2005.02.013.

Bunce, R.G.H., Metzger, M.J., Jongman, R.H.G., Brandt, J., De Blust, G., Elena-Rossello, R., Groom, G.B., Halada, L., Hofer, G., Howard, D.C., Kovar, P., Mucher, C.A., Padoa-Schioppa, E., Paelinx, D., Palo, A., Perez-Soba, M., Ramos, I.L., Roche, P., Skanes, H., Wrbka, T. (2008). A standardized procedure for surveillance and monitoring European habitats and provision of spatial data. *Landscape Ecology 23*, pp. 11-25. doi:10.1007/s10980-007-9173-8

CEC (Commission of the European Communities) (2001). *A Sustainable Europe for a Better World: A European Union Strategy for Sustainable Development. (Commission proposal to the Gothenburg European Council)*. COM(2001) 264. 17 p.

CEC (Commission of the European Communities) (2004). *Stimulating Technologies for Sustainable Development: An Environmental Technologies Action Plan for the European Union, Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions.* COM(2004)38. 49 p.

CEC (Commission of the European Communities) (2005a). *Review of the Sustainable Development Strategy - A platform for action.* COM(2005) 658. 52 p.

CEC (Commission of the European Communities) (2005b). *The 2005 Review of the EU Sustainable Development Strategy: Initial Stocktaking and Future Orientations.* COM(2005) 37. 23 p.

CEC (Commission of the European Communities) (2005c). *Thematic Strategy on the sustainable use of natural resources.* COM(2005) 670 final. 22 p.

CEC (Commission of the European Communities) (2005d). *Impact assessment guidelines.* SEC(2005) 791. 99 p.

CEC (Commission of the European Communities) (2007). *Progress Report on the Sustainable Development Strategy 2007.* COM(2007) 642 final. 15 p.

CLC 2000, http://terrestrial.eionet.europa.eu/CLC2000. (20.10.2008)

Cumming, S. - Vernier, P. (2002). Statistical models of landscape pattern metrics, with application to regional scale dynamic forest simulations. *Landscape Ecology 17*, pp. 433-444. doi:10.1023/A:1021261815066.

EEA (European Environmental Agency) (2002). *Europe´s biodiversity – bio geographical regions and seas.* – Available: http://reports.eea.eu.int/report_2002_0524_154909/en/tab_content_RLR. (20.11.2008)

EEA (European Environmental Agency) (2005). *Agriculture and environment, in EU-15 - the IRENA indicator report.* EEA Report No 6/2005. 128 p.

Ernoult, A., Freiré-Diaz, S., Langlois, E., Alard, D. (2006). Are similar landscapes the result of similar histories? *Landscape Ecology 21*, pp. 631-639. doi:10.1007/s10980-005-5321-1

Estreguil, C., Thierron, V., Guissard, V., Defourny, P., Dufrene, M. (2001). *Relevance of Corine Land Cover for reporting on nature protection at regional level.* DG-JRC, Ispra, Italy. JRC publication reference: EUR report number 19819/EN.

Forman, R.T.T. (1995). *Land Mosaics – The Ecology of Landscapes and Regions*. Cambridge University Press. 632 p.

Graymore, L.M.M., Sipe, N.G., Rickson, R.E. (2008). Regional sustainability: How useful are current tools of sustainability assessment at the regional scale? *Ecological economics 67*, pp. 362-372. doi:10.1016/j.ecolecon.2008.06.002

Haines-Young, R. - Chopping, M. (1996). Quantifying landscape structure: a review of landscape indices and their application in forested landscapes. *Progress in Physical Geography 20*, pp. 418 – 445

Helming, K., Pérez-Soba, M., Tabbush, P. (2008 eds.). *Sustainability Impact Assessment of Land Use Change.* Springer, Berlin, Heidelberg, Germany. 508 p.

Jongman, R.H.G. (2002). Homogenisation and fragmentation of the European landscape: ecological consequences and solutions. *Landscape and Urban Planning 58*, pp. 211-221. doi:10.1016/S0169-2046(01)00222-5

JRC, http://image2000.jrc.it/ (22.10.2008)

Kozak, J., Estreguil, C., Ostapowicz, K. (2008). European Forest cover mapping with high resolution satellite data: The Carpathians case study. *International Journal of Applied Earth Observation and Geoinformation 10*, pp. 44-55. doi:10.1016/j.jag.2007.04.003

Lang, S. - Tiede, D. (2003). vLATE Extension für ArcGIS - vektorbasiertes Tool zur quantitativen Landschaftsstrukturanalyse, ESRI Anwenderkonferenz 2003 Innsbruck. CD-ROM.

Lee, S.-W., Ellis, C.D., Kweon, B.-S., Hong, S.-K. (2008). Relationship between landscape structure and neighbourhood satisfaction in urbanized areas. *Landscape and Urban Planning 85*, pp. 60-70.

Millennium Ecosystem Assessment (2003). *Ecosystems and Human Well-being: A Framework for Assessment.* Island Press, 245 pp.

Moser, D., Zechmeister, H.G., Plutzar, C., Sauberer, N., Wrbka, T., Grabherr, G. (2002). Landscape patch shape complexity as an effective measure for plant species richness in rural landscapes. *Landscape Ecology 17*, pp. 657-669. doi:10.1023/A:1021513729205

Peterseil, J., Wrbka, T., Plutzar, C., Schmitzberger, I., Kiss, A., Szerencsits, E., Reiter, K., Schneider, W., Suppan, F., Beissmann, H. (2004). Evaluating the ecological sustainability of Austrian agricultural landscapes: the SINUS approach. *Land Use Policy 21*, pp. 307-320. doi:10.1016/j.landusepol.2003.10.011

Pino, J., Rodà, F., Ribas, J., Pons, X. (2000). Landscape structure and bird species richness: implications for conservation in rural areas between natural parks. *Landscape and Urban Planning 49*, pp. 35-48. doi:10.1016/S0169-2046(00)00053-0

R Development Core Team (2006). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria.

Renetzeder, C., Van Eupen, M., Mücher, C.A., Wrbka, T. (2008). *A Spatial Regional Reference Framework for Sustainability Assessment*. In: Helming, K., Tabbush, P., Perez-Soba, M. (eds.): Sustainability impact assessment of land use changes, Springer. pp. 249-268

Schindler, S., Kati, V., Poirazidis, K. (2007). *Testing the performance of landscape structure variables as predictors of biodiversity: a case study from Dadia NP, Greece*. In: Bunce, R.G.H., Jongman, R.H.G., Hojas, L., Weel, S. (eds.): 25 Years of Landscape Ecology: Scientific Principles in Practice – Proceedings of the 7th IALE World Congress 7/2007, Wageningen, pp. 337-338

Schindler, S., Poirazidis, K., Wrbka, T. (2008). Towards a core set of landscape metrics for biodiversity assessments: A case study from Dadia National Park, Greece. *Ecological Indicators 8*, pp. 502-514. doi:10.1016/j.ecolind.2007.06.001

Turner M.G., Gardner, R.H., O'Neill, R.V. (2001 eds.). *Landscape ecology in theory and practice, pattern and process*. Springer, New York, USA, 401 p.

Turner, M.G. - Ruscher, C.L. (1988). Changes in the spatial patterns of land use in Georgia. *Landscape Ecology 4*, pp. 21-30. doi:10.1007/BF00157696

Odum E.P. - Turner M.G. (1989). *Georgia Landscape: A Changing Resource*. In: Zonneveld I.S. and Forman R.T.T. (eds.), Changing Landscapes: An Ecological Perspective. Springer, New York, USA, pp. 137–146

Wrbka, T., Erb, K.-H., Schulz, N., Peterseil, J., Hahn, C., Haberl, H. (2004). Linking pattern and process in cultural landscapes. An empirical study based on spatially explicit indicators. *Land Use Policy 21*, pp. 28-306. doi:10.1016/j.landusepol.2003.10.012

Zebisch, M., Wechsung, F., Kenneweg, H. (2004). Landscape response functions for biodiversity - assessing the impact of land use changes at the county level. *Landscape and Urban Planning 67*, pp. 157-172. doi:10.1016/S0169-2046(03)00036-7

Zechmeister, H. G., Schmitzberger, I., Steurer, B., Peterseil, J., Wrbka, T. (2003). The influence of land-use practices and economics on plant species richness in meadows. *Biological Conservation 114*, pp. 165-177. doi:10.1016/S0006-3207(03)00020-X

Zechmeister, H.G. - Moser, D. (2001). The influence of agricultural land-use intensity on bryophyte species richness. *Biodiversity and Conservation 10*, pp. 1609-1625. doi:10.1023/A:1012008828522

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Can we measure ecological sustainability? Landscape pattern as an indicator for naturalness and land use intensity at regional, national and European level

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ABSTRACT

European landscapes have been shaped over the centuries by processes related to human land use, which are reflected in regionally distinct landscape patterns. Since landscape pattern has been linked to biodiversity and other ecological values of the landscapes, this paper explores landscape pattern as a tool for ecological sustainability assessments at the regional (Austrian Cultural Landscapes), national (Austria) and European (European Union + Norway, Switzerland) level with focus on agricultural landscapes. A set of landscape metrics served as a basis to assess naturalness and geometrisation of Austrian and European landscapes as a proxy for their sustainability. To achieve an accurate spatially explicit assessment, we applied a spatial reference framework consisting in units that are homogeneous in biophysical and socio-economic contexts, adapted the regional approach for its application at European level, and developed relative sustainability thresholds for the landscape metrics. The analyses revealed that several landscape metrics, particularly the "Number of Shape Characterising Points" showed a high correlation with the degree of naturalness. The sustainability map of Austria based on an ordinal regression model revealed well-known problem regions of ecological sustainability. At the European level, the relative deviation from the average pattern showed clearly the simplification processes in the landscapes. However, a better spatial resolution of land cover data would add to the refinement of pattern analysis in regions and therefore the assessment of sustainability. We recommend the combination of information of different scales for the formulation and implementation of sustainability policies.

1. Introduction

Sustainability has become a keynote of policy for the past 30 years. Ensuring a holistic benefit for society, sustainable development consists of three pillars comprised of economic, social and environmental (CEC, 2001) and should meet the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland Commission, UN, 1987). A list of Commission Strategies and Action Plans for the European Union (CEC, 2001, 2005a, 2007) affirms sustainable development to be of major importance for the future. To assess the impact of these policies, operational approaches, indicators (f. ex. EEA, 2005) and guidelines for Sustainability Impact Assessment (SIA) have been developed (CEC, 2005b), and an integrated application at the European level is currently under development (Helming et al., 2008). However, sustainability remains a political concept which is not easy to grasp scientifically, and several approaches have been developed recently to overcome challenging aspects of SIAs (Antrop, 2006; Graymore et al., 2008).

Changes in a landscape regarding the anthropogenic influence are a highly integrative indicator for sustainability (Helming et al., 2008; Peterseil et al., 2004). The removal of small biotopes or changes in the patch size of land use parcels to larger units can therefore be seen as an unsustainable development, at least in terms of ecological sustainability. Opposing processes, such as the introduction of small biotopes can be seen as sustainable development in its ecological dimension. Our approach was based on the idea to describe the ecological sustainability with two concepts: (1) the hemerobiotic state or hemeroby (Naveh and Liebermann, 1984) and (2) geometrisation of landscape pattern (Forman, 1995; Turner et al., 2001). Hemeroby is defined as the magnitude of the deviation from the potential natural vegetation

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caused by human activities. An overview of the categories of the hemerobiotic state and their attributes is given in Naveh and Liebermann (1984) and Zechmeister and Moser (2001). The spatial patterns of landscapes are a result of former activities and processes in the landscape ('frozen processes') and reflect not only natural settings but also history and the impact of mankind throughout the centuries (Antrop, 2005; Ernoult et al., 2006). This "pattern and process" paradigm is a key concept in modern landscape ecology (Turner et al., 2001). It relates to the spatial and functional relationship between distinct local ecosystems by describing the distribution of energy, resources and species in relation to size, shape, number and type of ecosystems in a particular landscape. Human influence tends to result in a simplification and geometrisation of landscape pattern and impact on ecological values (Millennium Ecosystem Assessment, 2003; Peterseil et al., 2004) and biodiversity (Moser et al., 2002; Pino et al., 2000; Zechmeister and Moser, 2001) of landscapes have been shown.

In Europe, due to complex biophysical and political patterns, regional differences in economical, social and environmental situations are pronounced (Jongman, 2002). Even in a small country such as Austria, the ecological conditions and land use vary highly (Wrbka et al., 2002). In principle, the current standard of knowledge about pattern and sustainability is derived from case studies (Turner and Ruscher, 1988; Moser et al., 2002; Wrbka et al., 2004). Hence, there is a need to get information on structure in the different parts of Europe in a consistent and statistically robust way. Therefore, to achieve an accurate spatially explicit SIA, it is necessary to account for these complexities and to modify indicator systems that originated at the regional level. Successful upscaling of the approaches can be enabled by identifying and delineating spatial units that are relatively homogeneous in both biophysical and socio-economic contexts. The 'Classification of Austrian Landscapes' (Wrbka et al., 2002) served as the Austrian spatial framework for the sustainability assessment, whereas at the European level, the Spatial Regional Reference Framework (Renetzeder et al., 2008) was developed for this purpose.

In this paper landscape pattern is used as a tool for sustainability assessment of agricultural landscapes at the regional (Austrian Cultural Landscapes), national (Austria) and European (European Union 27 + Norway, Switzerland) level. We investigated regarding the following main objectives: (1) to evaluate measures of landscape pattern that depict sustainable land use and (2) to apply these sustainability indicators for assessing the current state of the agricultural landscapes.

The project framework for the investigations presented in this paper was provided by an interdisciplinary national research project entitled 'SINUS—Structural features of landscape ecology as INdicators for sustainable land USe' in Austria (Peterseil et al., 2004). It was set up to describe spatial indices of sustainable land use by combining remote sensing methods with ecological field investigations (Wrbka et al., 1998). At European level, in the Integrated Project of the 6th Framework Programme SENSOR, the main objective was to develop an ex ante sustainability impact assessment tool including pan-European databases and spatial reference frameworks for the analysis of land and human resources in the context of European land use policies.

2. Materials and methods

2.1. Definition of spatial regional reference frameworks

Types of landscapes were assessed at the Austrian and at the European level by delineating and classifying landscapes based on biophysical and land use data to form meaningful ecological land units. In Austria, the 'Classification of Austrian Landscapes' (Wrbka et al., 2002) defined these land units at a regional scale of 1:200 000. Therefore, a visual classification of Landsat TM5 images was conducted. The polygons derived by this procedure, i.e. the "landscapes", were homogeneous in respect to their landscape pattern, land cover and prevailing site conditions. For the whole Austrian territory, 12 first-order and 43 second-order landscape types were classified. These landscape types provide a framework for the description of the natural preconditions of agricultural land use in Austria and give a current status of its intensity and the degree of transformation.

On the European scale, we used the Spatial Regional Reference Framework (SRRF, Renetzeder et al., 2008) that integrates biophysical and socio-economic dimensions into homogeneous European regions. The SRRF identifies spatial administrative units on the basis of statistical clustering of biophysical (climate, topography and bedrock) and socio-economic data (including population density, population change rate, activity rate, gross domestic production, unemployment rate, functional urban areas and land cover data), which were later aggregated by post-processing rules guaranteeing geographical and political coherence. It covers the EU 27, Norway and Switzerland and delineates 27 SRRF regions.

2.2. Sampling design

In Austria, 167 landscape plots of 1 km × 1 km were selected according to the Austrian national grid using stratified random sampling to guarantee statistical representativeness for the whole variety of Austrian agricultural landscapes (Peterseil et al., 2004). Geo-morphological features (e.g. altitudinal level, exposition), historical land use pattern and preliminary coarse landscape types were used as layers in the stratification procedure. Focus was given to agricultural landscapes with a forest cover below 60% including the subalpine and alpine summer pastures, but excluding larger settlements and industrialised areas, forested landscapes and larger wilderness areas, like the nival belt of the Alps.

At the European level, we randomly selected ten SRRF regions with the condition of representing European biogeographic regions (EEA, 2002): Boreal Forest, Central Atlantic Mixed agricultural activities, Continental Forest, Continental Heterogeneous agricultural areas, Mediterranean Arable land, Mountain Open spaces, North Atlantic Arable land, North Atlantic Pastures, Nemoral Mixed agricultural activities, and Pannonian Arable land. Within the selected regions, three satellite images of 50 km × 50 km were randomly selected using the official European grid system (Fig. 1).

2.3. Landscape data

At the national level, two different scales were used for producing information on land cover and land use. For the Austrian territory, landscape elements were automatically delineated and identified on satellite images, applying a segmentation method that produced results most closely resembling the delineation of landscape elements by visual interpretation. This region growing algorithm was applied to the geocoded Landsat TM5 scenes of 30m pixel size and the result of the segmentation process was directly coded in vector format (Steinwendner et al., 1998). Spectral, textural and shape parameters were determined as attributes of the individual segments. Land cover information on the segments was obtained in a classification step. To avoid misclassifications, the number of land cover classes was kept as low as possible (e.g. one class of urban and built-up land cover only), and finally 15 land cover classes were defined (Appendix A (a)). The segments were classified according to their attributes by using a decision-tree classification method. The decision rules were formulated using expert knowledge on satellite image interpretation. Information

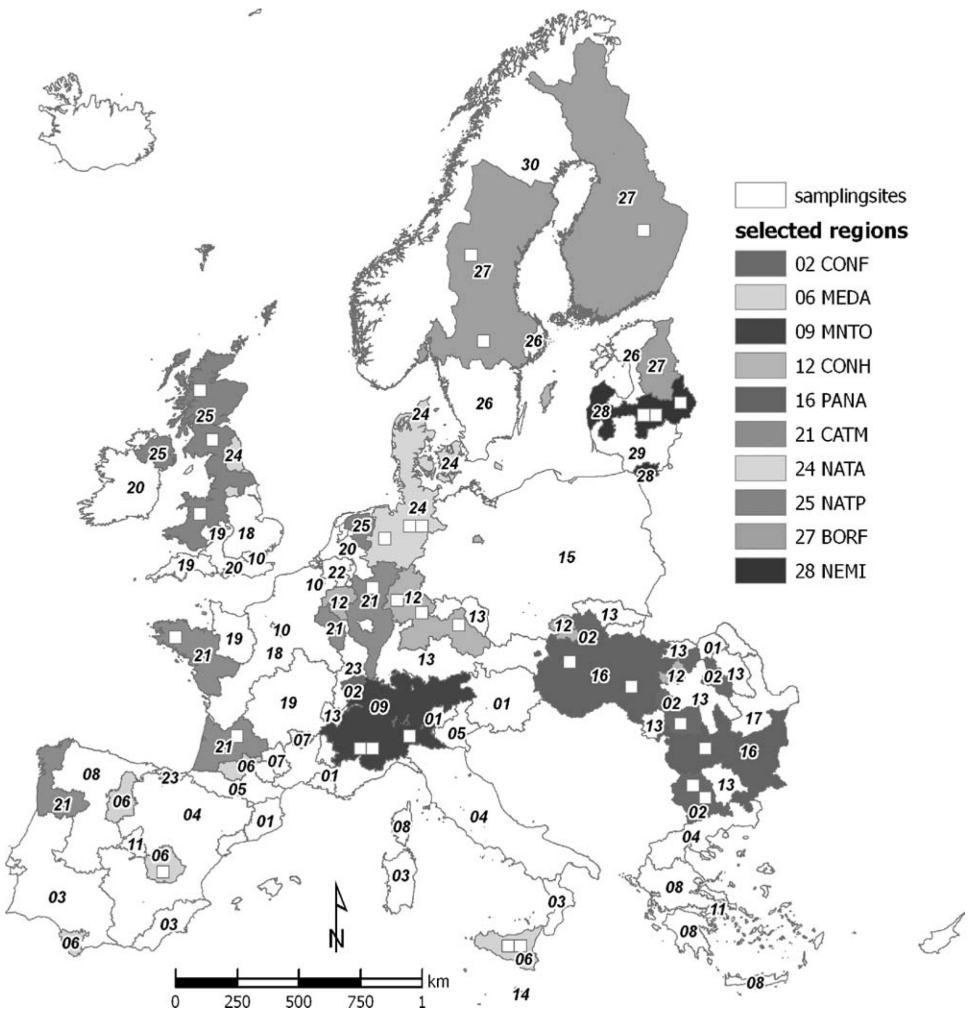

Fig. 1. Sampling sites selected in the ten SRRF regions (Renetzeder et al., 2008). BORF = Boreal Forest, CATM = Central Atlantic Mixed agricultural activities, CONF = Continental Forest, CONH = Continental Heterogeneous agricultural areas, MEDA = Mediterranean Arable land, MNTO = Mountain Open spaces, NATA = North Atlantic Arable land, NATP = North Atlantic Pastures, NEMI = Nemoral Mixed agricultural activities, PANA = Pannonian Arable land.

from training samples was used for iterative refinement of the decision rules.

On the local scale, land use categories were assigned to each landscape element directly in the field. Austrian field mapping was done in 1996 and 1997 at a scale of 1:10 000 on copies of aerial photographs that were adequate for the density of information content. For each sample landscape, 78 land use types in ten different land use classes such as arable land, grassland, permanent crops, forests, fallow land, and water bodies were distinguished (Appendix A (b)). Ecological attributes like the hemerobiotic state, species richness of vascular plants, trophic level of the topsoil (e.g. oligotrophic) and others were recorded (for the detailed manual see http://131.130.59.133/projekte/sinus/pdf/anh_B.pdf). The description of the landscape pattern in the recorded Austrian sites was undertaken most carefully, and identifying the patch origin types sensu Forman (1995) played an essential role. For each landscape element it was estimated to what extent it represents disturbance, regeneration, introduced, remnant or environmental resource patches. This was done directly in the field by using four values that described the degree of membership to functional interrelated groups.

Regarding the European landscape data, we used image data of 'Image2000' (Joint Research Centre-JRC; http://image2000.jrc.it/), derived from satellite images of Landsat 7 Enhanced Thematic Mapper ETM + , which cover most of the European countries. The segmentation of the images was performed with eCognition (© Definiens Inc.). To appoint a thematic meaning to the individual landscape element, Corine Land Cover (CLC2000; http://terrestrial.eionet.europa.eu/CLC2000) was intersected with the segmented images in ArcGIS (ESRI, Inc., Redlands, CA). Corine land cover data have a minimum mappable unit of 25 ha, a minimum width of 100m, and a thematic resolution of 44 classes categorised into five major groups (Appendix A (c)).

2.4. Information on landscape pattern

The field maps were digitised using a Geographical Information System and related to a database. Landscape pattern of landscape plots was calculated using the ArcView Extension PatchAnalyst 2.1 (Elkie et al., 1999). To achieve better comparability between the landscape plots, we selected a set of four metrics out of the multitude of existing indices that presented the differences among the cultural landscapes and described the ecological conditions within these (e.g. Neel et al., 2004; Schindler et al., 2008). These selected metrics were the Shape Index (SHI), the Perimeter-Area-Ratio (PAR), the Fractal Dimension (FD) and the Number of Shape Characterising Points (NSCP, Moser et al., 2002), describing the complexity of the landscape pattern. These metrics were computed for the landscape elements and averaged on the landscape plots. Analyses were done on both levels.

At the European level, we selected five landscape metrics: Patch Size (PS), Patch Edge (PE), SHI, PAR, and FD, and computed them at patch level with V-Late 1.1, Vector-based Landscape Analysis Tools Extension (Lang and Tiede, 2003). We then averaged them for the land cover classes that were most interesting in terms of the ecological–anthropogenic interface: non-irrigated arable land, pastures, complex cultivation patterns, agricultural land with natural vegetation, and natural grasslands. After testing for normal distribution and variance homogeneity, Mann–Whitney *U*-test, discriminant and factor analysis were performed with R2.6.0 (R Development Core Team, 2006) and Statgraphics 5.0 to detect differences in terms of class level landscape metrics among the regions. In particular, the factor analysis with varimax rotation was carried out to determine the contribution of the individual landscape metrics to the variation in the data at class level (Cumming and Vernier, 2002; Schindler et al., 2008). The quadratic discriminant function analysis (QDA) was performed to test whether the function with the variables classified according to the existing groups, and thus whether the multivariate set of landscape metrics allows an accurate separation of the data into SRRF regions.

2.5. Indices as indicators

The next step is to give the numbers of the indices a meaning in terms of ecological sustainability. For this purpose, consistent information of field data not only on landscape pattern and land use but also on naturalness in Austria was used. At landscape as well as at patch level the link between hemeroby and landscape pattern was analysed, using Kruskal–Wallis Test, Pearson Correlation and Spearman Correlation. Only landscape plots which belonged >75% to one cultural landscape type were used for the correlation analysis to assure homogeneity in the landscape samples ($n = 89$). The deviation of the hemerobiotic state of a certain landscape compared to the average situation of the respective landscape type was applied as indicator of sustainability in ecological terms. This approach was developed within the Austrian SINUS project and is termed 'Concept of Relative Deviance'.

Table 1
Result of Kruskal–Wallis Test (KWT): SHI (Shape Index), FD (Fractal Dimension), PAR (Perimeter-Area-Ratio) and NSCP (Number of Shape Characterising Points) are significantly different among the 7 hemerobiotic classes.

KWT	SHI	FD	PAR	NSCP
Chi-square	1178.9	2193.6	2944.2	2888.6
df	6	6	6	6
Asymptotic significance	<0.001	<0.001	<0.001	<0.001

The findings of the field survey on hemeroby were used to formulate sustainability within the cultural landscape types at the national level. Variables for topography, land use mosaic, shape and configuration of the land mosaic (derived from the Land Cover Classification), biophysical appearance of land cover (e.g. greenness, wetness, brightness) derived from Landsat TM images and fragmentation of the land mosaic were calculated for every single land cover type within a landscape cell. Taking the median of the hemeroby as response variable, an ordinal regression model could be developed within SPlus2000 (Bender and Bender, 2000) to produce a spatial model for all landscape samples presenting the most probable value of hemberoby. On basis of the model, a nation-wide hemeroby probability map could be produced and applied for sustainability assessment. This indicator resulted in five categories deviating from the average hemeroby situation: strongly negative, slightly negative, no deviation, slightly positive and strongly positive.

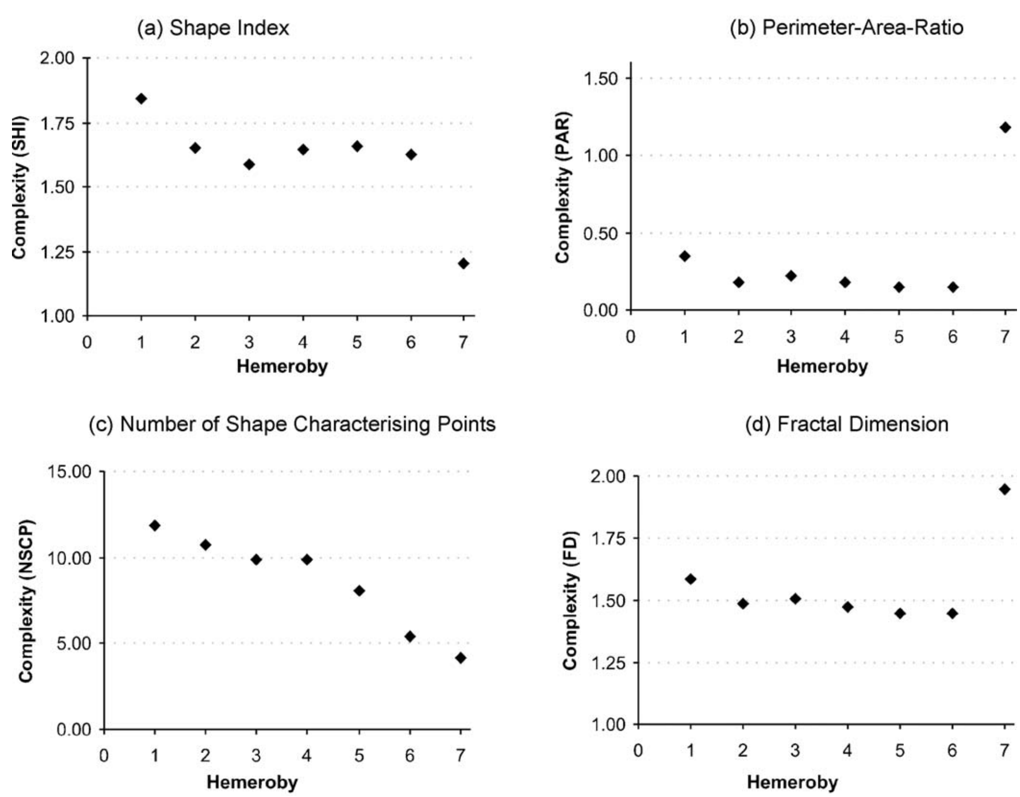

Fig. 2. Relationship between the complexity of a landscape element and the land use intensity displayed via the concept of hemeroby for each individual hemerobiotic class (higher hemerobiotic class presents higher land use intensity): (1) ahemerob, (2) oligohemerob, (3) mesohemerob, (4) β-euhemerob, (5) α-euhemerob, (6) polyhemerob, (7) metahemerob. The average of the respective complexity landscape index is displayed.

As at European level, there is no consistent data available on human impact or hemeroby to correlate with, so we chose the application of simple rules for assessing trends in sustainability. Intensification of land use generally leads to simpler geometry and configuration of landscape elements (Forman, 1995; Turner et al., 2001). A first indication is the deviation of landscape metrics from the average, based on the Austrian 'Concept of Relative Deviance'. Thus, based on the statistical analysis, it was possible to highlight regions which were at least more unsustainable than the average. The loadings of the factor analysis revealed which landscape metrics had the highest influence in the individual land cover classes. In each region, the confidence interval of the median of the landscape metric with the highest loading was used to define an ordinal scale of three (un)sustainable classes—below average (−1), average (0), above average (1) for the individual land cover classes.

3. Results

3.1. Austria regional level

For Austria, the Kruskal–Wallis Test revealed at patch level significant differences among the seven hemeroby classes (Table 1), although the statistical spread is quite high. The individual landscape indices showed different performance in relation to the hemerobiotic classes (Fig. 2).

At the landscape level, correlation analysis showed high correlations between each landscape index ($p < 0.01$) and the average hemeroby (median), with NSCP performing best (Spearman-Rho Coefficient of 0.72). Fig. 3 shows that different groups of cultural landscapes have a slightly different relation between hemeroby and complexity parameters.

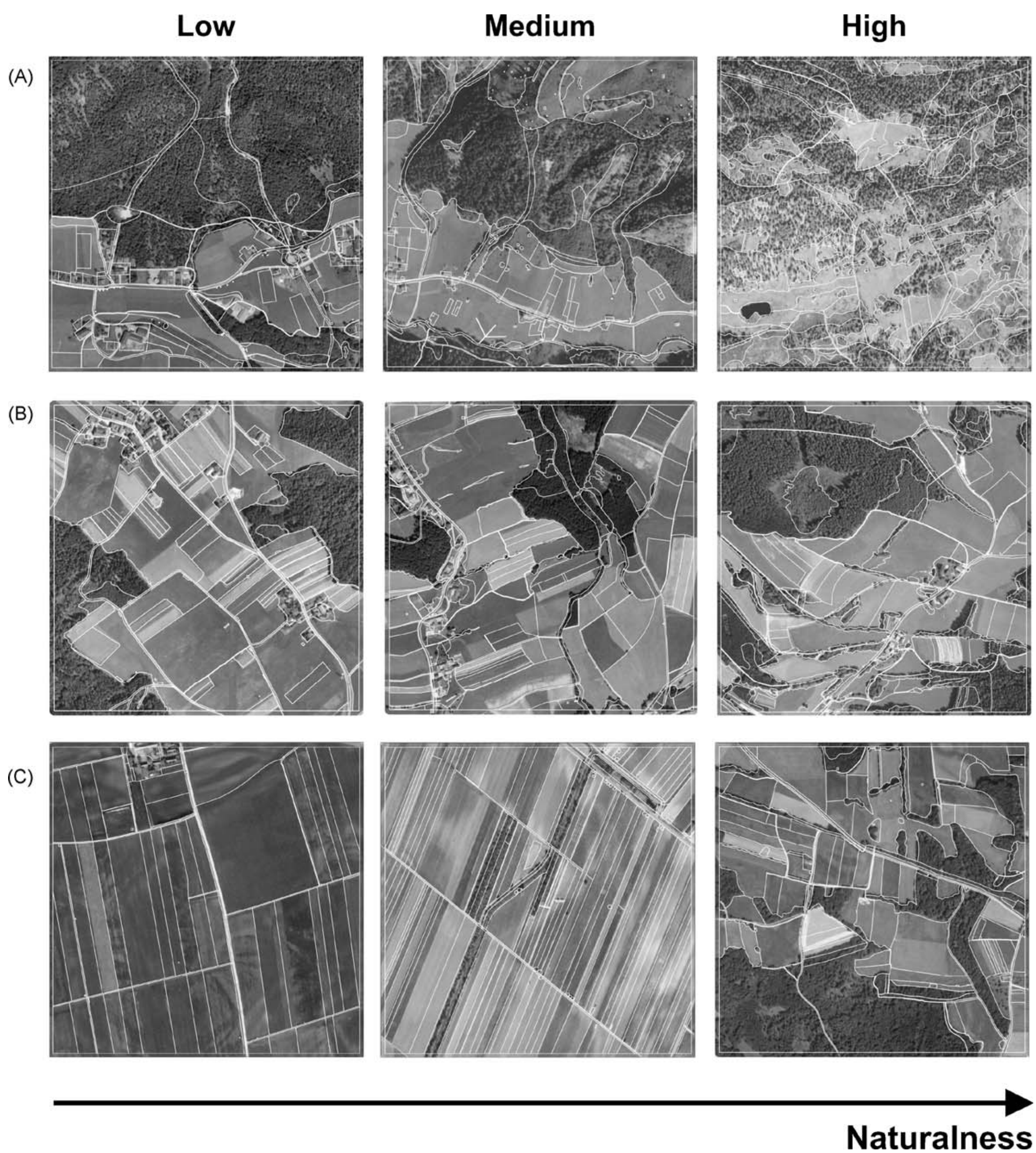

Fig. 3. Examples of sampled Austrian landscape units of different naturalness; on the left sample landscapes with low numbers of landscape metrics and naturalness, in the middle a medium situation and on the right those with the highest numbers in landscape metrics and naturalness in three different Austrian cultural landscape types; (A) forested mountain slopes, (B) grassland dominated landscapes of extra-alpine uplands, (C) extra-alpine basins and valley floors with dominant grain farming.

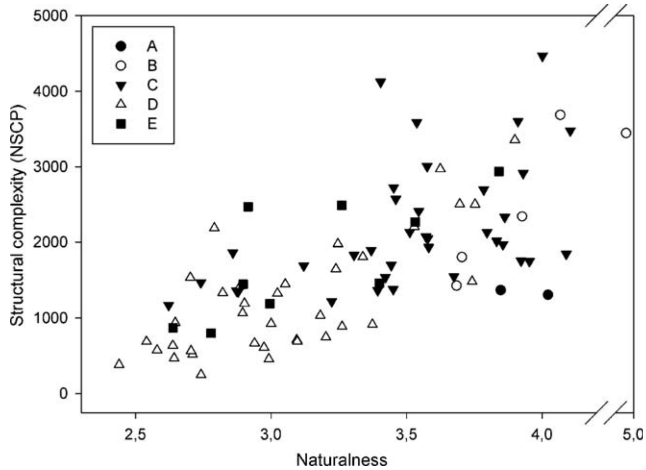

Fig. 4. Relationship between naturalness and structural complexity expressed by Number of Shape Characterising Points in different groups of cultural landscapes in Austria. A = Alpine rocks and areas of ice, B = Alpine and subalpine grassland landscapes, C = Elongated forest landscapes, D = Areal forest landscapes, E = Upland dairy farming landscapes with high proportion of permanent grassland, $n = 89$.

3.2. Austrian national level

The correlation between landscape pattern and naturalness can be seen throughout different cultural landscapes in Austria (Fig. 4). These relationships are the basis of assessing ecological sustainability via hemeroby for the whole Austrian territory. Based on the ordinal regression model for the hemeroby ($R^2 = 0.535$; $p < 0.001$), the sustainability was assessed for the different cultural landscape types in Austria and considerable differences among the regions resulted. For instance, well-known problem regions of ecological sustainability could be revealed. With regards to arable land, land use intensity as expressed in structure indices was high above average in the large basins and lowlands of Eastern Austria. With respect to grassland management, low sustainability was measured in some large alpine valleys. Higher spatial heterogeneity and related ecological sustainability was detected in mixed agricultural systems of low Alps and Hercynian Uplands (Fig. 5).

3.3. European level

Mann–Whithney *U*-test and box-and-whisker-plots revealed significant differences of landscape pattern among the 10 SRRF regions. We also detected that the metrics regarding the different land covers performed differently in depicting these differences. The landscape pattern of natural grassland was least different among the regions, while the highest differences were uncovered for non-irrigated arable land. The most contrasting SRRF regions were Continental Forests and Mountain Open spaces as nearly every metric in each land cover class distinguished them significantly. Very similar regions were Central Atlantic Mixed

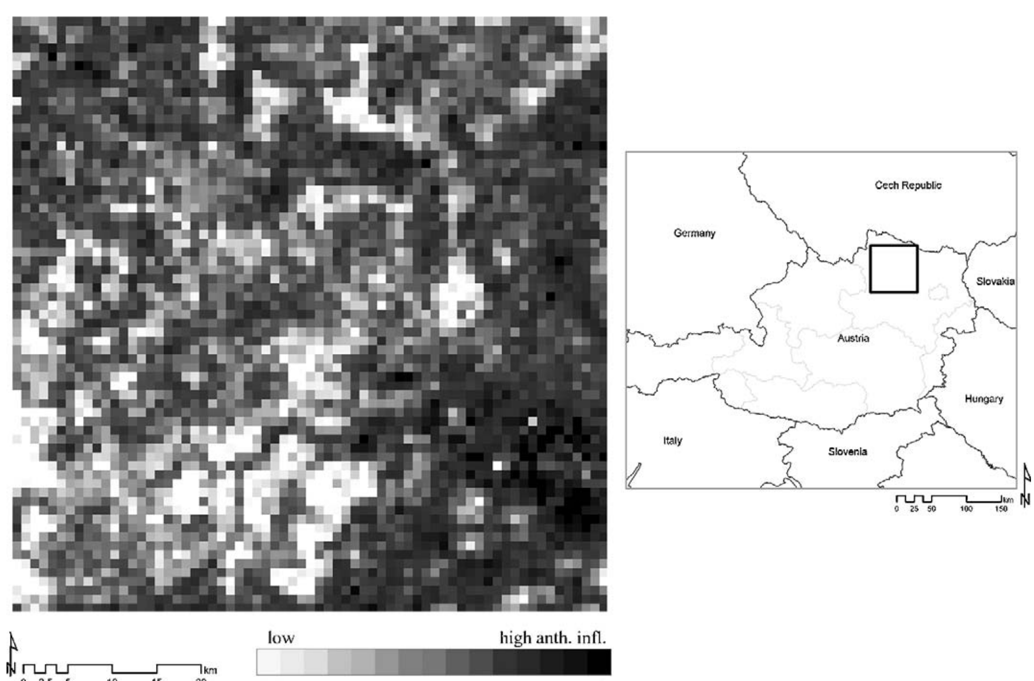

Fig. 5. Section of landscapes in the Hercynian Uplands in Lower Austria. Different classes of modelled anthropogenic influence (hemeroby) are indicated in greyscale colours on a 1 km × 1 km grid.

Table 2
Factor Analysis at the European scale including the five class level metrics for each land cover class; Mean Patch Size in ha (MPS_ha), Mean Patch Edge (MPE), Mean Shape Index (MSI), Mean Perimeter-Area-Ratio (MPAR) and Mean Fractal Dimension (MFRACT).

	Non-irrigated arable land		Pastures		Complex cultivation patterns	
	Factor1	Factor2	Factor1	Factor2	Factor1	Factor2
MPS_ha	0.930	−0.260	0.900	0.336	0.735	−0.630
MPE	0.997		0.822	0.565	0.879	−0.471
MSI	0.905	0.385	0.501	0.844	0.980	
MPAR	−0.380	0.760	−0.762	0.326	0.808	
MFRACT	0.515	0.854	−0.102	0.992	0.869	0.489

	Agricult. land with natural. veg.		Natural grasslands	
	Factor 1	Factor 2	Factor 1	Factor 2
MPS_ha	0.778	−0.584	0.933	0.256
MPE	0.916	−0.395	0.879	0.472
MSI	0.984		0.588	0.783
MPAR	0.808		−0.741	0.357
MFRACT	0.826	0.560	0.997	

agricultural activities with North Atlantic Arable land, Boreal Forest with Nemoral Mixed agricultural activities, Central Atlantic Mixed agricultural activities with Continental Forest, and Mediterranean Arable land with Nemoral Mixed agricultural activities.

The factor analysis revealed two different dimensions of landscape pattern, but the loadings were rather different for the individual land cover classes (Table 2). The metric with the highest loading of the first FA factor was for non-irrigated arable land the Mean Patch Edge (MPE), for pastures the Mean Patch Size (MPS), for complex cultivation pattern and agricultural land with natural vegetation the Mean Shape Index (MSI), and for natural grasslands the Mean Fractal Dimension (MFRACT). The QDA showed that the multivariate combination of landscape metrics was only poorly distinguishing landscape cover classes among the SRRF regions and the error rate was in general rather high.

Applying the 'Concept of Deviation' to the European landscape samples, areas of lower and higher sustainability within the European regions were detected. The relative sustainability in the example areas of North Atlantic Arable land and Pannonian Arable land (Fig. 6) is mainly visualised by the large sizes of pastures. Generally, a gradient of landscapes with different sustainability areas can be seen in each sampling region.

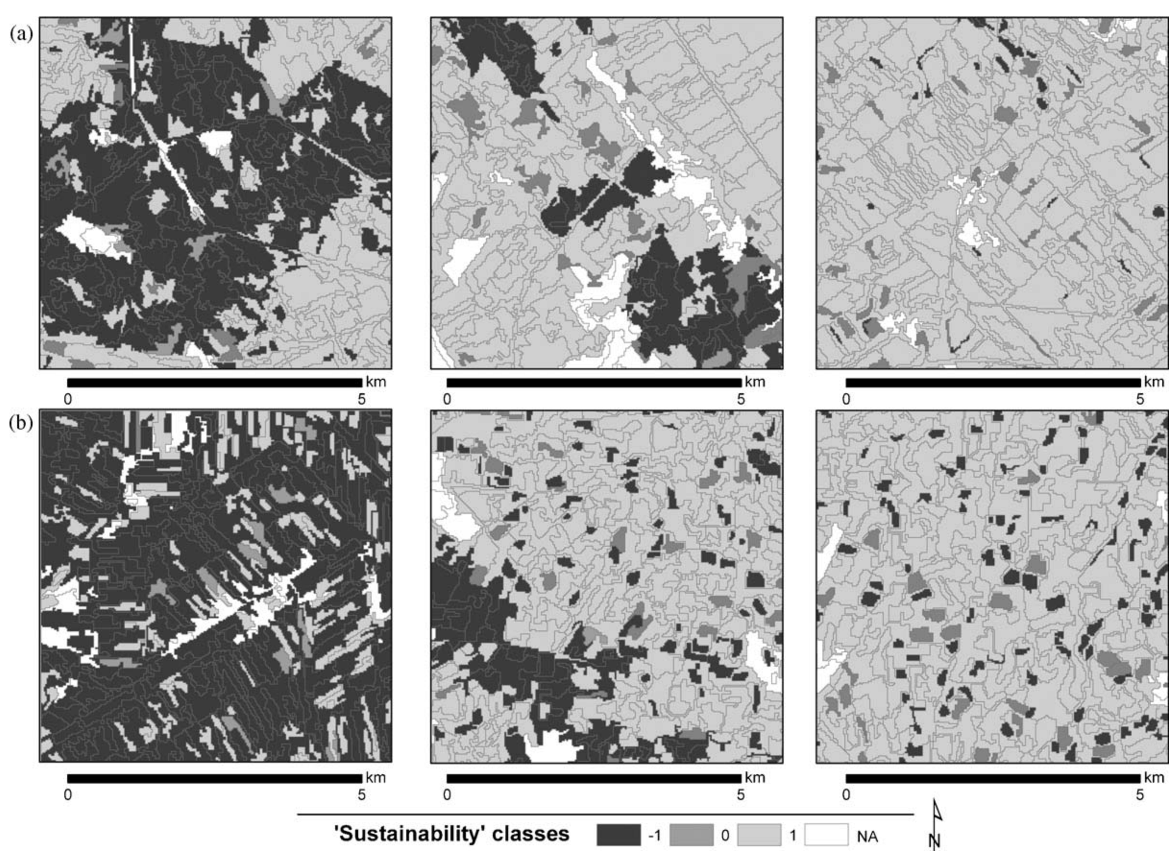

Fig. 6. Examples of sustainability classes according to the deviation from the average landscape pattern; detailed map of (a) Pannonian Arable land; (b) North Atlantic Arable land; −1 indicates landscape indices below the lower confidence interval of the median, 0 values between the lower and the upper confidence intervals of the median, and 1 values above the upper confidence interval of the median. No colour is given for land cover classes not analysed.

4. Discussions and conclusions

4.1. Landscape simplification and land use intensification

Odum and Turner (1989) have shown in their classical work how increasing consumption of fossil energy and agrochemicals are coupled with a geometrical simplification of landscapes expressed by a decrease in Fractal Dimension. Although the driving forces behind the process of simplifying landscape patterns are manifold, some general conclusions can be drawn. Agricultural land generally shows regular patterns caused by modern cultivation methods (Krummel et al., 1987; Moser et al., 2002), remnant semi-natural areas are normally bounded by cultivated land and therefore show straight boundaries (Hulshoff, 1995; Krummel et al., 1987) and the intensification of land use often leads to a decline of natural and semi-natural areas (Mander et al., 1999; Wrbka et al., 2008). Even at the European scale, single landscape metrics react differently depending on land cover, suggesting that such sensitive indices could be utilised as indicators for ecological sustainability of land use when applied together with land cover types in a spatial regional reference.

4.2. High resolution thematic information

Strategic environmental impact assessment needs spatially explicit data for the development of optimal policies (Helming et al., 2008). Large scale landscape studies very often refer to land cover information with relatively coarse spatial resolution (e.g. CORINE land cover) because such data are widely available. However, as only the dominant land use of an investigated area is captured by information of this kind, various authors have rightfully criticised such approaches (Estreguil et al., 2001; Kozak et al., 2008). In contrast, high-resolution images and fine grain habitat and land use maps would provide very useful tools to relate small scale ecological processes with the landscape level (Schindler et al., 2008). Such spatially explicit information is particularly important to improve the effectiveness of important environmental policies like agri-environment programmes that operate at the landscape and parcel level and which have been found to be currently not targeted enough (Herzog et al., 2005; Kleijn et al., 2006; Wrbka et al., 2008). Therefore large scale and widely used datasets such as Corine Land Cover should be supplemented and combined with an innovative derivation of homogeneous spatial units by segmentation as presented in our study. Objective of the segmentation was to identify the individual agricultural parcels and semi-natural patches as good as possible. Multispectral landsat satellite imagery had a spatial resolution of 25 m which in some cases was suboptimal to identify parcels and patches that were smaller than 1 ha. No shape and compactness parameters were set in the segmentation process due to no predefined assumptions on the shape of the patches. Major drawback of the segmentation process was that larger (agricultural) patches that had a large variability in, e.g. soil properties such as soil moisture, resulted in large differences in reflectance within the parcel and showed as a result different segments while these should be considered as subsegments of the parcel.

The elaboration of a scientifically sound knowledge-base for any impact assessment requires the establishment of statistically valid relationships between observed patterns and a particular ecological process of interest. This is especially true for biodiversity and sustainability related studies at the landscape level (Bunce et al., 2008) and calls for not only the combined use of geo-datasets with different spatial resolution, but also for the inclusion of empirical data derived by representative field observations. In our case, the development of an ordinal regression model that links the local with the regional scale (Fig. 5) was only possible on the basis of field-data from stratified randomly sampled landscapes. As Moser et al. (2002) have shown, the appropriate extent of sample landscapes has to be carefully decided and may vary with different land use systems. Upland pastoral landscapes, for instance, require larger areas for pattern analysis than lowland cropland dominated landscapes do. The size of 1 km^2 proved useful for analyses at national level in Austria (Peterseil et al., 2004; Wrbka et al., 2008). Similarly, the UK Countryside survey (Barr, 1994) and Bunce et al. (2008) conclude that for a Europe-wide sampling framework 1 km $\times$ 1 km sample squares are a satisfying pragmatic solution. However, in other landscapes (such as in Denmark) larger sampling units might be appropriate for the mapping of small biotopes (Brandt et al., 1999).

4.3. Meaningful landscape units for spatial reference frameworks

As it has been shown that agricultural landscapes show distinctive patterns (Figs. 3 and 4), it is crucial to apply regional reference frameworks (Blaschke, 2006) to achieve meaningful SIAs. Assessments implying remote sensing, landscape geometry and ecological quality are only meaningful when completed for comparable areas (such as SRRF and Austrian Cultural Landscapes). For example, the shape index of land cover class "arable land" is per se significantly higher in regions dominated by forest than agricultural regions.

At the national level we were not restricted to administrative units and the correspondence of ecological quality and landscape pattern was strong (Figs. 2 and 3). At the European level, the use of administrative units (NUTS 2/3 implemented into the SRRF) has weakened the desirable homogeneity in terms of primary and to some extent also secondary landscape structure, by resulting in fewer meaningful units for ecological assessment as confirmed by the poor performance of the set of metrics in the QDA.

As a consequence and based on the experience of the presented studies addressing both the Austrian and the European scale, we propose the development of tailor-suited approaches for the assessment of ecological sustainability. Such approaches are expected to yield satisfying results if they link scales and databases appropriately, making use of field observations in combination with carefully selected and adapted EO data.

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Appendix A

Land cover and land use classifications used at the different levels (a) national level Austria, (b) regional level Austria and (c) European level.

(a) SINUS land cover	(b) SINUS main land use types	(c) CLC (2000)
1. Water bodies	1. Arable land	1. Continuous urban fabric
2. Areas with ice and snow	2. Grassland	2. Discontinuous urban fabric
3. Areas void of vegetation (e.g. gravel pits, quarries, rocky areas)	3. Vineyards and fruit trees	3. Industrial or commercial units
4. Coniferous forests	4. Forests	4. Road and rail networks and associated land
5. Mixed forests	5. Water bodies	5. Port areas
6. Deciduous forests	6. Fallow land	6. Airports
7. Vineyards and orchards	7. Small features in agricultural land	7. Mineral extraction sites
8. Managed grassland	8. Built-up area	8. Dump sites
9. Grassland with bushes, trees and small woods	9. Traffic infrastructure	9. Construction sites
10. Mires and reeds	10. Special biotopes	10. Green urban areas
11. Bare soil areas		11. Sport and leisure facilities
12. Crop land		12. Non-irrigated arable land
13. Built-up areas with a low density		13. Permanently irrigated land
14. Built-up areas with a medium density		14. Rice fields
15. Built-up areas with a high density		15. Vineyards
16. Shadows. Clouds and undefined areas		16. Fruit trees and berry plantations
		17. Olive groves
		18. Pastures
		19. Annual crops associated with permanent crops
		20. Complex cultivation patterns
		21. Land principally occupied by agriculture, with significant areas of natural vegetation
		22. Agro-forestry areas
		23. Broad-leaved forest
		24. Coniferous forest
		25. Mixed forest
		26. Natural grasslands
		27. Moors and heathland
		28. Sclerophyllous vegetation
		29. Transitional woodland-shrub
		30. Beaches, dunes, sands
		31. Bare rocks
		32. Sparsely vegetated areas
		33. Burnt areas
		34. Glaciers and perpetual snow
		35. Inland marshes
		36. Peat bogs
		37. Salt marshes
		38. Salines
		39. Intertidal flats
		40. Water courses
		41. Water bodies
		42. Coastal lagoons
		43. Estuaries

References

Antrop, M., 2005. Why landscapes of the past are important for the future. Landsc. Urban Plann. 70, 21–34, doi:10.1016/j.landurbplan.2003.10.002.

Antrop, M., 2006. Sustainable landscapes: contradiction, fiction or utopia? Landsc. Urban Plann. 75, 187–197, doi:10.1016/j.landurbplan.2005.02.014.

Barr, C., 1994. Countryside Survey 1990—an overview. Ecosystems 15, 9–18.

Bender, R., Bender, A., 2000. Calculating ordinal regression models in SAS and S-Plus. Biometr. J. 42, 677–699, doi:10.1002/1521-4036(200010)42:6<677::AID-BIMJ677>3.0.CO;2-O.

Blaschke, T., 2006. The role of the spatial dimension within the framework of sustainable landscapes and natural capital. Landsc. Urban Plann. 75, 198–226.

Brandt, J., Primdahl, J., Reenberg, A., 1999. Rural land-use and landscape dynamics: analysis of "driving forces" in space and time. In: Krönert, R., Baudry, J., Bowler, I.R., Reenberg, A. (Eds.), Land-use Changes and their Environmental Impact in Rural Areas in Europe. UNESCO, London, pp. 81–102.

Brundtland, G. (Ed.), 1987. Our common future: The World Commission on Environment and Development. Oxford University Press, Oxford.

Bunce, R.G.H., Metzger, M.J., Jongman, R.H.G., Brandt, J., De Blust, G., Elena-Rossello, R., Groom, G.B., Halada, L., Hofer, G., Howard, D.C., Kovar, P., Mucher, C.A., Padoa-Schioppa, E., Paelinx, D., Palo, A., Perez-Soba, M., Ramos, I.L., Roche, P., Skanes, H., Wrbka, T., 2008. A standardized procedure for surveillance and monitoring European habitats and provision of spatial data. Landsc. Ecol. 23, 11–25, doi:10.1007/s10980-007-9173-8.

CEC (Commission of the European Communities), 2001. A Sustainable Europe for a Better World: A European Union Strategy for Sustainable Development. (Commission proposal to the Gothenburg European Council). COM, p. 264.

CEC (Commission of the European Communities), 2005a. Review of the Sustainable Development Strategy—A Platform for Action. COM 658.

CEC (Commission of the European Communities), 2005b. Impact Assessment Guidelines. SEC 791.

CEC (Commission of the European Communities), 2007. Progress Report on the Sustainable Development Strategy. COM 642 final.

CLC 2000, http://terrestrial.eionet.europa.eu/CLC2000 (20.10.2008).

Cumming, S., Vernier, P., 2002. Statistical models of landscape pattern metrics, with application to regional scale dynamic forest simulations. Landsc. Ecol. 17, 433–444, doi:10.1023/A:1021261815066.

EEA (European Environmental Agency), 2002. Europe's Biodiversity—Biogeographical Regions and Seas. Available: http://reports.eea.eu.int/report_2002_0524_154909/en/tab_content_RLR (20.11.2008).

EEA (European Environmental Agency), 2005. Agriculture and Environment in EU-15—the IRENA Indicator Report. EEA Report No 6/2005.

Elkie, P.R., Rempel, R., Carr, A., 1999. Patch analyst user's manual. Ont. Min. Nat. Resour. Northwest Sci. Technol. Thunder Bay Ont. (TM-002).

Ernoult, A., Freiré-Diaz, S., Langlois, E., Alard, D., 2006. Are similar landscapes the result of similar histories? Landsc. Ecol. 21, 631–639, doi:10.1007/s10980-005-5321-1.

Estreguil, C., Thierron, V., Guissard, V., Defourny, P., Dufrene, M., 2001. Relevance of CORINE Land Cover for reporting on nature protection at regional level. DG-JRC, Ispra, Italy. JRC publication reference: EUR report number 19819/EN.

Forman, R.T.T., 1995. Land Mosaics—The Ecology of Landscapes and Regions. Cambridge University Press.

Graymore, L.M.M., Sipe, N.G., Rickson, R.E., 2008. Regional sustainability: how useful are current tools of sustainability assessment at the regional scale? Ecol. Econ. 67, 362–372, doi:10.1016/j.ecolecon.2008.06.002.

Helming, K., Pérez-Soba, M., Tabbush, P. (Eds.), 2008. Sustainability Impact Assessment of Land Use Change. Springer-Verlag, Berlin, Heidelberg, Germany.
Herzog, F., Dreier, S., Hofer, G., Marfurt, C., Schlüpbach, B., Spiess, M., Walter, T., 2005. Effects of ecological compensation areas on floristic and breeding bird diversity in Swiss agricultural landscapes. Agric. Ecosyst. Environ. 108, 189–204.
Hulshoff, R.M., 1995. Landscape indices describing a Dutch landscape. Landsc. Ecol. 10, 101–111, doi:10.1007/BF00153827.
Jongman, R.H.G., 2002. Homogenisation and fragmentation of the European landscape: ecological consequences and solutions. Landsc. Urban Plann. 58, 211–221, doi:10.1016/S0169-2046(01)00222-5.
JRC, http://image2000.jrc.it/ (22.10.2008).
Kleijn, D., Baquero, R.A., Clough, Y., Díaz, M., De Esteban, J., Fernández, F., Gabriel, D., Herzog, F., Holzschuh, A., Jöhl, R., Knop, E., Kruess, A., Marshall, E.J.P., Steffan-Dewenter, I., Tscharntke, T., Verhulst, J., West, T.M., Yela, J.L., 2006. Mixed biodiversity benefits of agri-environmental schemes in five European countries. Ecol. Lett. 9, 243–254, doi:10.1111/j.1461-0248.2005.00869.x.
Kozak, J., Estreguil, C., Ostapowicz, K., 2008. European Forest cover mapping with high resolution satellite data: the Carpathians case study. Int. J. Appl. Earth Obs. 10, 44–55 10.1016/j.jag.2007.04.003.
Krummel, J.R., Gardner, R.H., Sugihara, G., O'Neill, R.V., 1987. Landscape patterns in a disturbed environment. Oikos 48, 321–324.
Lang, S., Tiede, D., 2003. vLATE Extension für ArcGIS - vektorbasiertes Tool zur quantitativen Landschaftsstrukturanalyse, ESRI Anwenderkonferenz. Innsbruck. CD-ROM.
Mander, Ü., Mikk, M., Kulvik, M., 1999. Ecological and low intensity agriculture as contributors to landscape and biological diversity. Landsc. Ecol. 46, 169–177, doi:10.1016/S0169-2046(99)00042-0.
Millennium ecosystem assessment, 2003. Ecosystems and Human Well-being: A Framework for Assessment. Island Press.
Moser, D., Zechmeister, H.G., Plutzar, C., Sauberer, N., Wrbka, T., Grabherr, G., 2002. Landscape patch shape complexity as an effective measure for plant species richness in rural landscapes. Landsc. Ecol. 17, 657–669, doi:10.1023/A:1021513729205.
Naveh, Z., Liebermann, A., 1984. Landscape Ecology—Theory and Application. Springer-Verlag, Berlin and New York.
Neel, M.C., McGarigal, K., Cushman, S.A., 2004. Behavior of class-level landscape metrics across gradients of class aggregation and area. Landsc. Ecol. 19, 435–455, doi:10.1023/B:LAND.0000030521.19856.cb.
Odum, E.P., Turner, M.G., 1989. Georgia landscape: a changing resource. In: Zonneveld, I.S., Forman, R.T.T. (Eds.), Changing Landscapes: An Ecological Perspective. Springer, New York, USA, pp. 137–146.
Peterseil, J., Wrbka, T., Plutzar, C., Schmitzberger, I., Kiss, A., Szerencsits, E., Reiter, K., Schneider, W., Suppan, F., Beissmann, H., 2004. Evaluating the ecological sustainability of Austrian agricultural landscapes: the SINUS approach. Land Use Policy 21, 307–320, doi:10.1016/j.landusepol.2003.10.011.
Pino, J., Rodà, F., Ribas, J., Pons, X., 2000. Landscape structure and bird species richness: implications for conservation in rural areas between natural parks. Landsc. Urban Plann. 49 (1–2), 35–48, doi:10.1016/S0169-2046(00)00053-0.
R Development Core Team, 2006. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
Renetzeder, C., Van Eupen, M., Mücher, C.A., Wrbka, T., 2008. A spatial regional reference framework for sustainability assessment. In: Helming, K., Tabbush, P., Perez-Soba, M. (Eds.), Sustainability Impact Assessment of Land Use Changes. Springer, pp. 249–268.
Schindler, S., Poirazidis, K., Wrbka, T., 2008. Towards a core set of landscape metrics for biodiversity assessments: a case study from Dadia National Park. Greece Ecol. Indic. 8, 502–514, doi:10.1016/j.ecolind.2007.06.001.
Steinwendner, J., Schneider, W., Suppan, F., 1998. Vector segmentation using multiband spatial subpixel analysis for object extraction. Int. Arch. Photogr. Rem. Sens. 32 (B3/1), 265–271.
Turner, M.G., Gardner, R.H., O'Neill, R.V. (Eds.), 2001. Landscape Ecology in Theory and Practice, Pattern and Process. Springer, p. 401.
Turner, M.G., Ruscher, C.L., 1988. Changes in the spatial patterns of land use in Georgia. Landsc. Ecol. 4, 21–30 10.1007/BF00157696.
Wrbka, T., Reiter, K., Szerencsits, E., Mandl, P., Schneider, W., Suppan, F., 1998. Landscape structure derived from satellite images as indicator for sustainable landuse. In: Proceedings of the EARSEL Symposium on Operational Remote Sensing for Sustainable Development, Enschede.
Wrbka, T., Erb, K.-H., Schulz, N., Peterseil, J., Hahn, C., Haberl, H., 2004. Linking pattern and process in cultural landscapes. An empirical study based on spatially explicit indicators. Land Use Policy 21, 28–306, doi:10.1016/j.landusepol.2003.10.012.
Wrbka, T., Fink, M., Beissmann, H., Schneider, W., Reiter, K., Fussenegger, K., Suppan, F., Schmitzberger, I., Pühringer, M., Kiss, A., Thurner, B., 2002. Kulturlandschaftsgliederung Oesterreich. Endbericht des gleichnamigen Forschungsprojektes. Forschungsprogramm Kulturlandschaft 13 (CD-ROM), Wien, Bundesministerium für Bildung, Wissenschaft und Kultur.
Wrbka, T., Schindler, S., Pollheimer, M., Schmitzberger, I., Peterseil, J., 2008. Impact of the Austrian Agri-Environmental Scheme on diversity of landscape, plants and birds. Commun. Ecol. 9, 217–227 10.15556/ComEc.9.2008.2.x.
Zechmeister, H.G., Moser, D., 2001. The influence of agricultural land-use intensity on bryophyte species richness. Biodivers. Conserv. 10, 1609–1625, doi:10.1023/A:1012008828522.

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Publications	
Journals	**Renetzeder, C.,** Schindler, S., Peterseil, J., Prinz, M.A., Mücher, S., & Wrbka, T. (2010). Can we measure ecological sustainability? Landscape pattern as an indicator for naturalness and land use intensity at regional, national and European level. Ecological Indicators 10, 39-48.
	Hazeu, G. W., Metzger, M. J., Mücher, C. A., Perez-Soba, M., **Renetzeder, C.**, & Andersen, E. (2010) European environmental stratifications and typologies: an overview. Agriculture, Ecosystems and Environment, in press, doi: 10.1016/j.agee.2010.01.009
Book chapters	**Renetzeder, C.,** Wrbka, T., Mücher, S., van Eupen, M., Kiers, M. (2010). Landscape Structure Analysis in selected European Regions and its use for Sustainability Impact Assessment. In: Andel J, Bicik I, Dostal P, Lipsky Z, Shahneshin SG (Eds.): Landscape modelling: geographical space, transformation and future scenarios, Springer. pp. 159-170.
	Wrbka, T., **Renetzeder, C.** (2009). Lesachtal: Kulturlandschaft eines österreichischen Alpentales In: Krzywinski K., O'Connell M., Küster H. (Hrsg.) Europäische Kulturlandschaften - Wo Demeter ihre Felder hat und Pan zu Hause ist. Aschenbeck Media, Bremen. 217 S. ISBN 978-3-941624-31-3. pp. 116-117.
	Renetzeder, C., Wrbka, T. (2009). Wachau: Weinterrassen im Donautal. In: Krzywinski K., O'Connell M., Küster H. (Hrsg.) Europäische Kulturlandschaften - Wo Demeter ihre Felder hat und Pan zu Hause ist. Aschenbeck Media, Bremen. 217 S. ISBN 978-3-941624-31-3. pp. 132-133.
	Renetzeder, C., Wrbka, T. (2009). Südburgenland: Kulturlandschaft der Obstwiesen und Weingärten. In: Krzywinski K., O'Connell M., Küster H. (Hrsg.) Europäische Kulturlandschaften - Wo Demeter ihre Felder hat und Pan zu Hause ist. Aschenbeck Media, Bremen. 217 S. ISBN 978-3-941624-31-3. pp. 120-121.
	Renetzeder, C., Wrbka, T., Grünweis, F.M. (2009). European Diversity in review – the major landscapes on the Green Belt. In: Wrbka, T., Zmelik, K., Grünweis, F.M. (eds): The European Green Belt. Borders. Wilderness. Future. Bibliothek der Provinz, Weitra. pp. 27-31.
	Renetzeder, C., van Eupen, M., Mücher, C.A., Wrbka, T. (2008). A Spatial Regional Reference Framework for Sustainability Assessment. In: Helming, K., Tabbush, P., Perez-Soba, M. (Eds.): Sustainability impact assessment of land use changes, Springer. pp. 249-268.
Conference Proceedings	**Renetzeder, C.** (2009). Major Geo-Ecological Landscapes along the Green Belt of Europe. In: Breuste, J., Kozová, M., Finka, M. (Eds.): European Landscapes in Transformation: Challenges for Landscape Ecology and Management (Proceedings of the European IALE Conference 2009), p. 571.
	Renetzeder, C., Knoflacher, M., Wrbka, T., Loibl, W. (2009). CROSS - Climate Change Response of Sensitive Habitats and Landscapes in Austria. In: Breuste, J., Kozová, M., Finka, M. (eds): European Landscapes in Transformation: Challenges for Landscape Ecology and Management (Proceedings of the European IALE Conference 2009), p. 523.
	Renetzeder, C., Knoflacher, M., Wrbka, T., Loibl, W. (2008). CROSS - Climate Change Response of Sensitive Habitats and Landscapes in Austria. In: Löffler, J., Breuste, J., Lenz, R., Müller, F., Steinhardt, U., Walz, U. (eds): Global Change and Landscape Response. Die Rückkopplungen von

	Landschaften auf den Globalen Wandel (Tagungsband zur IALE Jahrestagung, Sektion Deutschland, 2008), p. 43.
	Mücher, S., Vos, C., Kiers, M., **Renetzeder, C.,** Wrbka, T., van Eupen, M. (2008). The use of satellite imagery to identify landscape permeability through observed landscape structure and land cover. In: Dilly, O., Helming, K. (eds.): Impact Assessment of Land Use Changes. (Book of Abstract of the International Conference 2008), p. 56.
	Renetzeder, C., Wrbka, T., Mücher, S., van Eupen, M., Kiers, M. (2008). Landscape structure analysis as tool for sustainability assessment on the regional level. In: Dilly, O., Helming, K. (Eds.): Impact Assessment of Land Use Changes. (Book of Abstract of the International Conference 2008), p. 57.
	Mücher, S., Vos, C., **Renetzeder, C.,** Wrbka, T., Kiers, M., van Eupen, M., Bugter, R. (2007). The use of satellite imagery to identify landscape structure. In: Bunce, R.G.H., Jongman, R.H.G., Hojas, L., Weel, S. (eds.): 25 Years of Landscape Ecology: Scientific Principles in Practice. (Proceedings of the 7th IALE World Congress 2007), pp. 590-591.
	Renetzeder, C., van Eupen, M., Mücher, S., Wrbka, T. (2007). Linking landscape characteristics and socio-economic profiles for sustainable impact assessment at the regional level – the Spatial Regional Reference Framework (SRRF). In: Bunce, R.G.H., Jongman, R.H.G., Hojas, L., Weel, S. (eds.): 25 Years of Landscape Ecology: Scientific Principles in Practice. (Proceedings of the 7th IALE World Congress 2007), pp. 1032-1033.
Reports	Mücher, C.A., van Eupen, M., Vos, C.C., Kiers, M.A., **Renetzeder, C.,** Wrbka, T. (2009). Spatial Cohesion – An indicator for regional assessment of biodiversity in SENSOR. In: Helming, K., Wiggering, H. (Eds.): SENSOR. Report Series 2009/1, www.sensor-ip.eu, ZALF, Germany.
	Wrbka, T., Prinz, M., **Renetzeder, C.,** Stocker-Kiss, A., Brandenburg, C., Ziener, K. (2009). Man & Biosphere - Redesigning the Biosphere Reserve Neusiedler See - Endbericht. Akademie der Wissenschaft. Wien.
	Prinz, M., **Renetzeder, C.,** Schmitzberger, I., Stocker-Kiss, A., Wrbka, T. (2007). Obstbaumwiesen als Schlüsselelemente zur Erhaltung und Foerderung der natürlichen Vielfalt in oesterreichischen Agrikulturlandschaften. Online-Fachzeitung des Bundesministeriums für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft. http://www.laendlicher-raum.at
	Wrbka, T., Zmelik, K., Durchhalter, M., Willner, W., **Renetzeder, C.,** Krommer, V., Marchsteiner, L., Stocker-Kiss, A. (2006). Biodiversitätsforschung im Nationalpark Thayatal Teilbereich Waldvegetation. Endbericht. Im Auftrag der Nationalpark Thayatal GmbH.
	Renetzeder, C., van Eupen, M., Mücher, S., Wrbka, T., Wascher, D., Kienast, F. (2006): Spatial Regional Reference Framework – Methodology and Report. In: Helming, K., Wiggering, H. (Eds.): SENSOR Report Series 2006/04, www.sensor-ip.eu, ZALF, Germany.
	Renetzeder, C., van Eupen, M., Mücher, S., Wrbka, T., Wascher, D., Kienast, F. (2006): Spatial Regional Reference Framework – Annex 2 (Maps). In: Helming, K., Wiggering, H. (Eds.): SENSOR Report Series 2006/04, www.sensor-ip.eu, ZALF, Germany.