Identification and Characterisation of Environments and Landscapes in Europe

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ABSTRACT

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At the European level, both environmental policy and research require increasingly reliable and methodologically unbiased spatial reference systems in support of environmental reports and monitoring using indicators, impact analysis or scenarios. Due to recent advances in the availability and accuracy of internationally harmonised geographic data, this project applies state-of-the-art data management techniques and data with the objective to produce two new stratifications of the terrestrial environment of Europe: (1) a Environmental Classification of Europe based on a top-down bioclimatic approach, and (2) a European Landscape Classification linking top-down and bottom-up methods of landscape character assessment. This report discusses the underlying concepts, methodologies and database constructions. The two classifications are meant to be tested and further developed through practical applications by researchers and policy experts at both the European as well as the national level.

Keywords: Environment, Landscapes, Climate, Classification, eCognition, GIS

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Preface

The European dimension is becoming an increasingly important research asset for environmental and social studies on rural areas, including natural and cultural landscapes. Issues such as biodiversity, sustainability, climate change, rural development and land use changes are characterised by multi-spatial dimensions and require therefore for at least an international and sometimes even a continental or global approach. The complex nature of the underlying – sometimes overlapping and sometimes conflicting – scientific concepts require transparent, systematic and consistent methodologies, should cover a maximum of countries and produce data that overarch fragmented and yet integrate relevant national approaches. The principle challenge is hence to design central concepts, typologies and data storage systems that are truly international while taking into account the needs of national and regional authorities. This is a major effort in view of current differences in data, typologies and interpretations between the various countries. As there are many relevant geographical differences in land properties, influences from land use or other forces and impacts, it is crucial to strike the right balance between reducing the inherent complexity and maintaining the adequate level of detail with regard to future applications. So what is needed is a well-chosen so-called stratification of the land in relatively homogeneous regions, while the mosaics of these units can exhibit the relevant regional differences. These will provide a framework not only for analysis but also for monitoring purposes, indicator development and interpretation, scenario studies as well as generally for better presenting environmental and social information.

This report presents the results of two closely inter-related, yet relatively independently implemented projects that, however, both follow the same rationales and commonly face the same challenges addressed in the previous paragraph.

One project presents an attempt to provide users with an advanced **Environmental Classification of Europe** with a focus on bioclimatic conditions for flora and vegetation. Drawing upon early British initiatives in developing environmental classifications for strategic ecological surveys, R.G.H. (Bob) Bunce carried his vision of an improved (more detailed) European approach to the Continent when joining Alterra and starting on a framework for monitoring European habitats and their biodiversity as part of the BIOHAB project. Last year, when high resolution climate data created by Tim Mitchell of the Climate Research Unit of the University of East Anglia became available through the ATEAM project data co-ordinator Markus Erhard and when Marc Metzger, a PhD student at the Plant Production Systems Group of Wageningen University, joined the project team, these visions could become reality.

The other project is an attempt to develop for the first time a **European Landscape Classification** combining different layers of the most recent geographic data while drawing upon existing national approaches. The need for developing a European landscape map received a first high level policy attention in the making of the Dobríš Assessment of Europe's Environment, for which the Dutch landscape architect Johan Meeus developed a first approach as input to the chapter on landscapes. Subsequently, Dirk Wascher, one of the lead authors of the Dobríš report, co-ordinated the implementation of the Action Plan on Landscapes as part of the Pan-European Strategy for Biological and Landscape Diversity launched by UNEP and the Council of Europe, calling for the development of an improved European landscape map. This initiative together with Rob Jongman's attempt on developing a new landscape zonation in contribution to a project for the European Environment Agency led to further research carried out by Jan Klijn, Jelle Vervloet and Theo Spek at Alterra. However, only the establishment of the expert network Landscape Europe in 2001 and the subsequent launching of the ELCAI project on European landscape character assessment provided the right stimulus for aiming at a new European Landscape Map. The bottom-up information deriving from various national approaches as well as the arrival of high quality data and more sophisticated software (eCognition) provided the opportunity to make decisive progress in the classification and mapping of European landscapes.

Both products can actually be better viewed as principle references for flexible geographical information systems allowing a multitude of configurations and overlays according to specified goals rather than just as two singular typologies or maps. Both databases are still in the process of being revised and refined on basis of the comments of the international scientific community and we hope to present final versions in 2005. By making approaches, methodologies as well as preliminary classifications and databases public we encourage the scientific community to take part in discussions, to suggest improvements and to add knowledge to these new tools so that some degree of international consensus can be achieved. Eventually, this will form a solid basis for internationally accepted policies.

Summary

This report presents the conceptual and practical aspects of two strongly, yet independently implemented projects: (1) the Environmental Classification of Europe as well as (2) the European Landscape Classification.

The Environmental Classification of Europe

Stratification into relatively homogeneous regions is an essential basis for strategic sampling of ecological variables and consistent modelling exercises. Within a given stratum, changes or effects can be analysed within a homogeneous environment, which then enables variation to be partitioned. Such a process is imperative to produce statistically robust results, which require data to be representative from a defined population. For example, when examining a single class to determine the influence of causal factors of change on species abundance, statistical procedures can ensure that the observed effects are indeed caused by that change and not by inherently different environments.

A first statistical approach, carried out by Jones and Bunce (1985), was followed by a grid based European Land Classification by the Institute for Terrestrial Ecology (ITE) – now Centre for Ecology and Hydrology (CEH) – in 1992 (Bunce et al, 1996a, b and c). The grid size of 0.5° degrees is considered nowadays too coarse and improvements were suggested.

In this report an eighty-four class Environmental Classification of Europe (EnC) is described that has been constructed by principal component analysis and statistical clustering of climatic and topographic variables. The EnC is appropriate for strategic random sampling for resource assessment, measurement of change, and modelling. Three levels of aggregation are described to further facilitate analysis within thirteen Environmental Zones that are considered appropriate for summary purposes. Marc Metzger of Wageningen University was responsible for implementing the European Environmental Classification. The EnC is already used in several projects, ranging from site selecting to global change scenarios, and is available for non-commercial use by applying to Marc Metzger.

The European Landscape Classification

Recent policy developments in the field of agri-environmental indicators as addressed in European projects such as ELISA (Wascher, 2000a), ENRISK (Delbaere, 2003) and IRENA (EEA, 2003) have demonstrated the explicit need for a systematic classification of landscape aspects in Europe for a wide array of applications. First attempts were carried out about in the 1980’s, e.g. by Meeus et al. (1990), Milanava and Kushin (1993) and there are ample reasons and possibilities to accomplish major improvements.

The European Landscape Classification (LANMAP) is fully based upon a hierarchy in parameters of various components and within that scheme we made a choice of

key parameters that are considered most important and readily available, i.e. three important parameters: topography, parent material and land use. The next question was how to combine the geographical information layers into one overarching landscape concept following a systematic and retraceable procedure. For that purpose we made use made of a new software package, called eCognition. The three core information layers (topography, parent material and land use) were stacked into one RGB colour composite which created the appearance of a 1km resolution satellite image. This image was segmented in eCognition on a first level using topography and parent material only, which was considered to be a fixed matrix. On a second level the (landscape) segments were further subdivided on the basis of land use. This resulted finally in 202 different landscape types.

Integration with the EnC was implemented by means of labelling each landscape unit with the dominant Environmental Zone. The Environmental Zone is seen as an important attribute in the description of the landscape type with respect to vegetation and/or farming systems that are sometimes largely determined by bio-climatic and biogeographical features. While the Environmental classification is nearly finished the European Landscape classification still needs revisions and elaboration. Especially, a comprehensive description of the landscape types for the aspects already incorporated as well as possible additional information on the cultural and historic aspects of the landscapes needs major efforts. By making both databases public we are hoping (and this is already partly happening) that they will be used in a wide variety of applications and that comments and suggestions will help us to improve the two databases.

1 Introduction

The outstanding richness and diversity of Europe’s landscapes are widely recognised attributes of the continent’s unique natural and cultural heritage. Natural assets are the long and winding coastline, a climate gradient from the Arctic to the Mediterranean, from oceanic to more continental regimes, from lowlands to alpine peaks and a rich pattern of geological and soil conditions. In Europe we encounter a wide range of biogeographic regions spanning from the Macaronesian Azores and Canary Isles towards the Arctic region’s Barents Sea. Within Europe the signs of human interaction with nature in the landscapes are sometimes millennia old, extremely varied from period to period and from region to region, as well as related to distinct cultures. (Stanners & Bordeaux, 1995; Klijn & Vos, 2000; Green & Vos, 2000; Delbaere, 1998; Aalen, 2002; Klijn, 2003; Wascher, 2000b; Council of Europe et al., 1996). Past as well as current influences on Europe's landscapes have resulted in a rich palimpsest: layers upon layers of various periods of time are sometimes traceable in close vicinity at the present-day surface like remnants from many artists’ brushworks on an ancient painting. The complexity of natural and man-made phenomena that contribute to the shaping of Europe’s landscapes is also reflected in the many values that are being attached to them: ecological values, archaeological and historical values, scenic values, present-day cultural values, earth-scientific values as well as economical values such as recreation and tourism, craft and art works. All together they contribute to the identity of landscapes. Landscapes never have been static and never will be. The question is how to safeguard or even restore values amidst a host of changes affecting these landscapes.

Many landscapes are exposed to dynamic *driving forces* related to policy implementation, land use or demographic trends and changes (Meeus et al., 1998). Such driving forces affect production and planning processes in agriculture, forestry, urbanisation and traffic, which in turn impact on environmental conditions spanning from local pollution, regionally extensive forest fires or flood events to global impacts such as climate change which can be seen as both as a driving force for changes as well as a result of a globally orchestrated human pressure system.(Delbaere,1998 ; Cattizone et al., 1998). The concern that essential landscape values are getting temporally or permanently lost due to conflicting driving forces and pressures has been addressed in recent policy documents such as the Pan-European Biological and Landscape Diversity Strategy (Council of Europe et al., 1996) and more recent the European Landscape Convention (Council of Europe, 2000). Inescapably a reliable overview of landscape types is required. As stated in the Dobríš report of the EEA on the state of Europe’s Environment (Stanners & Bordeaux, 1995) there is still a substantial discrepancy between the large variety of European landscapes and the lack of internationally harmonised and accepted approaches to characterise and identify them. In this report the map of Meeus (1995) was presented as a first approach to exhibit Europe’s diversity in landscapes: an endeavour that was equally brave and inspiring but provisional and rather subjective due to a lack of data. As such it has been considered a good incentive to improve

European - wide information on the character, whereabouts and properties of landscapes. The essential shortcoming in basic information has been repeated at various occasions (e.g. Wascher, 1999) but did not yet lead to a co-ordinated action towards a European Landscape classification and mapping. A comparable situation can be met in other domains of crucial information of Europe's environments: there still is a lack of scientifically sound information on environmental conditions in Europe, that allows a better understanding of basic conditions for biodiversity (e.g. vegetation), spatial conditions, effects of measures in land use and land management, impact of climate change, interpretation of monitoring or the design of an efficient monitoring system as such.

For both challenges, the advanced environmental classification and a systematic landscape classification, major investments are needed for concept development, data gathering and processing, preliminary and repeatedly improved classifications, for a first draft and discussions among scientists and users to eventually attempt to achieve a broadly accepted product. We are aware of the fact that such attempts meet various hurdles, e.g. financial problems, lack of time, possible lack of acceptance of an international classification that deviates from existing national approaches, etc. Still, there are several good examples of systems that have overcome comparable problems, such as the CORINE landcover classification (CEC, 1994) and the still older example of the European (CEC, 1985) and World Soil Classification (FAO, 1991). Recently a detailed Potential Natural Vegetation map of Pan Europe was published (Bohn et al., 2000) based upon extensive and longterm co-operation among the participants. These examples show at the same time that successes ask for long term investments, effective co-ordination and the willingness of partners to accept an international classification that sometimes cannot be forged into existing national moulds. And last but not least, a group that is prepared to invest and expose his products. At Alterra we realised that a group of experts, the availability of data, experience in comparable endeavours, necessary tools and expertise for data processing were sufficiently available.

Because a Environmental Classification of Europe as well as a European Landscape Classification are a prerequisite for Alterra’s projects or future work as well as for a wider audience and because both activities are scientifically interlinked, the initiative has been taken in the SEO Landscape programme to develop a scientifically sound conceptual framework for both the characterisation and identification of the European environment and the classification and mapping of landscape characteristics. Such a conceptual framework needs to fit user requirements including the possibility to give answers to questions from the policy world. This latter point is a key issue and of particularly importance with regard to future research projects that are externally funded. As the first phase of the SEO project concentrated on the development of a common conceptual framework and the identification of required and existing databases, the second phase concentrated on the implementation and demonstration of the classifications themselves.

Chapter 2 discusses the selection of adequate data layers, the framework conditions as well as the conceptual framework for European environmental and landscape classification and mapping activities. Chapter 3 discusses the newly established Environmental Classification of Europe (EnC) by its background, selected data variables, methodology, and it's applications. Chapter 4 discusses the newly established European Landscape Classification (LANMAP). In Chapter 5 an overall evaluation is given on both activities. In the Annex I all existing data sources are discussed which were identified as important data layers within the conceptual framework.

2 Development of an integrated conceptual framework

2.1 Background and rational

Despite efforts to design a unified European landscape typology (e.g. Meeus et al., 1990; Meeus, 1995; Milanova & Kushlin, 1993) and an ecologically oriented environmental typology, such as DMEER (1997), an approach that is scientifically accepted and application-oriented, objective and retraceable in its classification and aiming at policy development and decision support on a European scale is still lacking. The absence of a conceptual framework for European environmental and landscape classifications is felt by various groups, amongst others by ecologists, historical geographers, landscape planners, as well as those involved in policy makers in relevant fields. Applications as mentioned in the previous chapter are all hampered by the absence of a conceptual framework. There have been extensive discussions on the shortcomings of earlier attempts and the need to deliver a more widely accepted data supported landscape and environmental classification that could serve EU policy development (Bunce et al. 1996a, Jongman & Bunce, 2000, Klijn, 1999, Wascher 1998, Wascher 2000 and Vervloet & Spek, 2002). This chapter describes the starting points, the important issues in a conceptual framework, as well as the selection of important data layers within that framework for both environmental and landscape classifications.

An analysis of the recent processes in research and policy leads to the following conclusions:

- Broadly accepted environmental and landscape classifications maintained in a GIS are both urgently needed for policy makers dealing with the environment, landscapes as well as landscape qualities. Previous approaches such as the Map of Biogeographic Regions (for the implementation of the EU Habitat Directive), the Digitial European Map of Ecological Regions (DMEER, 1997), or the map of European landscapes (Meeus, 1995) offered initially reasonable results, but must nowadays be considered as largely outdated given their methodology, resolution and age of the underlying data. During the last 10 years, data quality and conceptual understanding in the field of the terrestrial environment has advanced substantially. This awareness is undisputed, but the lack of consensus on a clear conceptual framework, lack of easily accessible databases in an operational setting, the lack of co-ordination and the lack of financial support are repeatingly hampering progress. This situation calls for a break-through made possible by conceptual agreement, commitment of various expertise-groups from European countries, desires of end-users and an open and flexible data architecture.
- The ever increasing number of European research projects for which reliable geographic references are needed, have led Alterra to invest in first approximations and organise and incorporate sufficient support from various expert-groups from different countries, to overcome differences in insights, attitudes or differences in practical applications. These differences can be

addressed by constructing an open and flexible data-architecture and a distinct phase in which preliminary products can be criticised and improved accordingly.

- Novel methods and techniques should make it possible to develop an approach that is open, flexible and aiming at building upon regional, national or international expertise. This approach is based on a central concept and systematic data, while still leaving ample opportunities for refining, adapting and adding data for specific or regional goals.

The major challenges for forthcoming scientific research and are listed in box 1.

Box 1. Challenges for forthcoming research based on limitations of earlier attempts can be summarised as follows:

- Explicit end-user orientation (biodiversity; cultural heritage; land-use policy; landscape policy) at an international level.
- Flexibility to be guaranteed by a well structured GIS containing the necessary information layers that can be approached easily to deliver tailor-made products at various scales, as well as easy updates and improvements; flexibility in data interpretation and/or aggregation/generalisation of results.
- A commonly shared conceptual framework.
- Methodological transparency: what data are used, what is qualitative (nominal), what is quantitative information (rank order, ratio). Being applied in a systematic way (so without inconsistencies across borders due to hidden national differences).
- Sufficient support from scientists and policy-makers in order to guarantee that data are really accepted and being used.
- Moving away from a subjective, intuitive and qualitative approach towards a more formal, objective and quantitative standardised system.

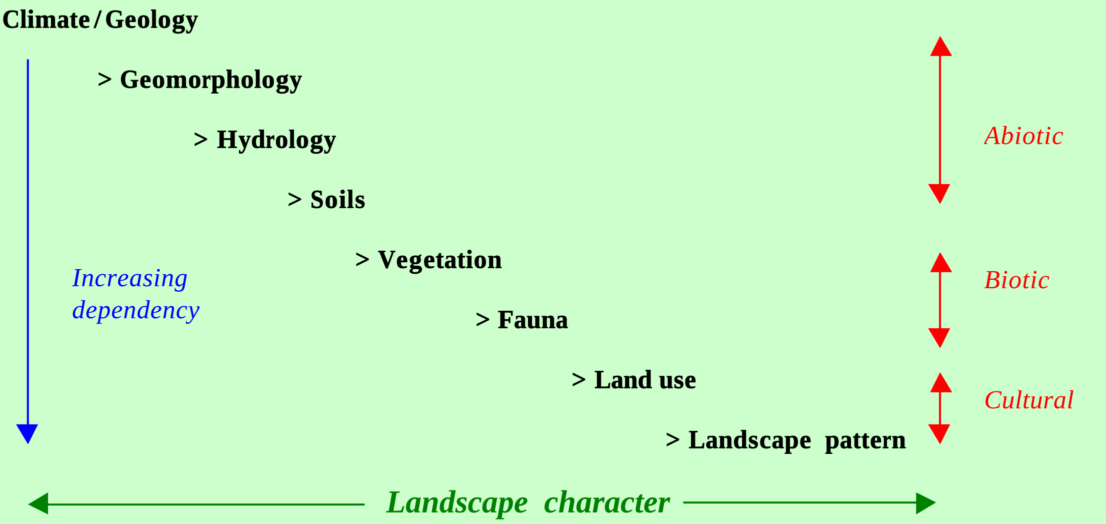
2.2 Methodological references for environmental and landscape classifications

From literature the following key references relevant for environmental and landscape classifications can be extracted:

1. One has *to distinguish the various components*: abiotic, biotic and cultural aspects insofar meaningful and efficient.
2. One should make *clear distinctions* between *primary data* (e.g. rainfall data), *interpreted data* (e.g. land cover data derived from remotely sensed interpretations) and attached *values* (e.g. ecological value, economic value, priority for conservation of natural or cultural aspects).
3. The components or characteristics mentioned under point 1 are often interrelated in history, in actual functioning and in spatial distribution (*correlative complex*). This circumstance enables us to construct units (classes, legend-units) with a specific combination of characteristics frequently met in reality.
4. The *type of relationships* in terms of dependencies between phenomena in a correlative matrix can be envisaged as asymmetric. Some components are relatively stable and independent while other data are dependent. In general, it is accepted that relatively independent abiotic phenomena determine the presence and nature of relatively dependent biotic phenomena. Changes in abiotic

characteristics therefore lead to change in biotic components. It is possible to rank and order the various phenomena in the following way (see the *functional hierarchy* below). This hierarchy shows an increasing dependency at lower levels. An environmental or landscape classification should incorporate these insights by ordering and ranking phenomena in a comparable way (e.g. Klijn, 1995). Human influences have grown in importance and impact during history and one can witness the various serious impacts even on relatively independent natural components. So human influences can be ordered and ranked according to their specific impacts or degree of interference with the ecosystem (e.g. Mücher, 1992; Stomph et al. 1997) affecting components on the various hierarchical levels (e.g. geomorphology, soils and vegetation).

Box 2. Landscape character as a functional hierarchy of abiotic, biotic and cultural phenomena



5. *Ecologically relevant classifications of environmental factors*. Though independent phenomena (e.g. abiotic conditions) determine dependent phenomena (e.g. vegetation), classifications of the former are only relevant when they really match ecologically relevant distinctions; for example climate typologies should be based upon ecologically relevant thresholds or they should be determined by statistical analysis.
6. *Landscape character* is strongly linked to structural appearance and cultural heritage, representing above all a process of visual perception of a certain landscape condition (bio-physical structure). Generally, it is found that structural aspects are only partly determined by physical phenomena e.g. climate, geology, geomorphology, soil conditions. Demography, cultural history, political history act also as independent factors that explain a certain (former) land use type or occupation pattern. A second aspect, namely ‘cultural heritage’ is the social dimension of a landscape, e.g. the social embeddedness of a rural population and the socio-economic interest of stakeholders. Some cultural phenomena, however, reflect physical conditions, for example the distribution of vineyards and related

phenomena in buildings are historically conditioned by climate zones. Though management activities could partly determine the landscape perception (e.g. farmers harvesting crop or cutting willows), the most persistent and dominant aspects is the *result* of the management, namely the image of the landscape, either seen with the eyes of the local observer, or the photos and digital snapshots from aerial photography and remote sensing. In this context, 'Landscape pattern shall be defined as the possibility to recognise one specific landscape type in contrast to another (adjacent) one and to do so by interpreting a set of *structural* components. The attributes that describe structural aspects of landscapes are typology, diversity/coherence, naturalness, man-made objects such as architecture, stone walls, hedges, etc. as well as patterns, lines and points (Wascher, 2003). Landscape pattern is often related to *archaeological, historical and architectural features*. Generally, cultural phenomena are often too complex to categorise in a comprehensive and internationally accepted way. Maybe due to that fact, discussions on how to interpret and classify data did not yet reach sufficient international consensus, compared to abiotic or biotic data.

7. From previous observations it can be concluded that *landscape character is based on a regionally distinctive correlation between various sets of bio-physical and cultural features.* Since cultural aspects such as land use type and land use intensity are not always or only partly directly correlated with landscape character, any From previous observations it can be concluded that landscape character is based on a regionally distinctive correlation between various sets of bio-physical and cultural features. This means that any attempt to design a European-wide classification, legend and map that delineates homogeneous areas with distinct combinations of successively abiotic, biotic and cultural features are often not in agreement with the actual situation.
8. Delineation of homogeneous landscape types that is based on successive combinations of abiotic, biotic and land use features is likely to ignore a variety of other regionally relevant cultural features.
9. *A basic requirement for multi-purpose use is hence flexibility.* Neither the dynamics in policy development, landscape evaluation, landscape changes and scientific progress support the idea of a final and static system. Moreover, technical facilities for data collection, storage and retrieval sustain this idea. It leads to the conclusion that flexible storage in a GIS and the acceptance of various classification procedures and evaluation systems should be key factors in designing information systems. However, it can still be worthwhile to produce one or more maps with a more definitive classification insofar these maps could present the state of the art of e.g. a landscape typology, providing that comparisons with other maps and underlying data can be made. In policy making a map can receive a certain status, when expressing political agreements about the values or status of protection of certain areas. For that reason a more rigid classification can be required.
10. *The role of classification (i.e. determining a number of thematic classes related to the nature or number of phenomena) and the description of each class are crucial to deliver meaningful information. Modern GIS techniques however brought far more flexibility and degrees of freedom.* When compared to older maps with pre-defined legends and classes,

classifications nowadays can be adapted to a certain goal and changed in a later stage by taking advantage of the flexibility of digital databases.

11. The choice for a *scale should be related to both the applications and the availability of data*. Data analysis should be an important module in research plans, whereas the lack of available or easily accessible data forms an important handicap.
12. Information with a high resolution should be easily aggregated and generalised to more general and coarse grained information by upscaling techniques.

2.3 Review of relevant data layers

A short overview is given of relevant data layers within a common conceptual framework for European environmental and landscape classifications. The important thematic data sources are described in terms of major characteristics; motivation to use, data availability and importance compared to data availability based on expert judgement. More detailed descriptions on available data sources that were relevant within this framework are given in Annex I.

2.3.1 Climate

Motivation. Essential for ecology, because distribution of ecosystems and species is determined by climate conditions. Climate determines together with parent material the soil characteristics, type and hydrology – and therefore the ecological boundary conditions for flora and fauna. Furthermore climate (averages and extremes) exert direct influences on biota by physiological and phenological responses. Climate also sets conditions for land use by frost periods, water availability, growing season, temperature distribution and rare events. On a European scale climate zones and climate gradients as determined by altitude are observable in many dependent factors, notably vegetation zones. Climate factors act as independent variables, but climate conditions are far from stable as is shown by palaeo-climatic data and by climate scenarios for the coming century.

Data availability. Climate data are generally accepted as crucial for many applications; existing data are available as point data on many variables; various classifications designed from an ecological point of view are available. These climate databases are subject to improvements using independent data of weather stations, a thorough interpretation from an ecological viewpoint, smart application of data on topography that allow more geographical detail and a geostatistical procedure that allows a well founded new classification. Moreover, shifts in climate and so in environmental regions should be addressed properly in scenario studies.

Conclusion. Essential, available, operational although minor adjustments and further choices have to be made.

2.3.2 Geology

Motivation. Geology (e.g. rock-type, sediments such as sand, clay or peat) is of considerable importance for soil formation, hydrology and therefore natural vegetation, fauna and potential land use (e.g. agriculture, extraction of water or minerals, building, or forestry). Its role can be explained by both physical conditions (hard rock, soft sediments determining for instance water availability and water fluxes) and chemical conditions (poor or rich in minerals). Within Europe as well as within many individual countries a wide variety of geological conditions can be observed.

Data availability. For ecological and land use studies data should be available on nature, thickness, area distribution of parent material – rather than on their age and genesis. In reality, however, geological maps often lack this type of information altogether or can hardly be interpreted in these terms, while they show large differences in classification approaches from country to country. Many maps and classification are mainly expressed in genetic and/or chronological units (for example Aeolian deposits from the early Pleistocene). Its relevance is therefore very limited, whereas attempts to translate original data in interpreted data with more relevance proved to be difficult. As geological mapping is time consuming and expensive any improvement on a short timescale can hardly be expected.

Conclusion. Useful as background information from which descriptive information can be derived. However, not available in an adequate and operational format; not necessary to include except when independent information on specific, rare geological sites should be necessary. In addition it can be postulated that soil data, especially parent material, reflect geological conditions to a certain, often high, degree and can therefore be seen as “stand-in” information.

2.3.3 Geomorphology and topography

Motivation. In all literature dealing with both ecological and cultural heritage, geomorphology issues and scenery, topography is a central subject. Topography (primarily altitude, exposition, slope) or relief largely determines soil conditions, erosion and sedimentation), meso – and macroclimate, suitability for agriculture or settlement, surface water discharge, flows of groundwater as well as all other dependent biotic features (such as vegetation zones following altitude and soil type). Many geomorphologic features, e.g. such as landform, age, origin, and surface geology, are directly connected to topography .

Data availability. Topographic data (principally altitude, slopes and exposition data) are readily available in digital format at various spatial scales. Information on geomorphology, that additionally describes and explains the origin and age of landforms systematically is more scattered (Embleton, 1984) and rather subjective or specific for a region or country due to national classifications (Ten Cate en Maarleveld, 1977).

Conclusion. Essential data, but only topographic data are readily available and operational.

2.3.4 Hydrology

Motivation. Surface waters such as lakes, rivers, canals and reservoirs form important ecological features (aquatic biotopes), routes for dispersal and migration of organisms. Rivers determine ecologically relevant phenomena such as floods, erosion, sedimentation, groundwater flows, soils and vegetation patterns. Rivers are also important as water sources and transport ways for men and goods and are therefore relevant to explain human settlement and activities. Groundwater bodies are important in the fact that they partly determine soil conditions e.g. soil saturation, redox-status, chemical status, water flows and are therefore ecologically significant. Equally important is their significance for man, as these characteristics superimpose conditions for land use, water extraction and other activities. Most important are data on groundwater depth and dynamics near the surface.

Data availability: Generally geographical data on surface waters are readily available, mostly in digital form. Additional data on discharge, currents, water quality, and other factors are less generally available. Geographic information on groundwater bodies (depth, dynamics of water tables or flow direction, water type or quality) for large parts of Europe are hard to find or not available. To some extent soil maps provide some indication on groundwater regimes and can be used as proxies. Still, some of this information is either indirect or sub-fossil as it can be subject to major changes when groundwater conditions have been altered. So, the reliability of soil maps is limited.

Conclusions. Information on both surface water as well as ground water characteristics is very relevant. Data availability on surface waters is quite well organised and operational. Groundwater data are equally relevant but far less readily available or standardised. Sometimes soil maps provide information that can be inaccurate.

2.3.5 Soils

Motivation. Soil conditions form a crucial combination of physical and chemical conditions for natural vegetation and soil fauna. At the same time soil information is essential to assess the suitability for agricultural practices (arable land, grassland) and to assess production levels. As such, soil conditions (together with climate, topography and hydrology) can both help to determine potential agricultural use (in terms of suitability and limitations) and explains often former land use in recent or more distant history. Together with geological and geomorphological values pedological (= soil related) values can be considered as important. The contents of soil maps and their legends offer sufficient insight in surface geology, so that soil maps could serve also as proxies for surface geology which cannot be derived directly from most geological maps.

Data availability: Soil maps of Europe are available based upon internationally accepted classifications. Interpretations for agriculture and environmental issues (acidification, leaching of nutrients or contaminants) are available. Ecological interpretations are however more recent and incomplete or need further co-ordinated efforts.

Conclusion. Essential information, available and largely operational.

2.3.6 Natural vegetation

Motivation. Data on actual or potential vegetation are ecologically important. Vegetation characteristics offer first hand information on potential biodiversity as well as on biotope type and quality. The distinction between actual vegetation (really present at this moment reflecting the full range of natural, semi-natural and man-dominated conditions) and potential natural vegetation (to be expected on basis of abiotic conditions) is relevant. Potential natural vegetation and information on actual land cover (showing classes such as arable land, heather and forests) give an indication of which species (plants and animals) might be expected. However, this interpretation of habitat suitability of vegetation units or mosaics depends on expert judgement and often suffers from a lack of knowledge. For historians the combination of actual and potential vegetation data could both help to explain certain settlement patterns and historical land-use. Present day vegetation indicates certain land use (e.g. heath communities reflecting grazing regimes); potential vegetation could help to reconstruct prehistoric conditions that resembled a more pristine situation.

Data availability: Generally data on potential natural vegetation are readily available; these data are derived from data on actual vegetation remnants as well as the interpreted data on climate, soil- and water conditions and biogeographic zones and indicate the spectrum of species that could be expected. Data on actual vegetation are far less available in a standardised manner or are combined with land use/land cover data.

Conclusions. Both actual and potential vegetation data are crucial; systematic, full cover data of potential vegetation on European scale are available in digital format. Maps on actual vegetation are still not available in a standardised way, but a few countries have these data available.

2.3.7 Fauna

Motivation. Fauna represents a relatively dependent component in landscapes, as species composition, population size and densities are dependent on biogeographical regions, vegetation composition and structure, soil and water conditions, isolation or connectivity between habitats and human influences including land use or land management or environmental stress. Fauna data can be crucial for biodiversity assessments and policies, and sometimes for reasons of ecotourism.

Data availability. Though considerable progress has been made in inventories of important groups of animals (mammals, reptiles/amphibians, birds, fishes, butterflies) a systematic and European wide coverage of these groups in sufficient detail is still lacking or very difficult to obtain. Available information, gathered by various censuses, is mostly presented on a grid.

Conclusions. It can be concluded that the state of the art does not yet sustain a systematic inclusion of these data in a landscape typology. Existing data on land cover, vegetation type and biogeographical region enable a hypothetical faunal content of areas based upon acceptable assumptions on biotope suitability for certain species or species groups.

2.3.8 Land use

Motivation. Almost all relevant literature considers land use and land cover as essential. Land cover can be seen as the spatially and time specific expression of land use or natural vegetation. Land cover includes a full range typology of natural features (e.g. forest, marsh, rock, snow and ice), semi-natural or fully agricultural situations (extensive to intensive grassland, orchards or arable land,) and artificial land (built-up area, associated infrastructure). Most classifications have much in common and can be further detailed depending on the goals of the studies. Still legend categories are often difficult to compare and to combine.

Data availability: Generally data are available in full cover and of a recent date when satellite images are used. Their spectral and spatial resolution generally is adequate. Satellite data however have to be classified according to the specific goals and need sufficient checks with ground truth. Some land cover types are hard to distinguish from satellite pictures alone and need supplementary knowledge from other sources such as topographic maps or cadastral information as has been done within the CORINE land cover project (CEC, 1994). Satellite data are acquired on a regular basis and are therefore a potentially good tool for monitoring.

Conclusions. Land cover data are essential, widely applicable and relatively easily obtainable and can be considered as core data.

2.3.9 Landscape patterns

Motivation. Landscape patterns reflect bio-physical conditions as well as spatial and temporal aspects of human land use (e.g. use of management technique, field size, boundary types, seasonality of crops, cultural and archaeological components). The most persistent and dominant aspects is the *result* of the combination, namely the image of the landscape, either seen with the eyes of the local observer, or with photos or width digital snapshots from aerial photography and remote sensing. In this context, 'Landscape pattern' shall be defined as a structural characteristics related to land use, land use history and bio-physical components. European landscapes, which are dominantly cultural landscapes except for some regions (such as the tundra in the (sub-) arctic region, glaciers in the alpine regions or some wetlands) contain a historical wealth from various eras. Insight in actual or potential biodiversity is also strongly related to former land use.

Data availability: At the European level, the availability of harmonised data on landscape patterns related so field structures, linear and punctual landscape elements, archaeology, architecture and history is extremely limited (Vervloet & Spek, 2002). Currently several groups and research centres are active to overcome these problems, however it cannot be expected that the process of filling gaps in knowledge, accomplishing an internationally accepted typology and full cover surveys will deliver data within a few years. In between it is inevitable to use fragmented and seriously incomplete data.

Conclusions. For policy and scientific reasons these data are important, but seriously incomplete. Substantial improvements can only be partially expected, e.g. through automatic interpretations of aerial photography, while data on historical and archaeological features cannot be expected within a few years.

2.3.10 Overall remarks

A basic problem for nearly all data types is related to the consistency of data and confusion in terms of definition which is a major handicap when databases are combined. In this chapter a short overview has been given of what we consider essential data layers within a conceptual framework for a European environmental and landscape classification. In the Annex I those relevant data sets available in digital and spatially explicit format are being further explored and discussed.

2.4 European environmental and landscape classification

The goal, namely to develop a methodological framework that links an environmental classification with landscape character assessment at the European level, is supposed to build upon the identified main data sets, the types of dependencies between natural and where possible cultural phenomena, and the established principles for environmental and landscape classification. Since the final products are meant to be of practical use for decision makers, planners and analysts at the European as well as at the national and regional level, the potential criteria for designing such an operational framework add up to a challenging complexity (see Klijn 1995). The work undertaken in this project was designed to (1) overcome the inherent complexity; and (2) to identify key data layers for the development of two main products:

1. The Environmental Classification of Europe.
2. The European Landscape Classification.

A third product, namely landscape quality assessment, has not been part of this project, but the principles of landscape character assessment will in be described in Chapter 4 and are of major importance to consider in future activities. For the first two products, it is necessary to assign concrete methodological objectives (see also section 2.2).

Products

For all activities that are being undertaken, the main premises is that it should build as much as possible on already existing work and avoid duplication of effort.

Product 1.: Environmental Classification of Europe

This product is based on the research activities for establishing an 'Environmental Classification" (Jongman & Bunce, 2002). The methodological priorities are as follows:

- The objective is to produce an improved environmental classification that builds upon climate and topography data;
- The resolution and accuracy should be *truly* improved with regard to already existing classifications. Desired is the use of higher resolution primary data rather than technical 'downscaling' of coarse information in order to reach higher resolution;
- Since the first layer is supposed to provide the basis for integrating more specific natural and cultural information, the number of classes should be limited to an operational maximum (e.g. between 32 – 64);
- The goal must be that each identified class represents a unique environmental profile with clearly identified differences for the nature landscapes and land use. If there is no possibility to validate the spatially identified differences in environmental profile (only "theoretical differences"), the methodological approach should be critically reviewed.

Product 2: European Landscape Classification

While the previous product is entirely based on 'neutral' data of biophysical parameters, the second product will introduce the cultural component, however still in an objectively measurable way.

The proposed data layers are as follows:

- Topographic data must be considered as being of key relevance for expressing Landscape Character as differences in elevation have strong influence on land use and landscape scenery. Considerable amount of preparatory work has been spend on selecting the adequate stratification of elevation levels to meet European aspects;
- Parent material as a subset of the European Soil Database is considered to be used as a substitute for originally required geo-morphological map of Europe which does not exist in an appropriate digital and completed version. The choice for 'parent material' allowed to compensate this data gap.
- Land use provided by the CORINE land cover database is the only harmonised geographic database that allows to interpret human land use aspects at the European level. Because the total number of 44 classes deemed to be as too complex to arrive at useful stratifications, a selection of a landscape-relevant subset was necessary.

In the following chapter the first product – the Environmental Classification of Europe – is presented profoundly. In Chapter 4 the second product – the European Landscape Classification – is presented in detail. Chapter 5 contains a discussion about both products and discusses future outlooks.

3 The Environmental Classification of Europe

3.1 Introduction

The more environmental information that is available for a continent such as Europe, the greater the potential for subdivisions, and the more complex the continent may appear. Conversely some large areas of different continents are demonstrably uniform because of consistent geography and climate, e.g. the central European plains and the Prairies in the United States. Regional information can help to understand the driving forces of change but can also produce so much detail that it becomes impossible to identify the effects of these causal factors. It is necessary to develop standardised methods of structuring such complex environmental data and to synthesise this data into classes in order to develop a hierarchical framework for the European environment, which will permit aggregation from field observations to the European context.

When analysing environmental processes, statistical classification is the first step because areas and situations must be comparable in a reproducible way. On a continental scale of spatial research, e.g. biodiversity monitoring, data comparisons, and scenario building for the European Union (EU), a stratification of land into more or less homogeneous regions would provide a valuable framework since statistical inference requires data to be representative of a defined population. Within each stratum or class, changes or effects can then be analysed taking the environmental heterogeneity of Europe into account employing the classical statistical procedure of partitioning the sums of squares between classes. For example, when comparing the influence of different land-use changes on species abundance within an environmental class, one can be sure that differences in species abundance are indeed the result of those changes and not the product of inherently different environments. Furthermore, an environmental classification would provide a basis for stratified random sampling and would enable samples to be placed consistently within the context of the entire continent. It is, however, essential that the environmental classification has a sufficiently fine resolution and that it is unbiased and derived statistically so that the classes are unambiguously determined by the given variables. The classification would then be reproducible and independent of personal bias. This is of particular importance where large-scale continuous gradients are involved over thousands of kilometres, e.g. from Spain to Finland. No obvious boundaries are present in such cases, and statistical rules are needed to make robust divisions.

As discussed in chapter 2, most existing classifications are qualitative, with classes having ambiguous definitions. They depend on the experience and judgement of the originators and rely upon the intuition of the observer in interpreting observed patterns on the basis of personal experience. Quantitative classifications have been applied in some national studies, most notably in Countryside Survey (Firbank *et al.*, 2003; Haines-Young *et al.*, 2000) in the United Kingdom. An earlier continental classification did lack the detail necessary for ecological monitoring as it was at a 0.5°x0.5° resolution (Bunce *et al.*, 1996d). In this chapter we present a new Environmental Classification of Europe (EnC) in eighty-four classes with a 1km^2 resolution. The classification is based on statistical clustering, so that personal biases are minimised and that the environmental classes can be seen in the context of Europe as a whole. By demonstrating this new classification approach, and by making the EnC public, we are providing a new tool for European ecologists to use, e.g. for site selection for representative studies across the continent or to provide strata for modelling exercises and reporting.

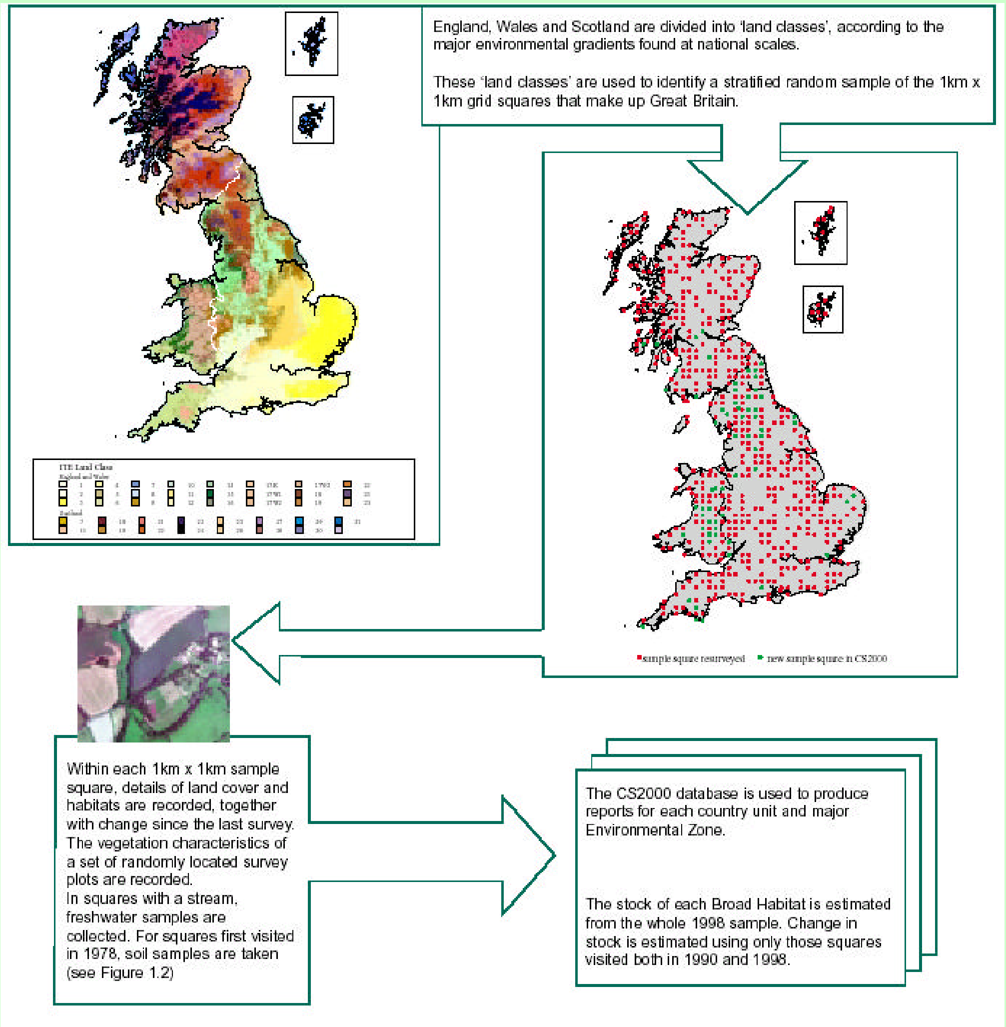
In the next section five examples of applications of environmental classifications are given in the next section: two national examples from the United Kingdom and three from Europe. Subsequently, in section 3.3, the creation of the EnC is discussed followed by a discussion (section 3.4), a list of envisaged applications of the EnC (section 3.5), and conclusion (section 3.6).

3.2 Examples of applications

Box 3. Example 1: A tool for strategic stratified random sampling

From: Haines-Young, R.H., Barr, C.J., Black, H.I.J. *et al.* (2000) Accounting for nature: assessing habitats in the UK countryside Department of the Environment, Transport and the Regions, London.

The Countryside Survey 2000 is a major audit of the British countryside. It has involved both detailed field observations and satellite imagery, which has provided a complete land cover census for Great Britain. The 32 ITE Land Classes were used to identify a stratified random sample, as shown in Figure 1. The Land Classes were subsequently aggregated to 6 Environmental Zones.



England, Wales and Scotland are divided into 'land classes', according to the major environmental gradients found at national scales.

These 'land classes' are used to identify a stratified random sample of the 1km x 1km grid squares that make up Great Britain.

Within each 1km x 1km sample square, details of land cover and habitats are recorded, together with change since the last survey. The vegetation characteristics of a set of randomly located survey plots are recorded. In squares with a stream, freshwater samples are collected. For squares first visited in 1978, soil samples are taken (see Figure 1.2)

The CS2000 database is used to produce reports for each country unit and major Environmental Zone.

The stock of each Broad Habitat is estimated from the whole 1998 sample. Change in stock is estimated using only those squares visited both in 1990 and 1998.

Figure 1. Downloaded from http://www.cs2000.org.uk/. The sampling approach used by the CS2000 field survey is summarized on its website and in Firbank et al. (2003)

Box 4. Example 2: A tool for analysing and integrating consequences of global change

From : 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.

MIRABEL (Models for Integrated Review and Assessment of Biodiversity in European Landscapes) is a conceptual framework, designed to facilitate analysis of the consequences of environmental change for biodiversity. 10 environmental pressures on 51 important European habitats are described.

The wide variety of European environments is too diverse to be considered without some subdivision. A stratification was developed, in order to group biodiversity impacts separately within areas of similar ecological characteristics. Furthermore, this stratification provides a geographical framework within which the predicted impacts can be analysed and mapped. The stratification, in 13 Ecological Regions, was based on the Digital Map of European Ecological Regions (DMEER), which in turn is based on the European classification and the potential natural vegetation map of Europe (Bohn & Gollub, 2000), both described in Annex I.

Box 5. Example 3: A tool to compare and analyse data sets

Within the UK Countryside Survey much effort has been put into analysing available ecological data. The Land Classification proved a valuable tool in comparing and analysing these data.

An example from: Bunce, R.G.H., Howard, D.C., Hallam, C.J., Barr, C.J., & Benefield, C.B. (1993). Ecological Consequences of Land Use Change. Institute of Terrestrial Ecology.

Two moth species, the Flounced Rustic and the Antler Moth are common species in the UK. A distribution map shows their presence throughout the UK. Plotting the geometric mean annual catch of 313 sites recorded by the Rothemsted Insects Survey against the first-axis DECORANA (Hill, 1979a) scores of the environmental Land Classes shows a principle environmental gradient from lowland to upland. The Flounced Rustic is especially abundant in lowland grasslands, where as the Antler Moth is usually found in more upland situations. This analysis demonstrates the application of the classification to identify the coincidence between environmental gradients and existing ecological data.

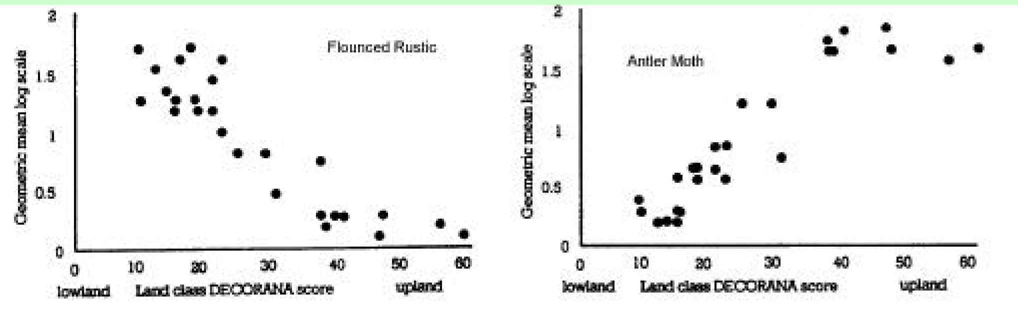


Figure 1. (Bunce et al., 1993)

Similar relations have been found for other species groups and used to predict species abundance based on distribution maps, i.e. foxes (MacDonald *et al.*, 1981) and wildcats (Easterbee *et al.*, 1991).

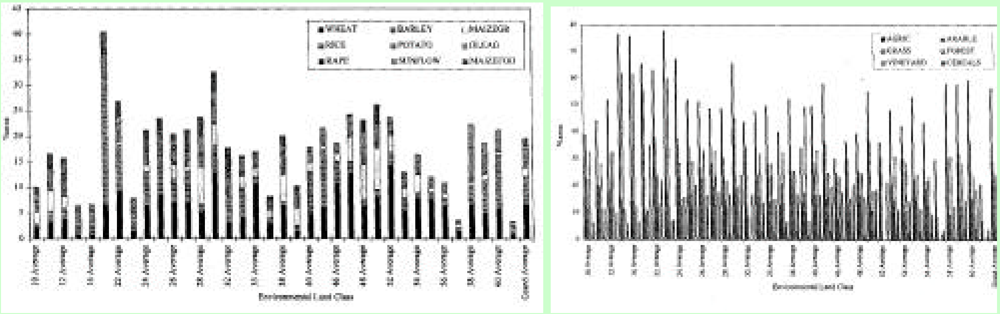
Box 6. Example 4: Overlaying classifications with other data sets

From: Bunce, R.G.H., J.W. Watkins, and M.K. Gillespie, *A stratification system for gathering agricultural and environmental data from different sources in the EU.*, in: *CAP and the regions: Building a multidisciplinary framework for the analysis of the EU agricultural space.*, C. Laurent and I. Bowler, Editors. 1997, INRA: Paris. p. 187-195.

Integration between data sets can yield important benefits, e.g. potential changes in the support systems of the Common Agricultural Policy (CAP) could be linked to their environmental consequences. Such a procedure was formalized within a project in Great Britain as described in the above reference. The scientific principle underlying the procedure is that agricultural patterns are correlated with the overall environment and can, therefore, be estimated if relationships are formalized. Data were coordinated with the classification from the EU for agricultural statistics from the NUTS 3 regions, potential natural vegetation, soils and limited species data from the Flora Europea.

Results
The environmental classes (section 3.3.3) are strongly correlated with different types of semi-natural vegetation, soil types and crop patterns. For example class 16, found in Scotland and southwest Norway, is dominated by oceanic heath lands, birch and pine forest, with peat soils and mainly open range grassland with sheep grazing. By contrast class 24, found in southwest England, Belgium, northeast France and northwest Spain, has heath land, forest and an even balance between crops and grass. The socio-economic characteristics of the farms are also linked to the classes; thus in class 16 the farms are large and mainly concerned with sheep production, whereas in 24 they are mainly small with a mixture of crops and grass, supporting especially dairy farming. The frequency of different crops within the classes was determined and the predictive power of the classification was shown to be superior to that by applying regression techniques to the raw climatic variables. The classes may therefore be described in terms of the mixtures of crops that are present and may then be linked to the socio-economic characteristics of the areas concerned.

In order to demonstrate the link with agricultural data, the results from the agricultural characteristics and crops from NUTS 3 were summarised by the classes shown in Figures 1 and 2. The oceanic classes (15, 16, 23) are dominated by grasslands, the sub-continental classes (19, 22, 24, 25, 29) are the core of high quality arable land, occupying central and Western Europe, the Alpine classes (10-12, 26, 27, 34, 36-41) are variable and depend largely upon altitude. The remaining classes are Mediterranean with vineyards, forests and mixed agriculture. The crop distribution parallels these with maize and wheat being for example in the continental classes.



Figures 1 & 2. Relative proportion of crops (3) and agricultural characteristics (4) per Land Class, derived by overlaying land classes with the NUTS regions

Box 7. Example 5: Creating Landscape Zones

From: Jongman, R.H.G. & Bunce, R.G.H. (2000). Landscape classification, scales and biodiversity in Europe. In Consequences of Land Use Changes (eds Ü. Mander & R.H.G. Jongman), pp. 11-38. WIT Press, Southampton.

The ITE European classification system (shown in section 7.4.2) has also been applied to identify landscape zones in Europe. Climate data representing dominant trends in variation in its variables were processed using the 64 classes for 5209 0.5°x0.5° cells of the European window, 45 classes for the EU, Norway and Switzerland were combined to identify broad landscape zones based on a statistical aggregation into clusters, described by Petit *et al.* (2001). These zones form a framework in which landscapes can be defined. Using vegetation data the 64 classes were statistically clustered into four climate-groups (level 1) and 12 landscape zones (level 2), see figure 6. The landscape zones can be further divided into mountains and lowlands (level 3).

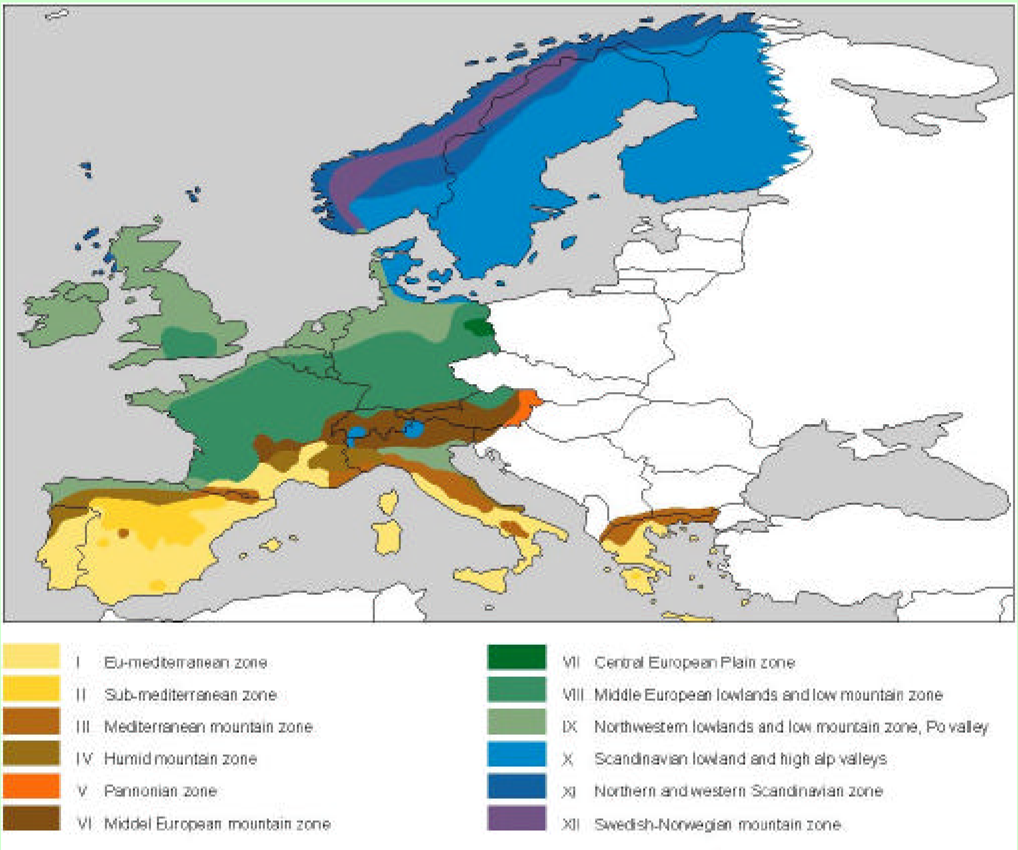


Figure 1. The twelve landscape zones of the European landscape zonation (Jongman & Bunce, 2000).

3.3 Creating the Environmental Classification of Europe

The creation of the Environmental Classification of Europe (EnC) has entailed three major stages (Fig 3.1). (1) The selection of the relevant environmental variables. (2) The extraction of principal components and subsequent statistical classification. (3) Post-processing to minimise isolated groups of squares. All calculations were carried out using ArcGIS 8.2 (ESRI, 2002). Finally the EnC was validated by analysing the correlation between the classes and available European ecological data sets.

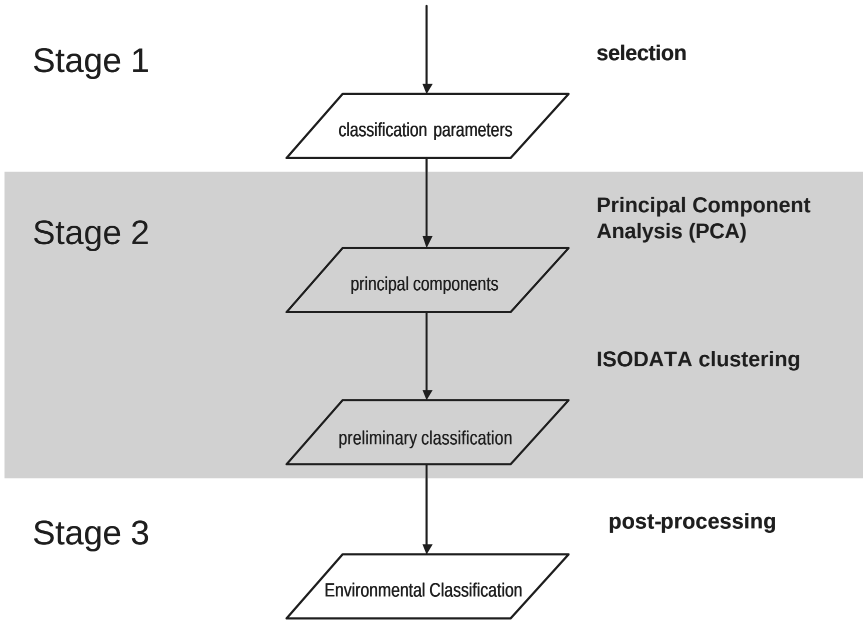


Figure 3.1 Flowchart of the three major stages in the creation of the Environmental Classification

3.3.1 Selecting relevant variables

It is generally recognised that ecosystem components determine spatial environmental patterns through a scale-dependant hierarchy. On a global or continental scale, climate and geology determine the main patterns. They are conditional for the formations of soils, which in turn determine the local potential vegetation. There are feedbacks in the other direction, for example vegetation also influences soil properties and can even influence local climate. Most ecosystem patterns are, however, caused by the above-mentioned hierarchy (Bailey, 1985; Klijn & de Haes, 1994). On a European scale, climate and geomorphology are recognised as the key determinants of ecological patterns; these are followed by geology and soil. Bunce *et al.* (1996a) have shown that this applies even on a national scale for large countries such as Great Britain.

Climate

The most comprehensive high-resolution climate dataset available for Europe is the CRU TS1.2 (T.D. Mitchell, in prep.), developed by the Climate Research Unit at the University of East Anglia. It has a 10'x10' resolution (approximately 16x16 km) and contains monthly values for five variables during the period 1900-2000. The dataset is closely related to CRU CL2.0, which contains global climatologies for 1969-1990 (New *et al.*, 2002). The variables are mean monthly values for temperature, precipitation, percentage sunshine, vapour pressure, and daily temperature range. From the daily temperature range and the mean temperature, the average minimum and average maximum temperature could be calculated. From the total dataset, 1971-2000 climatologies were calculated as thirty-year averages. The 10'x10' climate data was subsequently resampled to a 1km^2 grid using bilinear interpolation. The effects of altitude on the environment are mainly climatic and hence altitude was used as the basis for downscaling. Furthermore, Principal Component Analysis (PCA), used in the classification procedure described below, is designed to analyse auto-correlated data and removes any duplication (Bishop *et al.*, 1975).

To reduce the computational load it was necessary to select a subset of the total available data (7 variables x 12 months). For this purpose, a thorough statistical analysis in four stages was carried out in the earlier ITE classification (Bunce *et al.*, 1996d):

1. Separate PCAs for each of the major climate variables were calculated based on monthly data and other extant data.
2. Principal components with a high eigenvalue were selected from each of the analyses and used in a ranked correlation analysis to select the variables that correlate most for each climate variable.
3. The selected variables were pooled together and a PCA was performed on this dataset.
4. Principal components with the highest eigenvalues were selected and the climate variables that correlate most with these components were selected for classification.

This approach led to the selection of fifteen environmental variables (Table 3.1). In the present project a comparable set of variables was selected from the total available data. In order to reflect the overall seasonal climate variation, data were selected for four months in the year, January, April, July and October. This was done for the four variables that were closest to those used in the ITE classification, namely mean monthly minimum and maximum temperature, precipitation, and percentage sunshine. Table 3.1 lists the variables of the original ITE classification and the EnC.

Geomorphology

Geomorphology encompasses the formation and shapes of landforms, e.g. alluvial flats and alpine valleys. No consistent European geomorphological map exists. Alternatively, detailed digital elevation models (DEMs) are available, which convey a high proportion of the information required, i.e. altitude and slope. The best dataset available is the United States Geological Survey (USGS) HYDRO1k global digital elevation model, with a resolution of 1km^2. It is based on the USGS GTOPO30 dataset, which has a 30'' resolution. For the HYDRO1k, the GTOPO30 was projected onto an equal area Lambert Azimuthal projection from which slope, aspect, and flow properties were calculated. These data are distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at the U.S. Geological Survey's EROS Data Center (http://lpdaac.usgs.gov). Altitude and slope were included in the classification as surrogates for geomorphology.

Oceanicity and northing

In the ITE classification northing, in the form of latitude, as well as oceanicity were included. By including northing in the classification, differences in day length are incorporated as well as a degree of locational information. Oceanicity expresses the buffering influence of the ocean, resulting in cooler summers, milder winters, and a lower degree of interseasonal variability. In the ITE classification oceanicity was defined by climatic criteria as the mean annual temperature range adjusted for latitude. In the EnC, oceanicity was defined as the July - January temperature range divided by the sine of the latitude.

Geology and soil

As mentioned in chapter 2, it is generally considered that in the hierarchy of determinants for European ecological patterns, climate and geomorphology are followed by geology and soil. An investigation was conducted to assess whether it would be possible to include some geological or soil variables into the classification. Known ecological patterns in soils and geology (e.g. fluvial deposits and peat formations) are not present in a classification based on bioclimatic variables alone, although there will be strong associations, as shown below. For example, all permafrost soils are all in arctic and alpine climates. Unfortunately, the Geological Map of Europe is currently still under development by the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR). However, soil maps give insight into parent material. There are two digital soil maps that could be useful: the FAO soil map of the world (FAO, 1991) and the European Soil Bureau (ESB) soil map (Bullock *et al.*, 1999). The latter is an aggregated map of national soil maps. Both data sets contain a wealth of information but also have their limitations. The main problem arises from the classification method that is used for soil mapping: it is based on different expert knowledge of soil scientists, without specified critical thresholds and harmonised approaches. In particular the higher aggregation levels do not show an equal distribution of soil properties. Whilst these groups provide an excellent descriptive base, they are of limited value in statistical analysis. A second problem arises because soil maps contain nominal data, which are not easily incorporated in to the statistical clustering that is based on continuous data.

One possible way of incorporating soil data would be by deriving continuous values for several soil variables such as soil pH and water holding capacity, by pedo-transfer functions. Attempts to incorporate soil data in this way did not provide valid results; only a fragmented map showing little internal consistency of the groups, with little relation to climatic zones. For example, the same class occurred in both southern Spain and Scandinavia. The difficulties in clustering combinations of climate and soil variables probably arise from the fact that soil variables function at a lower hierarchical scale, thus showing far more regional differentiation than the climate variables. However, while the full incorporation of the soil data was inappropriate, the inherent correlation between soil and environment was indeed present. This could be shown by orthogonal regression, as described by Bunce *et al.* (1996a). The correlation between the first principal component of five soil variables, derived by pedo-transfer functions from the FAO soil map by IGBP-DIS Global Soil Data (Task, 2000) and the first principal component of the climate variables was significant ($R^2 = 0.62$, Pearson's correlation coefficient 0.78, significant at 0.01 level). Subsequent analyses with FAO and ESB soil types also showed significant correlations with the EnC (see section 3.4). This analysis showed that although it was impractical to include soil variables into the classification, sufficient information on soil is included through correlations. If a more detailed stratification is desired for regional purposes, geological or soil data can be incorporated using existing procedures.

The variables selected

The variables selected are comparable to those used in the original ITE classification (Table 3.1), although the original statistical selection procedure for the climate variables was not followed. As Bunce *et al.* (2002) have shown, the core patterns are stable regardless of the details pertaining to the variables and algorithms used.

Table 3-1 Comparison of selected parameters in the EnC and the ITE classification

EnC	ITE European Land classification
Altitude	Maximum altitude
	Mean altitude
	Minimum altitude
Slope	
Northing (latitude)	Northing (latitude)
Oceanicity	Oceanicity
Minimum temperature January	
Minimum temperature April	
Minimum temperature July	Frost days in July
Minimum temperature October	Frost days in November
Maximum temperature January	
Maximum temperature April	
Maximum temperature July	Maximum temperature in September
Maximum temperature October	Maximum temperature in October
Precipitation January	Rain days in December
Precipitation April	
Precipitation July	Precipitation in June
Precipitation October	Precipitation in October
	Precipitation in November
	Rain days in November
Sunshine January	
Sunshine April	Sun hours in May
Sunshine July	Sun hours in June
Sunshine October	
	Wind speed in April

3.3.2 Running the classification

Principal Component Analysis (PCA) allows redundant data to be compacted into fewer layers that are non-correlated and independent and are often more interpretable than the source data (Faust, 1989; Jensen, 1996). The ERDAS IMAGINE field guide (ERDAS, 1997), accessible on the internet (http://support.erdas.com/), gives a clear description of the process. In order to give all input layers of the selected classification variables equal weighting in the PCA, the variables were standardised to a 0 – 10.000 range. The PCA was run in ArcGIS using the PRINCOMP command. The first three principal components, shown in Fig. 3.2, explain 88% of the variation in the input variables

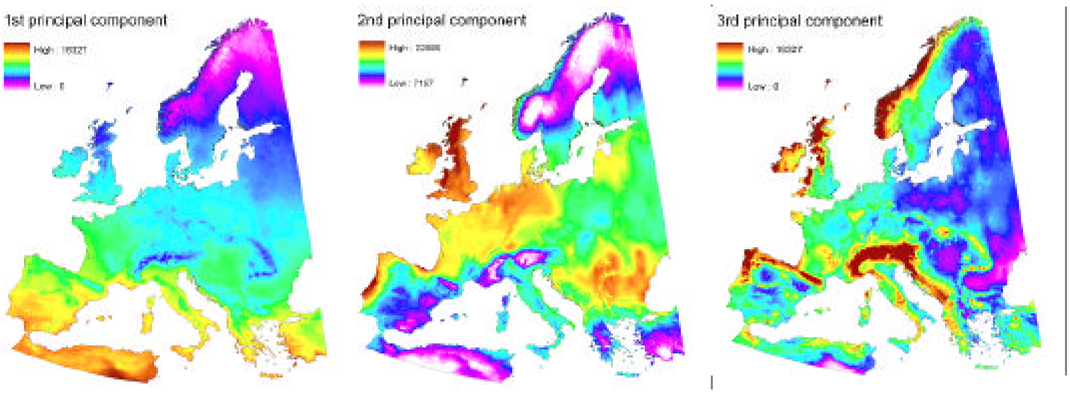


Figure 3.2 Maps of the first three principal components, together explaining 88% of the total variation in the variables

The Iterative Self-Organising Data Analysis Technique (ISODATA) (Tou & Conzalez, 1974) was used to cluster the principal components into environmental classes. This technique is widely used in image analysis fields, such as remote sensing and medical sciences, e.g. (Banchmann *et al.*, 2002; Pan *et al.*, 2003). ISODATA is iterative in that it repeatedly performs an entire classification and recalculates statistics. Self-organising refers to the way in which it locates clusters with minimum user input. In image analysis, the ISODATA method uses minimum spectral distance to assign a cluster (class) for each candidate grid cell. Instead, in creating the EnC, the principal components of the environmental variables were clustered, using ArcGIS commands ISOCLUSTER and MLCLASSIFY. The progress begins with a specified number of arbitrary cluster means and then the process is run repetitively so that those means shift to the mean values for the clusters in the data. The ITE classification distinguished sixty-four classes using an arbitrary stopping rule. In the new classification, a comparable rule led to seventy classes, a number which will make characterisation of the classes feasible. An example of a statistical characterisation of an EnC class is given in Fig. 3.9.

The original ITE classification showed that the Mediterranean region is considerably more heterogeneous than northern Europe. As a result running the classification as described above resulted in a relatively large number of small classes in the Mediterranean and several large classes in northern Europe. This means many classes

(>120) would be needed to divide northern Europe. This problem was solved by using a step-wise procedure to divide Europe in two zones, based on a PCA of the climate variables and clustering into two classes. The northern class covers 70% of Europe and the southern (Mediterranean) class covers 30%, as shown in Fig. 3.3. The division is comparable to that of the original ITE classification, with only minor differences in the northern boundaries, and it also corresponds with the definition posited by Kendrew (1953). In the next stage of the analysis, the principal components of the full set of variables were used to classify northern and southern Europe separately. Northern Europe was clustered into forty classes and southern Europe into thirty classes. In this way the greater heterogeneity in the Mediterranean region is emphasised, since, compared to the northern class, it has 30/70 of the number of classes, but only covers 30/100 of the extent.

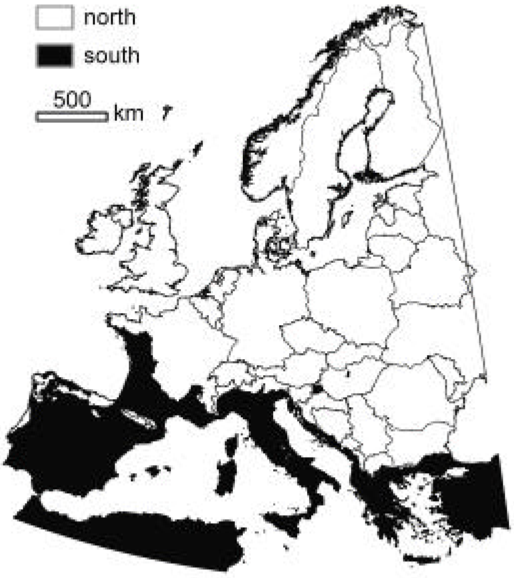


Figure 3.3 A north-south division was created by classifying the principal components of only the climate variables in two classes

3.3.3 Post-processing

Removing noise

In the original map of the environmental classes, there was a dispersed scatter of small regions of only a few square kilometres. Such fragmentation is not useful on a European scale. Therefore, all regions smaller than 250km^2 were identified, in total 1.2 ‰ of the mapped area, and assigned to the classes of the neighbouring grid cells using the ArcGIS command NIBBLE (see also fig 3.4 with an extended flowchart of the main (post)-processing steps). In this way most noise was eliminated. This procedure is analogous to the use of the discriminant function procedure in the original ITE classification.

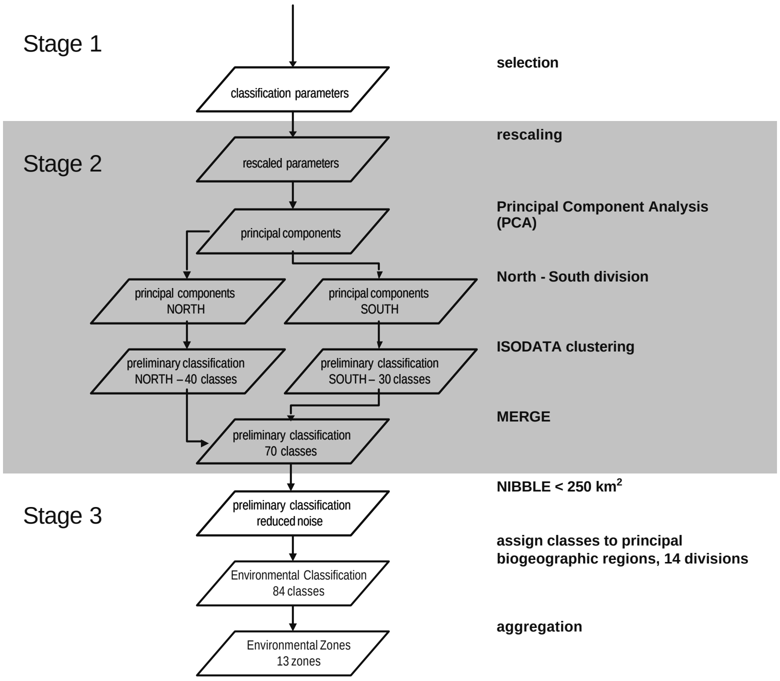


Figure 3.4 Extended flowchart of main processing and post-processing steps in the creation of the Environmental Classification

Aggregating and naming

In fourteen cases EnC environmental classes occurred in two distant biogeographic regions, for example there were several classes that occurred both in the Atlantic and Adriatic regions. Climatically these regions are indeed comparable, but biogeographically they have little in common. All classes were therefore assigned to one of six main biogeographic regions: Alpine, Boreal, Continental, Atlantic, and Mediterranean. Classes that occurred in two such biogeographic regions were separated. In this way a further fourteen environmental classes were produced, giving a total of eighty-four (i.e. 70 + 14) environmental classes.

The final eighty-four environmental classes provide a convenient set for a continent as diverse as Europe and are appropriate for stratified sampling and analysis of environmental data. However, eighty-four distinct classes are too many for summary reporting and presentation of the principal characteristics of Europe.

An aggregation of the classes into a limited number of Environmental Zones (EnZs) was created to facilitate communication, based on the experience of a similar situation in Great Britain where thirty-two land classes were reduced to six zones for reporting purposes. Subdividing the main biogeographic regions based on the first principal component score of the classes and aggregating the eighty-four classes created thirteen EnZs. As a rule northern and southern classes were assigned to specific biogeographic regions, and therefore EnZs. An exception is formed by the Atlantic biogeographic region, which comprises northern Atlantic zones and the southern Lusitanian zone (i.e. southern Atlantic). Furthermore, two northern classes were assigned to the Lusitanian zone and two Alpine classes were assigned to the Mediterranean mountains. A three dimensional scatter plot of 60.000 randomly chosen grid cells, given in Fig. 3.5, shows that each EnZ occupies a specific position in the environmental space.

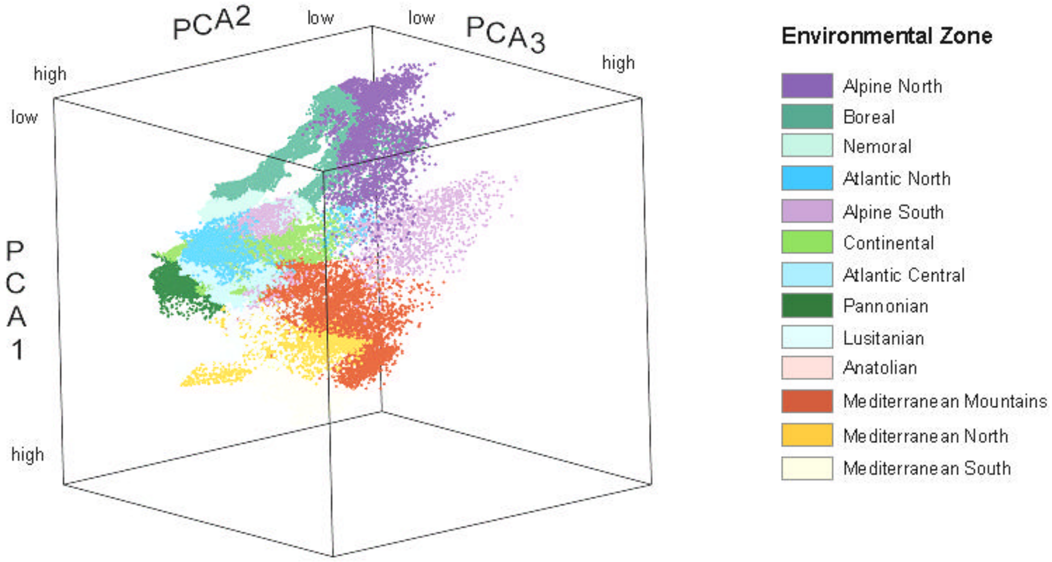


Figure 3.5 Three dimensional scatter plot of the first three principal components of the classification variables. Each EnZ occupies a specific position in the environmental space. The north-south gradient is clearly visible along the PCA1 axis, and an east-west g gradient can be discerned on the PCA2 axis, where PAN falls behind CON, which in turn falls behind ATN

Consistent naming is important to emphasise the statistical approach and prevent false assumptions. The EnZs have, therefore, been ordered by the mean value of the first principal component, which expresses the north-south environmental gradient across Europe. In the same way, the EnC classes that fall within the EnZs are also numbered by the mean value of the first principal component. The EnC classes have been given systematic names based on a three letter abbreviation of the EnZ to which the class belongs, and an ordered number based on the mean first principal component score. For example, the EnC class with the highest first principal component score within the Alpine North EnZ is named ALN1. The Environmental Classification can now be mapped by colouring the EnC classes according to their EnZ and labelling them with their consistent names, as shown in Fig. 3.6. Since a numerical label is sometimes more convenient, all EnC classes are also numbered based on first principal component score.

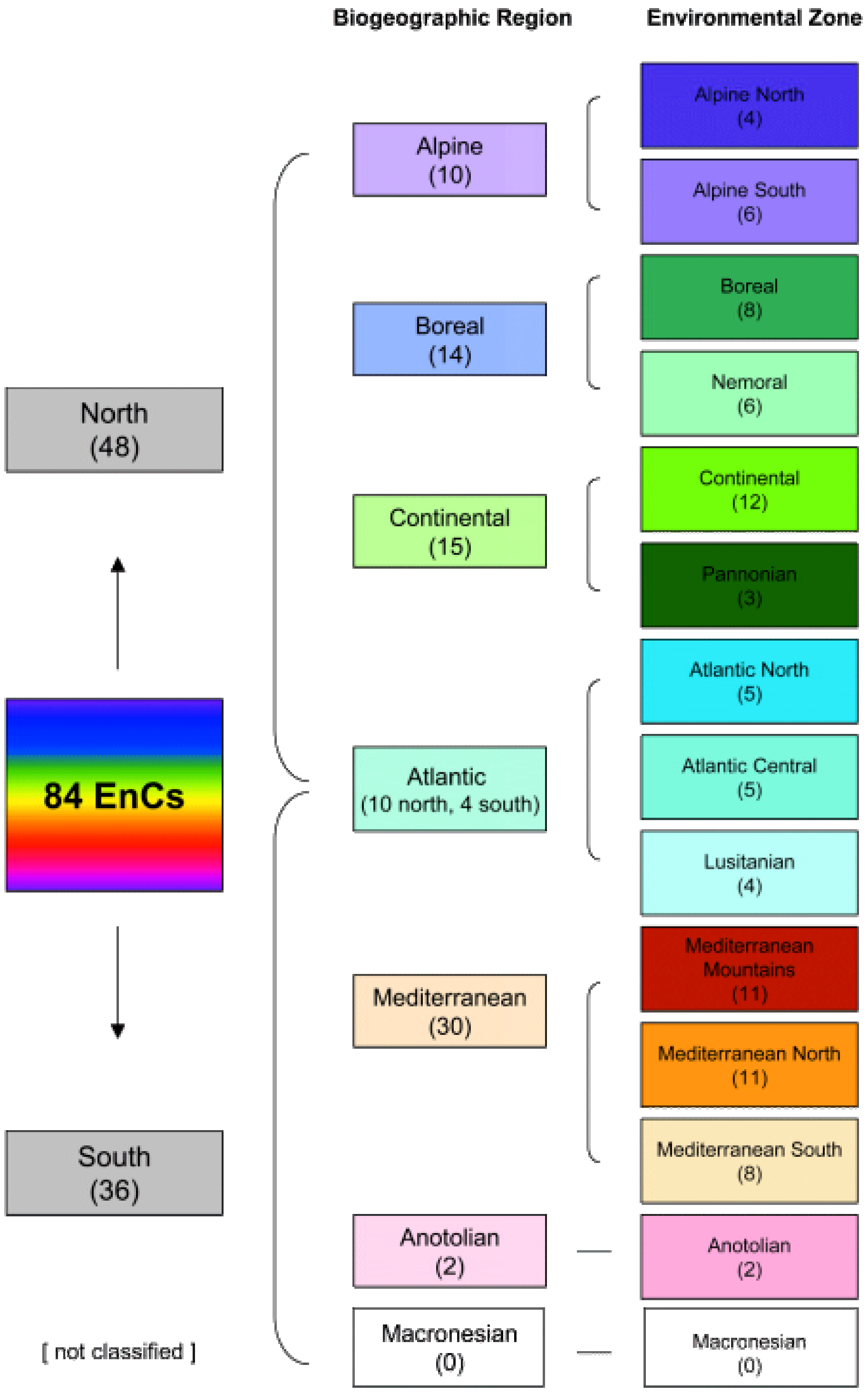


Figure 3.6 Aggregation scheme of the eighty-four EnC classes to thirteen Environmental Zones (EnZs). The EnC classes were assigned to a general biogeographic region. Within these regions the classes were assigned to a specific EnZ based on the mean values of the f first principal component of the classification variables for the class

Statistics

For each class statistics were calculated for the variables on which the classification is based. This was done using the ArcGIS command ZONALSTATS. These statistics help understand class boundaries and give a general description of the classes. Box plots for each variable can be used to summarise the spread of values in each class (Fig. 3.7). Existing ecological data sets can be used to give a more complete description of each class (Fig. 3.9).

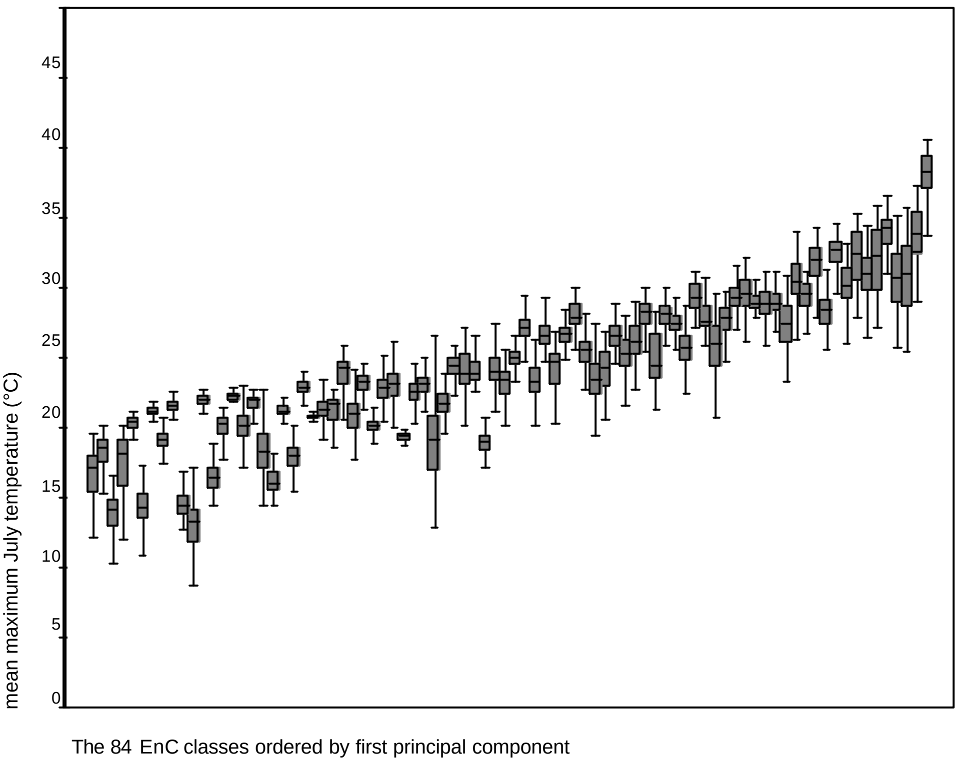


Figure 3.7 Box plots of the mean maximum temperature in July summarise the spread of the variable in each class. The classes are ordered by mean value of the first principal component for each EnC class, which depicts the north-south environmental gradient across

Result
The final result, the Environmental Classification of Europe with 84 environmental classes is shown in the figure below (fig 3.8).

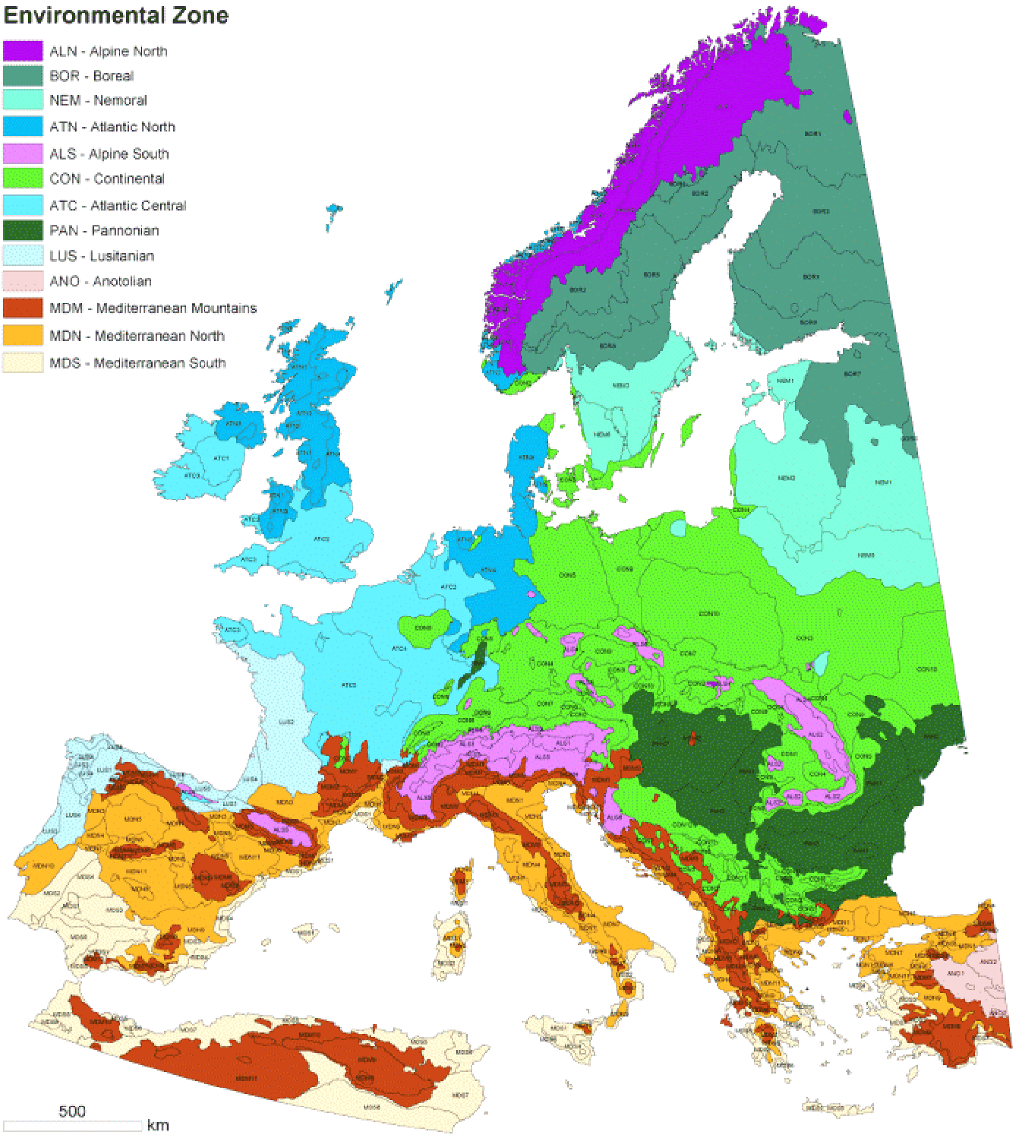
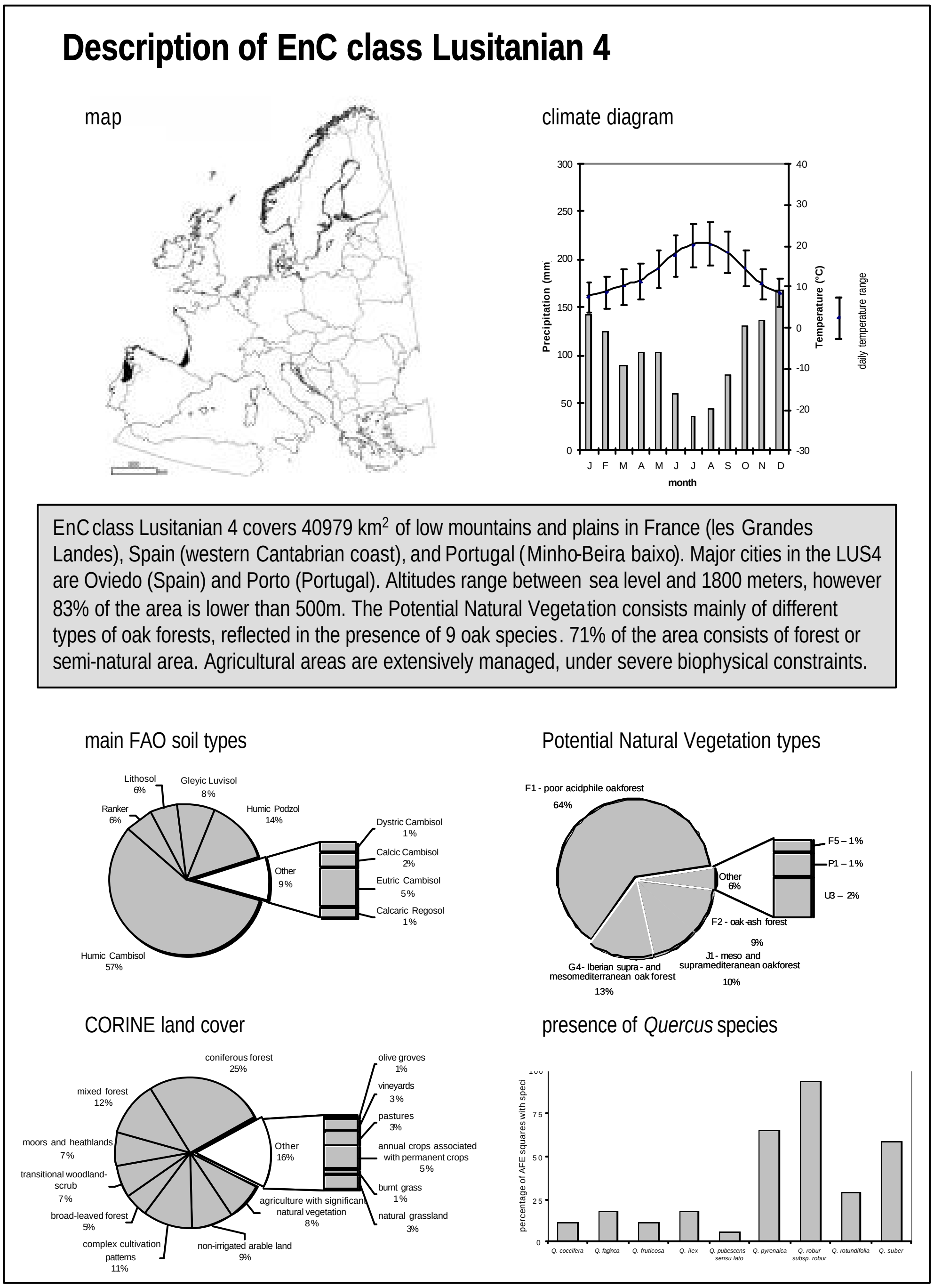


Figure 3.8 The Environmental Classification of Europe in eighty-four classes. Where the size of the class permits, the individual classes are labelled within the main Environmental Zones. The classification extends from 11° west to 32° east and from 34° north to 72° north. It is projected in a Lambert Azimuthal equal area projection. Because certain classes do not necessarily fit traditional experience, in this classification strict statistical rules have been maintained, recognising these apparent inconsistencies, e.g. PAN1 in the Vosges and Schwartzwald and CON2 in southern Norway

In the figure below (fig 3.9) an example is given for the description of one environmental class, in this case EnC class Lusitanian 4, of the Environmental Classification of Europe (ENC).



Description of EnC class Lusitanian 4

EnC class Lusitanian 4 covers 40979 km^2 of low mountains and plains in France (les Grandes Landes), Spain (western Cantabrian coast), and Portugal (Minho-Beira baixo). Major cities in the LUS4 are Oviedo (Spain) and Porto (Portugal). Altitudes range between sea level and 1800 meters, however 83% of the area is lower than 500m. The Potential Natural Vegetation consists mainly of different types of oak forests, reflected in the presence of 9 oak species. 71% of the area consists of forest or semi-natural area. Agricultural areas are extensively managed, under severe biophysical constraints.

Figure 3.9 All classes will be described in order to get a better feeling for the range of European environments. This figure shows some examples of statistical descriptions of Lusitanian class 4 (LUS4). Data sets used for this description were FAO main soil types (FAO, 1991), the agro-ecological zones (FAO/IIASA, 2000), the Potential Natural Vegetation map (Bohn et al., 2000), CORINE land cover (CEC, 1994), and the Atlas Flora Europea (Jalas & Suominen, 1976)

3.3.4 Validation

Although potentially desirable data sets such as the species-distribution atlases for mammals (Mitchell-Jones *et al.*, 1999), amphibians and reptiles (Gasc *et al.*, 1997), and birds (Hagemeijer & Blair, 1997) were not available for this study, some correlations with ecological data sets were made. Most available data sets are classifications with nominal classes, e.g. the soil maps distinguish soil types. For these nominal classifications the first principal component was calculated for the area-percentages of the nominal classes within the EnC classes, describing the association of the nominal classes with the EnC classes. It was subsequently correlated with the mean value for first principal component for each EnC class. In the case of binary species-distribution data Detrended Correspondence Analysis (DCA) can be performed in DECORANA (Hill, 1979a). As Table 3.2 and Fig. 3.10 show that all data sets used (Potential Natural Vegetation (Bohn *et al.*, 2000), *Quercus* species of the Atlas Flora Europea (Jalas & Suominen, 1976), different aggregation levels of the FAO soil map of the world and agro-ecological zones, PELCOM (Mücher *et al.*, 2001) and CORINE land cover (CEC, 1994)) show a significant correlation with the Environmental Classification. This supports the EnC as a useful tool for stratification in Europe.

Table 3-2 Significant correlations were found between the mean first principal component per EnC class of the classification variables and the available ecological data sets, using Pearson's correlations coefficient at the 0.01 level

Dataset	R^2 of the regression	Reasron's correlation coefficient
Potential Natural Vegetation	0.85	0.920
Quercus species distribution	0.72	-848
FAO DSMW, all soil types	0.59	0.771
FAO Agro-Ecological Zones	0.45	0.671
FAO DSMW, main soil group	0.43	0.659
PELCOM land cover	0.34	0.585
CORINE land cove	0.23	0.477

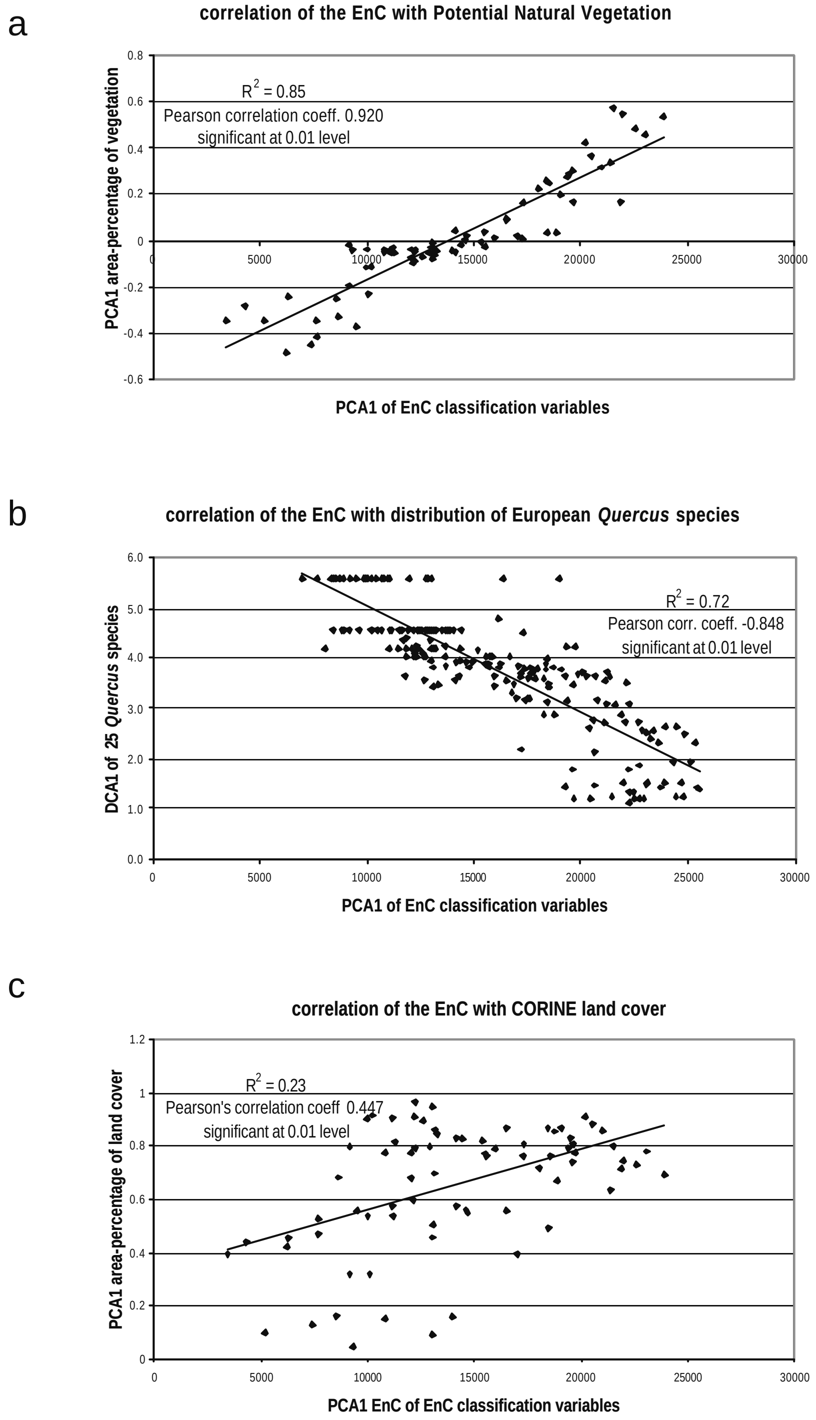


Figure 3.10 Generally recognised ecological data sets have significant correlations with the EnC at the 0.01 level. For nominal data sets (soil and potential natural vegetation) the first principal component was calculated for the area-percentages of the nominal class within the EnC classes, describing the association of the nominal classes with the EnC classes. For the species distribution data a detrended correspondence analysis (DCA) was performed. (a). Potential Natural Vegetation (Bohn et al., 2000). (b) CORINE land cover (CEC, 1994). (c) Quercus species in the Atlas Flora Europea (Jalas & Suominen, 1976)

3.4 Discussion

3.4.1 Quality of the stratification

At a global or continental scale ecological patterns are mainly driven by climate. When zooming in to more local scales, geology, hydrology, soil, and vegetation become important. This functional, scale-dependant hierarchy in ecosystem components has long been recognised, and many multi-scale ecosystem classifications are based on this hierarchy (Bailey, 1985; Klijn & de Haes, 1994). Ecosystem components are dependant on, and therefore correlate with hierarchically higher components, i.e. plant species are present in certain vegetation types that are associated with specific soil conditions. Taking into account this hierarchy, an environmental stratification on a European scale should be mainly determined by climate and geomorphology since soil properties cause regional environmental patterns that are not easily included in a continental statistical stratification. The aim of the Environmental Classification of Europe is to form a sufficiently detailed statistical stratification of Europe's environment that can be used for strategic random sampling and for the comparison and analysis of diverse ecological spatial data. In order for the classification to be functional, it should show sufficient detail and it should correlate well with ecological data. Keeping these requirements in mind, it follows that it should be possible to select the best classification from a suite of possible candidates, based on different variables and clustered into different numbers of classes and then choosing the classification which holds the highest correlation with independent ecological data sets. This was the approach that had originally been envisaged, but it was not followed for several reasons. Firstly by not being able to incorporate soil variables, possible combinations of variables were reduced. Secondly, it proved difficult to obtain ecological data sets to correlate with the classification. However, as Bunce *et al.* (2002) have shown, statistical environmental classifications will have much in common and decisions between them are arbitrary anyway and judgement is not involved in determining boundaries between the classes. Thirdly, in practice the eighty-four classes within the EnC is the maximum number of classes that can be handled, analysed and described conveniently. Furthermore, Table 3.2 and Fig. 3.10 demonstrate that significant correlations exist between the EnC and various ecological data, justifying its wider application.

In mountainous regions steep environmental gradients occur over short distances. Although the EnC picks up these gradients more accurately than the ITE classification, it still shows insufficient detail in most mountainous classes to form a good basis for defining distributions of predicted parameters at a lower level. The class ALS1 for instance covers a range of altitude from 630m – 4453m. This lack of detail can be solved with an algorithm dividing all mountainous classes into three subclasses that are equal in area, e.g. ALS1-high, ALS1-mid and ALS1-low. These classes are named altitude environmental classes (AEnCs). AEnCs created for the Alps distinguish valleys, slopes and mountaintops. Although the method of creating AEnCs is arbitrary, it offers a consistent division of mountainous classes, as is required for definition at a regional level (R.G.H. Jongman *et al.*, submitted).

3.4.2 A hierarchical framework

The statistical technique TWINSPAN (Hill, 1979b) used in the original ITE classification forms groups using a hierarchical procedure. However, adjacent classes are not necessarily the closest in their overall composition. The procedure described by Bunce *et al.* (1996a) uses the first principal component to construct a hierarchy, but it was not as deterministic as the approach used in creating the EnC, which is entirely rule-based. The eighty-four EnC classes have been aggregated into thirteen Environmental Zones, and even into seven generic Biogeographic Regions, but the EnCs can also be disaggregated into approximately 200 AEnCs. This hierarchical framework will allow for aggregation of local data into a European context. Alternatively it can be used to disaggregate regional data, as Petit *et al.* (2001) have shown for the distribution of habitats in Europe. A valuable demonstration of the hierarchical structure of the classification and its flexibility is shown in Figure 3.11. In Figure 3.11 (a) the definition of the Alpine region is shown at the EnZ aggregation level, comparable in detail to the ITE 0.5° x 0.5° classification. This level however, is appropriate for reporting at the European level together with summaries from the 12 other EnZs. Most of the applications described in the next section can be reported at this level. Figure 3.11 (b) shows the Alpine zone at the more detailed EnC level. This was the level originally intended as the units for monitoring. However, although the level of detail is much greater than in 5 (a) summits, valley sides and valley floors are still included in the same class, because of the smoothing effect of the climatic data. A further division according to altitude was therefore made as shown in Figure 3.11 (c). This demonstrates the full complexity of the Alpine zone and will enable any sample 1km^2 to be dispersed efficiently through the landscape, i.e. on valley floors, valley sides and summits. This procedure will also help in the projection of distribution patterns as described in the next section.

3.5 Applications of the Environmental Classification

The Environmental Classification of Europe can be applied in field research, reporting and scenario building. Depending on the need it can be used as aggregated zones for environmental overviews (Jongman and Bunce, 2000, Petit *et al.*, 2001) or in its full detail for strategic sampling and detailed reporting. The following major applications are envisaged for the EnC, with existing outputs being available from projects mainly at the national level. References are given to examples of such exercises.

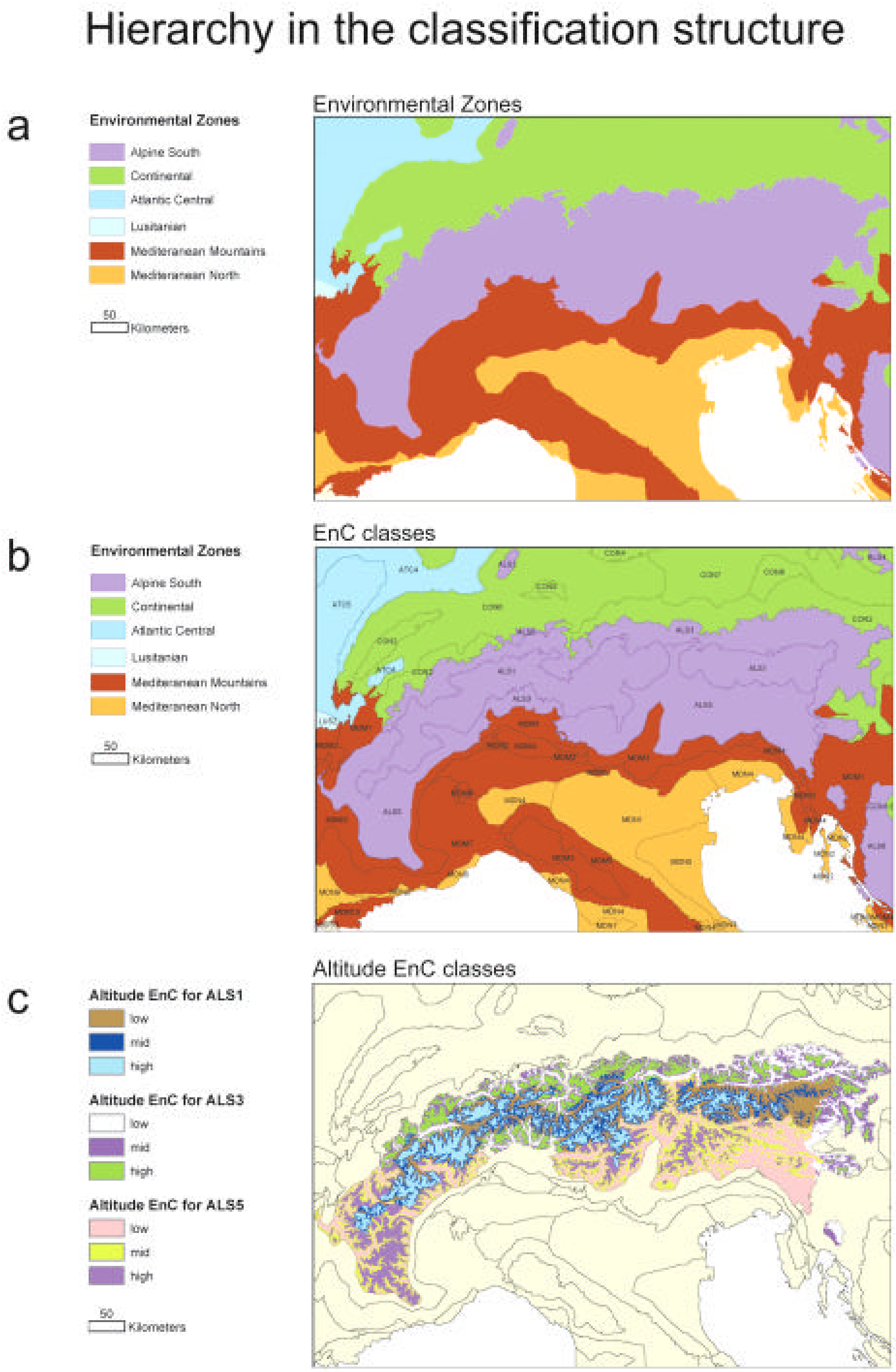


Figure 3.11 The Environmental Classification of Europe demonstrated here for the Alpine region forms a hierarchy which allows local field data to be placed in the European context. The thirteen Environmental Zones (a) are made up of the eighty-four EnC classes (b). Where required, these can be divided in subclasses, such as the Altitude EnC classes (c.

3.5.1 Distribution and change of resources

A fundamental requirement for many planning situations is to assess where the main centres of a given resource are situated. The UK Countryside Survey (Haines-Young *et al.*, 2000; Firbank *et al.*, 2003) has shown how the methodology can be used at a national level to carry out such mapping for many environmental characteristics (section 3.2, Example 1). The Countryside Survey data on landscapes, consisting of data on parcels, linear, and point features, were summarised into twenty-three broad habitats to show changes in Britain for six environmental zones. Linkage of these changes in broad habitats with stratified sampled data on biodiversity and habitat quality provides statistically reliable estimates for change.

Petit *et al.* (2001) have shown how expert judgement can also be attached to statistical classes to analyse and integrate consequences of global change on the distribution patterns of habitats in Europe (section 3.2, Example 2). Work is currently in progress to apply the classification for the further development of maps of habitats in Europe in co-ordination with other data sources e.g. the CORINE land cover map.

Brandt et al. (2001) have discussed the complementary nature of surveillance and monitoring and discuss the principles involved. There is a well-established need to monitor land-use change and ecological change so that appropriate policies can be developed. Monitoring needs especially strict protocols to separate real change from artefacts of sampling. Haines-Young et al. (2000) report the results of the audit of the UK based on the GB land classification. Elena-Roselló (1997) and Regato et al. (2000) have also shown how a strategic land classification for Spain can be used as a base to follow changes in habitat at the national level. The EnC was designed to extend the methodology of these natural sampling schemes onto the European level.

Although analysis of the consequences of land use change is of major policy significance, it is a difficult exercise to carry out because of the degree of uncertainty involved. The measurements of change inevitably involve value judgements. This is because the lack of replication of many processes in the context area – for example virtually all fertile grasslands in Britain are subject to the same management. Firbank *et al.* (2003) have shown how the Driving forces-Pressure-State-Impact-Response (DIPSR) model could be used to formalise such aspects at the national scale by using a stratification into environmental classes.

3.5.2 Integration and co-ordination with other databases

Bunce *et al.* (1993) have shown how the classification methodology can be used to integrate disparate data sources e.g. for moths in GB (section 3.2, Example 3). At the European level Bunce *et al.* (1997) have shown how the original ITE classification could be used to place data from various European databases into a common framework e.g. agricultural statistics, land cover and forest types (section 3.2, Example 4). The correlations of various European ecological data sets as listed in Table 3.2 form the first examples of such application of the EnC. Whilst the different scales of such databases need to be taken into consideration, such exercises can be used to identify hotspots for biodiversity. Currently however, the availability of data for such exercises remains limited, but as the potential of the approach is shown this situation might change.

3.5.3 Identification of gaps within designated areas

Bischoff & Jongman (1993) have shown how co-ordination of existing data can reveal gaps within areas designated for nature conservation. Currently a range of projects, e.g. NATURA 2000, are involved in review exercises to assess the representativeness of existing sites submitted by the member states. The present framework could assist this process by supplying a statistical comparison for the assessment of experts.

3.5.4 Assessment of resources through strategic sampling

One of the main objectives of constructing the EnC was to produce a system of strategic sampling for Europe. The BioHab (Co-ordination of Biodiversity and Habitats for Europe) project within the EU-Fifth Framework Research Programme is designed as the first stage along this process. The main concept behind BioHab is to develop more complete, specific and user-friendly tools in support of implementing the Habitat Directive, including NATURA 2000, as well as other policy initiatives, e.g. EMERALD. It is specifically designed to assist field practitioners as well as stakeholders in their work, because a good understanding in the field will ultimately ensure that the habitats are well defined and have policy relevance. The development of the original CORINE biotope classification and its replacement, EUNIS, is a clear recognition of the need for a consistent approach to habitats. The EUNIS Habitat classification has been developed to facilitate harmonised description and collection of data across Europe through the use of criteria for habitat identification. It is a comprehensive pan-European system, covering all types of habitats from natural to artificial, from terrestrial to freshwater and marine habitat types. However, it is a theoretical classification, which has not been tested in as a framework for sampling.

Habitat information is available in existing databases, which need to be systematically ascribed to the relevant levels of a habitat classification as developed in BioHab that follows the main division within EUNIS. For European-wide sampling common standards are necessary, as well as guidelines for future field recording. Most biodiversity measures, e.g. the number of plant species, biological indicators, and ecological indexes, can be related to the habitats in which they were recorded. The habitats can therefore act as the common framework for linking the biodiversity measures, e.g. the calcareous grassland habitat may have separate regional studies on the number of plant species, the number of butterfly species and ecological status. The EnC provides a framework to assign regional differences to comparable habitats in Europe. By using an Environmental Classification system that has links with climate and biogeographical diversity these differences can be addressed and integrated if needed.

3.5.5 Modelling change and scenario testing of climate change and socio-economic parameters

The environmental classification is ideally suited for modelling change. The classes can be used in linear programmes to produce optimal solutions. Parry *et al.* (1996) have demonstrated how this can be done for Britain and the same technique could readily be applied at a European scale. As with several applications described above such exercises could have a direct input into policy.

ITE classification was used to assess the impacts of climate change (Bunce *et al.* 1996a). Currently within the EU fifth framework project ATEAM (Advanced Terrestrial Ecosystem Analysis and Modelling) a scenario exercise is being carried out with the EnC and updated climatic change scenarios (Metzger, in prep). Initial results suggest comparable conclusions to an earlier ITE study, suggesting a high degree of stability both between the classifications and the climate change scenarios. For example Britain remains virtually unchanged because of the buffering of the ocean, while Spain shows dramatic change in the mountain areas with increasing temperatures. Socio-economic change has also been widely modelled at a strategic level because of the availability of European databases, but has hardly been explored at a more detailed level, although Bunce *et al.* (1996b) showed the potentiality of the classification to achieve such an objective

3.6 Conclusions

The Environmental Classification of Europe has been constructed using tried-and-tested statistical procedures and shows significant correlations with principal European ecological data sets. As such it can serve as a statistically robust stratification and is appropriate for strategic random sampling for resource assessment, for measurement of change and for modelling. The statistically robust hierarchy of the EnC framework allows regional applications to be aggregated into continent wide assessments, thus facilitating the growing demand for coherent European ecological data to assist EU policy and global state of the environment assessments such as the EU State of the Environment Report (EEA, in prep.) and the Millennium Ecosystem Assessment. The Environmental Classification is available for non-commercial use by applying to the corresponding author.

4 The European Landscape Classification

4.1 Introduction

Given the increasing demand for high-accuracy landscape information at the European level (Wascher, 2000b; Klijn 2002), and the observation, that existing approaches fall short of using state-of-the-art technology and addressing cultural attributes (e.g. land cultivation patterns, historical features, landscape elements, land use characteristics), there is a clear need to for a European Landscape Map as a main point of reference in support of both research and policy implementation at the European and national level. The strategic objectives are as follows:

- Establish a European-wide neutral and culturally unbiased typology of landscape types that is based on high-quality data of European coverage and which can be linked to existing national approaches while linking up with the European bio-climatic regions;
- Make sure that the proposed landscape types provide a meaningful reference base for policy application, e.g. Agenda 2000 (rural development), reporting according to the DPSIR framework (Driving Force - Pressure - State - Response); ESPON spatial planning, etc.;

A European Landscape Map should provide a practical and easy tool for European policy implementation. Important applications are integrated environmental assessment, monitoring and reporting, especially indicator-based approaches.

4.2 Background

Europe is very rich in it's variety of landscapes being shaped through a long history of human interaction with nature. However, nowadays many landscapes are being threatened by amongst others the increasing industrialisation and urbanisation of the rural areas and the major changes in agricultural practices and structure. Because of these threats "landscapes" have received increasing attention over the last ten years from policy makers and researchers at both the national and international level. At the Sofia conference in 1995, the ministers for the Environment decided on the Pan-European Biological and Landscape Diversity Strategy (PEBLDS) to enhance the importance of nature and landscapes (Council of Europe et al., 1996). From the discussions in Sofia 11 action-themes were defined of which the fourth theme concentrated on the conservation and development of European landscapes (Vervloet & Spek, 2002). Action 4 contains the following subjects (Vervloet & Spek, 2002):

- Establishment of a Pan-European Landscape Map
- The development of a series of landscape assessment criteria at a European scale

- A SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis within Pan-European landscapes.
- Formulation of policy perspectives.

Growing demand for landscape expertise can be recognised on the side of political institutions such as the European Commission, the Council of Europe, the Organisation for Economic Co-operation and Development (OECD) and UNESCO as well as on the side of NGOs such as the European Centre for Nature Conservation (ECNC). These interests appear to reflect a newly and more widely experienced awareness regarding landscape functions and values. These are rooted in culture, tradition, aesthetics, identification and in the environment and related landscape concepts offer new tools for sustainable land management through the integration of sectoral activities and through participatory processes involving a wide range of stakeholders. The launching of the European Landscape Convention (Council of Europe) developing national landscape research programmes and the increasing role of landscape research for indicator-based monitoring and reporting in support of – e.g. agri-environmental – policies are unmistakable signs that the demand for landscape expertise is real and is here to stay.

However, the state of the art for Europe is that there are almost no Landscape typologies and maps. The European Landscapes Map of Meeus (Meeus, 1995) is one of the few good examples, but misses especially spatial accuracy and should be considered as a good sketch based on expert knowledge (see figure 4.1).

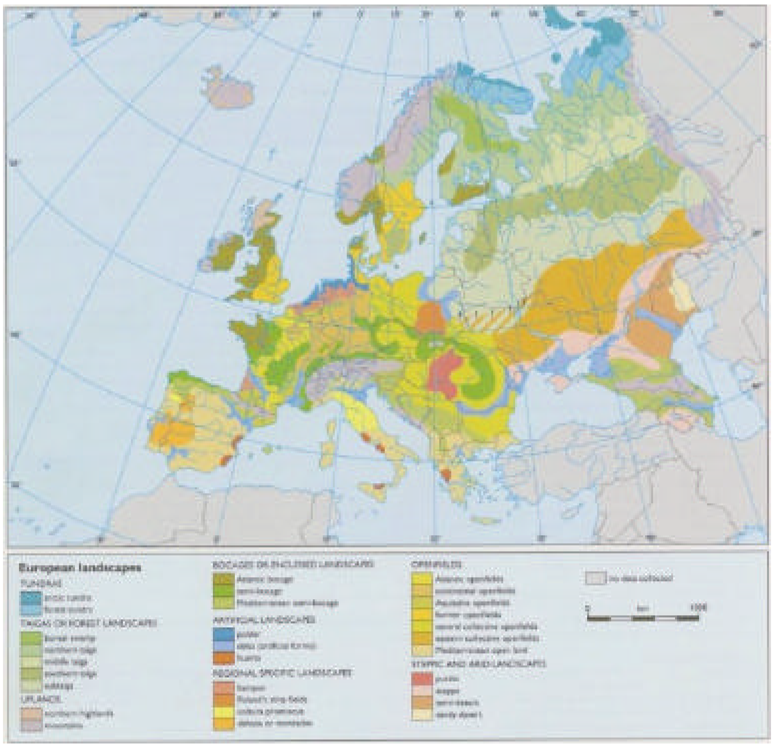


Figure 4.1 The Meeus Landscape Map of Europe (source: Dobríš report)

There are many national landscape typologies and maps but they use different approaches, scales, etc. and are therefore difficult to compare. Before we discuss the methodology used for the new European Landscape Classification the principles of landscape character assessment will be discussed shortly.

4.3 Principles of landscape character assessment

According to the definition of the Countryside Agency and Scottish Natural Heritage, 'Landscape Character' is "a distinct, recognisable and consistent pattern of elements in the landscape that makes one landscape different from another, rather than better or worse." This wording puts clear emphasis on landscape character as an objective attribute. While issues such as scale, level of detail and means of recognition (techniques) are not specified – it is clear that the identified 'characteristics' are not meant to (directly) serve value judgements, but – speaking in terms of environmental assessments – to determine the state or quality of a landscape.

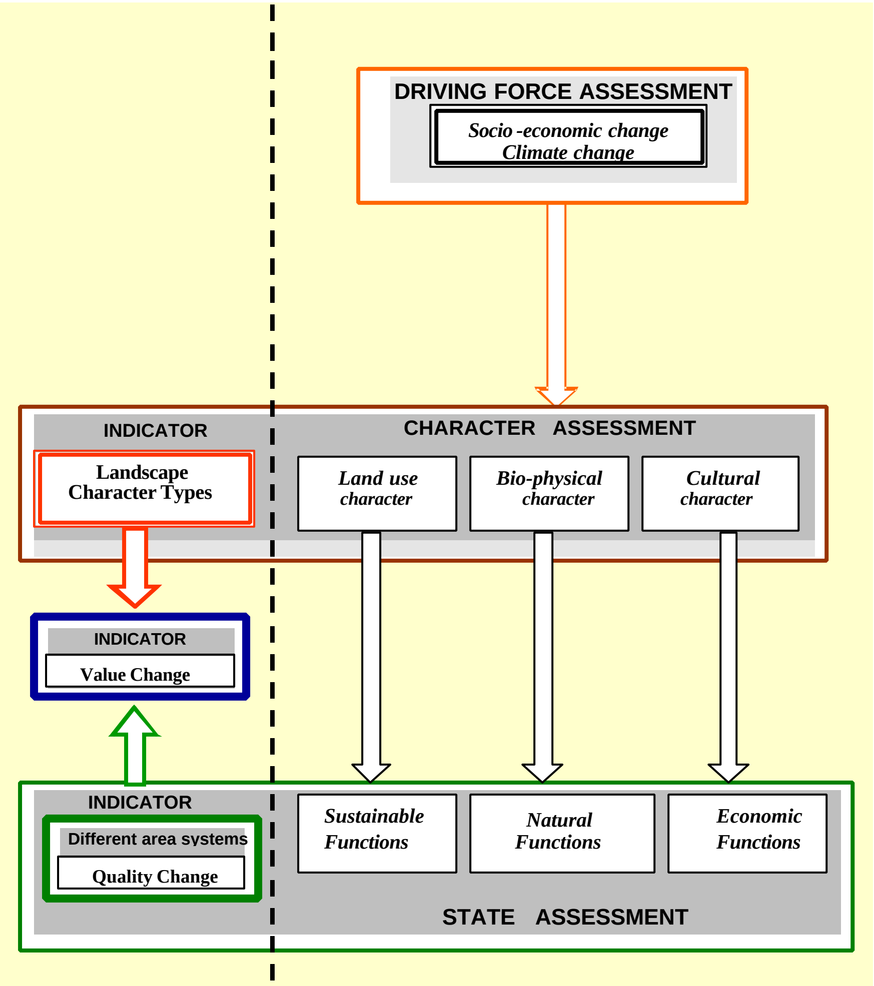


Figure 4.2 Conceptual approach for landscape assessment

Figure 4.2 illustrates how landscape assessment can be carried out as a dual and parallel organised methodological approach, distinguishing between objective landscape character assessment on the one hand (based on descriptive information) and state assessment on the other hand (based on environmental or socio-economic functions).

Given that policy makers and the public seem to be mainly interested in hard facts regarding the state of our environment rather than understanding the underlying principles and characteristics, it is stressed that the proposed methodology suggests that both pathways are intrinsically linked with each other. Though it is in principle possible to identify a set of landscape functions or values and measure their overall state and trends, only information derived from the landscape character assessment can provide the basis for it. This is especially true for assessments at larger (e.g. international) scale – mainly because the inconsistency of regional/national data sets and the great variety of socio-economic values requires criteria that are both transparent (scientific objective) and spatially as well as strategically flexible (policy oriented).

The approach to landscape classification reflects this duality in terms of the selected data types, the spatial reference systems and the conceptual design.

4.4 Basic goals of a European landscape classification

Building upon earlier discussions and conclusions on user requirements, data availability, available techniques and methodologies we formulated the basic goals of a digital landscape map.

4.4.1 Architecture of a flexible and transparent geographical information system

We focus on building an information system with systematic , scientifically sound, digital data that enables us to improve or extend data sets, to add new data sets, to enable selections or combinations of data for certain well defined goals, to enable aggregation/ simplification of data or zoom in certain data layers when more detail is required. Detailed underlying information allows producing statistical information on the contents of generalised maps. Such an information system should be built in such a way that it is well accepted by scientists and users (clearing house function), transparent as to the contents and data architecture and facilitate use for partners of the Network organisation Landscape Europe while respecting copy rights by Alterra.

4.4.2 Landscape map requirements

Advantages of a printed map

Notwithstanding the fact that all kinds of data are available in digital files, allowing numerous procedures to produce variants for all thinkable purposes, it has been established by many experiences and through consultation of users in various fields that a general, multi-purpose map of European landscapes published on paper is highly desired. A paper map, if based upon well set criteria and produced after a transparent method and therefore to be considered as “state of the art “and reflecting consensus in the scientific and policy oriented world offers an irreplaceable, widely accepted, geographical reference basis for sound discussions within scientific communities as well as by the users in various policy domains. It acts as a general tool for scientific analysis (e.g. the presence and dynamics of organisms; the possible effects of climate change, the effect of changing land use, a basis for monitor schemes, correlative studies of various nature), for policy making it offers a systematic overview of landscape characteristics and adherent values in specific regions that are instrumental for planning from a systematic international perspective. It therefore can support consistent policy and decision making in these fields. The main point is that a map with a recognisable legend and regionalisation acts as a highly efficient communication tool A paper map with a fixed scale and resolution and a pre-set legend certainly has its disadvantage through its inflexibility. That point however has been addressed by building a flexible GIS configuration. We explicitly choose for an and-and strategy (both a GIS and a printed consensus map) instead of an (unnecessary) either-or choice.

Map coverage

Basically the aim is to reach Pan European coverage.Lack of data however means that in the first stages we have to address the EU 15 countries.

Map scale and resolution

Referring to existing maps and their applicability as a communication tool we used a scale 1:5M. This scale allows us to plot the entire map at a size of 150 by 100 cm. This is a manageable size to have on a table or on the wall. It has to be stressed that GIS and printer technology allows other scales and map sizes to be delivered almost promptly. Map resolution, following rules of the thumb will be in the order of magnitude of minimal mapping units that represent 100 square kilometre (e.g. 10 by 10 km or comparable) at the minimum. Most mapping units will be considerably larger, as the aim is to delineate larger regions

Map legend

To give an understandable classification we aimed at a number of legend units between 80 and 150 units when related to the total European area. These units should be hierarchically nested in two or three levels: Individual units should be clustered in groups and (when desired) in larger clusters. Legend descriptions (and nomenclature should be transparent and easily digestible for non-specialists.

A map legend is the core of any map, to be seen as a compromise between availability of data, attempts to match expectations to apply data for one or more purposes and requirements as to the communication of information to the readers (readability) . Several considerations have led to the legend architecture based on the following criteria:

- Data relevance: what data are of prime importance and give added value
- Data availability in digital form
- Data quality (reliability; transparency and acceptability of methods; up-to-date, spatial resolution)

Distinction in differentiating and descriptive phenomena and data

Landscape information is manifold and there are many ways to integrate all information layers. To sustain clear decisions on content and delineation of landscapes a clear procedure has to be followed. This procedure relies on two lines of reasoning:

- Landscape ecological theory (Klijn, 1995) offers motives to rank landscape phenomena in relative independent, strongly determining respectively towards dependent, less determining factors. This so-called functional hierarchical ordering puts independent and stable phenomena such as relief or geology in front, whereas aspects such as vegetation are strongly dependent and less constant. This principle leads to the order of importance in the legend architecture.
- The next decision is that for the distinction of legend units and the geographical delineation of landscapes one should preferably use a limited and reliable set of so called differentiating criteria and related data. For reasons of. 1.hierarchical principles (mentioned above) availability of high quality digital data and 3. the manageability of data layers the following core data of the first order are used as differentiating phenomena: relief (limited to altitude classes); surface geology/soils conditions and land use/land cover. These data have been used to distinguish the majority of landscapes and form the basic framework determining the map lay-out.
- Second order core data have been used to verify certain classes or sometimes to add some relevant boundaries.
- Other additional, descriptive data are generally considered as adding extra information to landscapes and mapping units as distinguished on basis of the above mentioned data.: these data can be labelled to the earlier distinguished legend units and map units to allow further specification and verification. One could think of information on biogeographic phenomena, historical phenomena. In some cases this extra information could lead to extra classes or extra boundaries on the map. Generally this will not be the case and the information is additional within the existing legend structure and map patterns. Therefore this information is called descriptive.

4.4.3 Core data and additional data layers

Referring to the above considerations and a few practical motives the following division has been made:

- High quality cartographic basis showing coastlines, boundaries, rivers and lakes, infrastructure; these data are not considered as differentiating phenomena ! e.g. data derived from Bartholomew's Atlases.
- Topography (digital terrain model), altitude in classes (possibility to derive additional data on slopes, relief energy/areal unit); data from USGS GTOPO30.
- Parent material/agro-ecological soil conditions: these phenomena are very decisive for both historic, current or future land use by agriculture, nature or other land use types. Data are derived from the 1:1M European Soil Database (CEC, 1985)
- Land cover/current land use: based upon a generalisation of the CORINE land cover database. For other European areas data sources such as PELCOM land cover database can be used or are under construction.
- Environmental zones, as derived from the Environmental Classification of Europe (Chapter 3, Metzger et al., submitted, Jongman et al, submitted), based upon independent climate data, improved by adding data on topography (altitude, slope, exposition) and oceanicity.

4.5 Methodology and materials

In a first step, a conceptual framework for both the development of an Environmental Map as well as for the European Landscape Map has been developed. After formulating user requirements and possible target groups (see above), a critical review of the main European environmental data sets has been undertaken in order to select the following suitable core data sources for the delineation of the major landscape units:

- Topography (GTOPO30, resampled 1km resolution, figure 4.3)
- Parent material (ESDB 1:1M, resampled to 1km resolution, figure 4.4)
- Land use (CORINE land cover database, resampled to 1km resolution, figure 4.5)

The choice of data sets reflects that landscapes are a product of natural and cultural driving forces. Since a reliable European map on geomorphological aspects was not available, information on topography and parent material has been chosen as the adequate substitute. These three core data sets determine the matrix for a European Landscape Map. For the delineation of the European landscapes use was made of a the software package, eCognition, being discussed in the next paragraph.

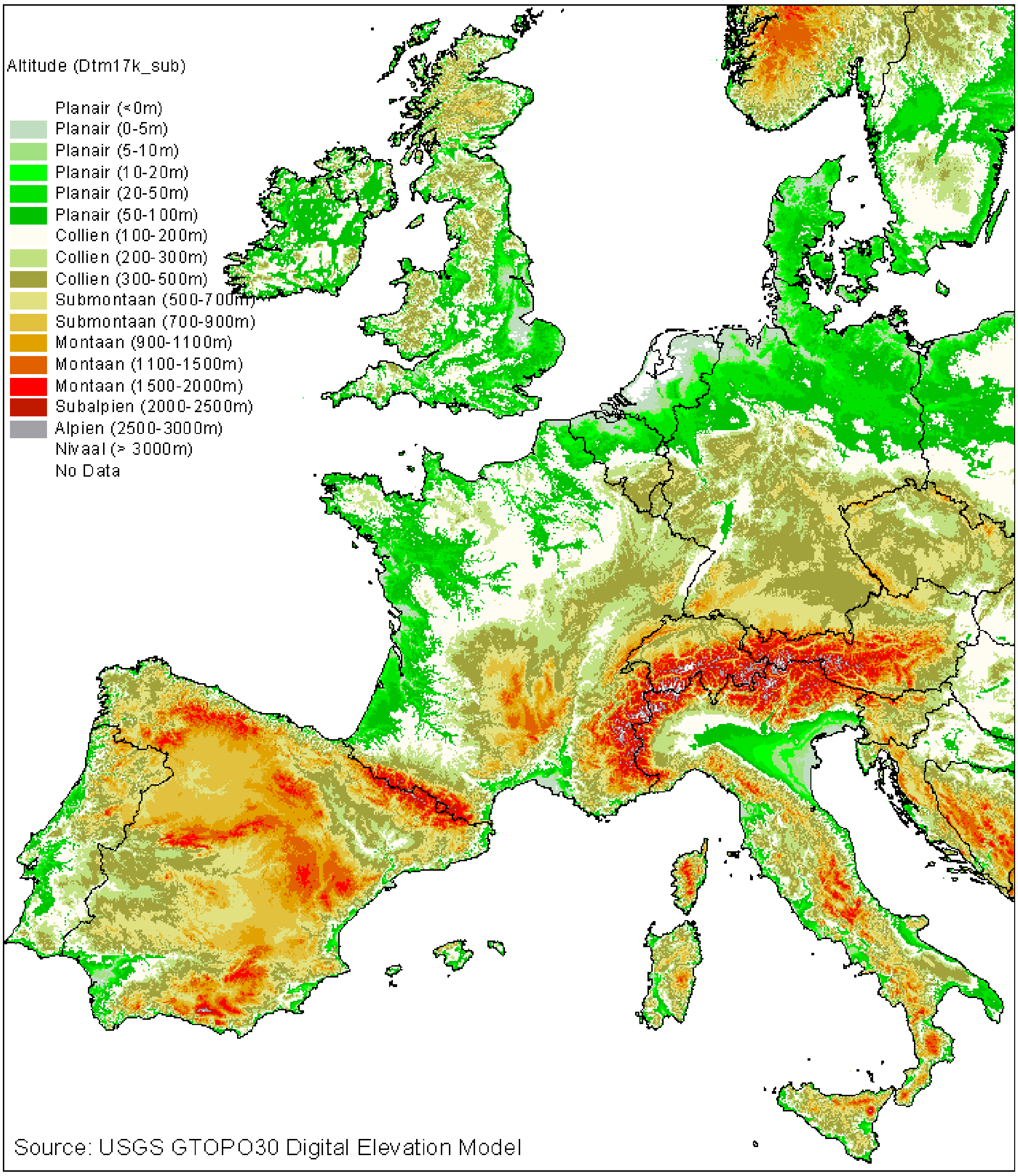
4.5.1 eCognition

eCognition is a object-oriented image classification software for multiscale analysis of Earth Observation data of all kinds. The image classification is based on attributes of image objects (semantic information) rather than on the attributes of individual pixels. For the segmentation of the major landscapes the software package eCognition is being used. eCognition is a unique object-oriented image classification software. eCognition is a powerful technology for multiscale analysis of earth observation data of all kinds. It allows extensive data fusion and handles even complex problems which require the consideration of local context information. eCognition supports the integration of remote sensing and geographic information systems, a significant step towards operational information extraction of remote sensing data. eCognition follows the concept that important semantic information necessary to interpret an image is not represented in single pixels but in meaningful image objects and their mutual relations. Therefore, the image classification is based on attributes of image objects rather than on the attributes of individual pixels. eCognition delivers results noticeably better than conventional methods. It leads to higher classification accuracy and to better semantic differentiation. Consequently, classification tasks can be addressed that until now could not be managed by state-of-the-art software. Image analysis with eCognition is based upon contiguous, homogeneous image regions which are generated by an initial image segmentation. Connecting all the regions, the image content is represented as a network of image objects. These image objects act as the building blocks for the subsequent image analysis. In comparison to pixels, image objects carry much more useful information. Thus, they can be characterised by far more properties than pure spectral or spectral-derivative information, such as their form, texture, neighbourhood or context. Analysing an image in eCognition means to classify the image objects either based on sample objects (training areas) or according to class descriptions organised in an appropriate knowledge base. The knowledge base itself is created by means of inheritance mechanisms, concepts and methods of fuzzy logic, and semantic modelling.

4.5.2 Input data segmentation

Before the segmentation could take place in eCognition, the three core data layers (topography, parent material and land use) have first been simplified to a limited number of relevant thematic classes. The continuous digital elevation model GTOPO30 was aggregated to 17 thematic elevation classes. In table 4.1 the definition of the 17 elevation classes is given. In the last column the classes are shown that have been used in the establishment of the landscape typology. The typology is discussed in more detail in paragraph 4.5.4. The parent material as derived from the European Soil Database has 127 classes at the second level and 9 classes at the first level. This list has been critically reviewed and resulted in a limited set of 15 thematic classes for parent material that are meaningful for a European landscape classification. In table 4.2 the thematic classes for parent material are given with in the last column the classes used in the typology. For the land use the CORINE land cover database has been used and this database has 44 thematic classes at the third level, 15 classes at the second level and 5 classes at the first level. For the purpose of landscape identification the CORINE land cover database has been aggregated to 10 major land cover classes, see table 4.3. After recoding the classes, the three data layers have been resampled to a 1 km resolution grid.

Finally, the three layers were stacked into one RGB colour composite as an ERDAS Imagine image file, which gives the impression of a satellite image (see Figure 4.6). This RGB colour composite, based on the three core layers topography, parent material and land use, has been segmented in a specific way using the eCognition software.



Source: USGS GTOPO30 Digital Elevation Model

Figure 4.3 Topography as first input layer in the segmentation process

Table 4-1 Data layer 1: Topography (GTOPO30)

Code	Altitude	Typology
1	<0	1. Lowland (L)
2	0-5	
3	5-10	
4	10-20	
5	20-50	
6	50-100	
7	100-200	2. Hills (C)
8	200-300	
9	300-500	
10	500-700	3. Mountains (M)
11	700-900	
12	900-1100	
13	1100-1500	
14	1500-2000	4. High mountains (H)
15	2000-2500	
16	2500-3000	5. Alpine (A)
17	3000-5000	

Table 4-2 Data layer 2: Parent Material (ESDB)

Code	Parent material	Typology
1	River alluvium	Alluvial sediments (A)
2	Marine alluvium	
3	Glaciofluvial deposits	Glacio-fluvial deposits (I)
4	Calcareous rocks	Calcareous rocks (C)
5	Soft clayey materials	Clayey sediments (L)
6	Hard clayey materials	Clayey rocks (H)
10	Silstone	
7	Sands	Sandy sediments (S)
8	Sandstone	Sandy rocks (R)
9	Soft loam	Loamy sediments (T)
11	Detrital formations	Detrital rocks (D)
12	Crystalline rocks and migmatites	Crystalline rocks G)
13	Volcanic rocks	Volcanic rocks (V)
14	Other rocks	Other rocks (X)
15	Organic materials	Organic Materials (O)

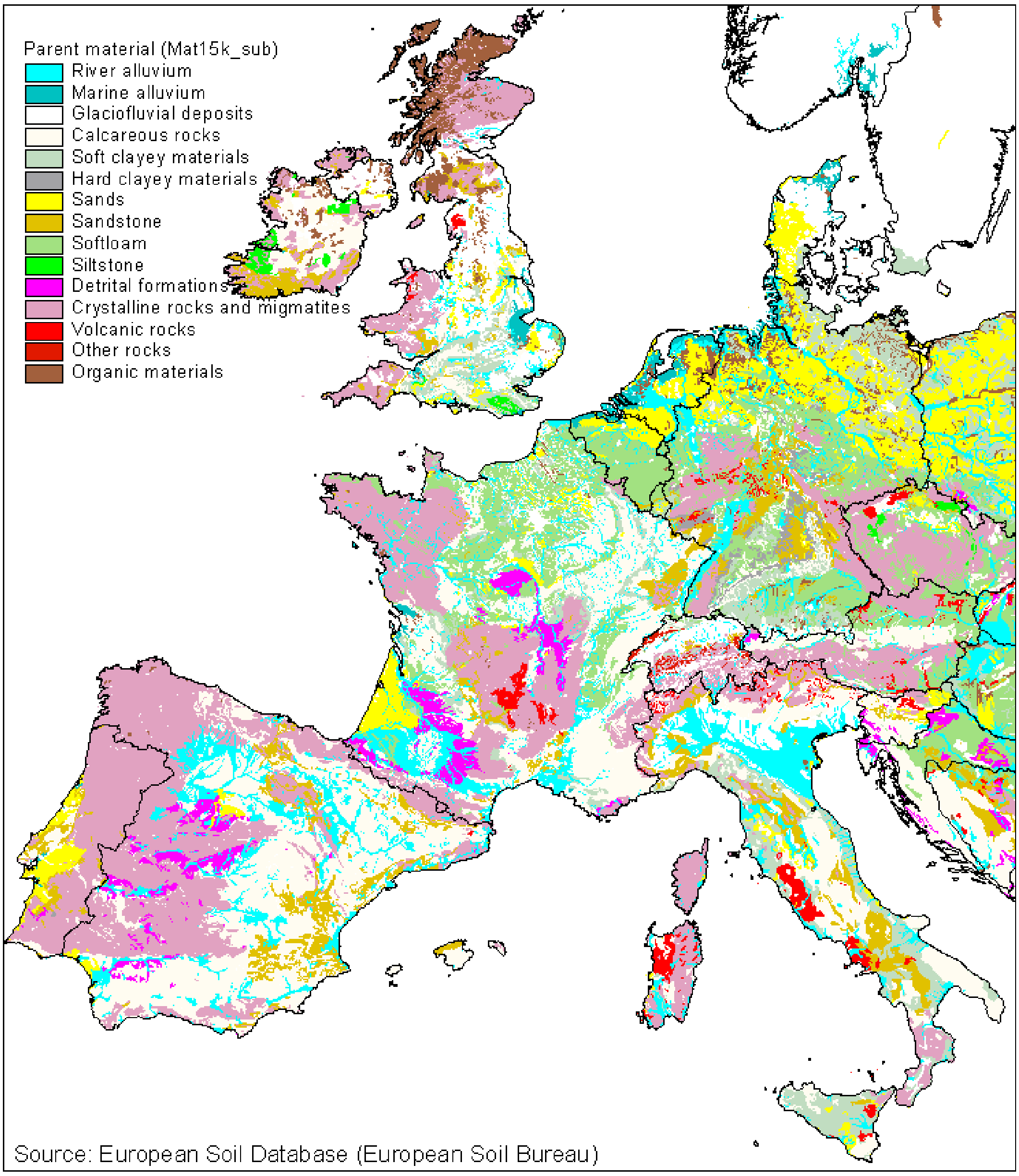
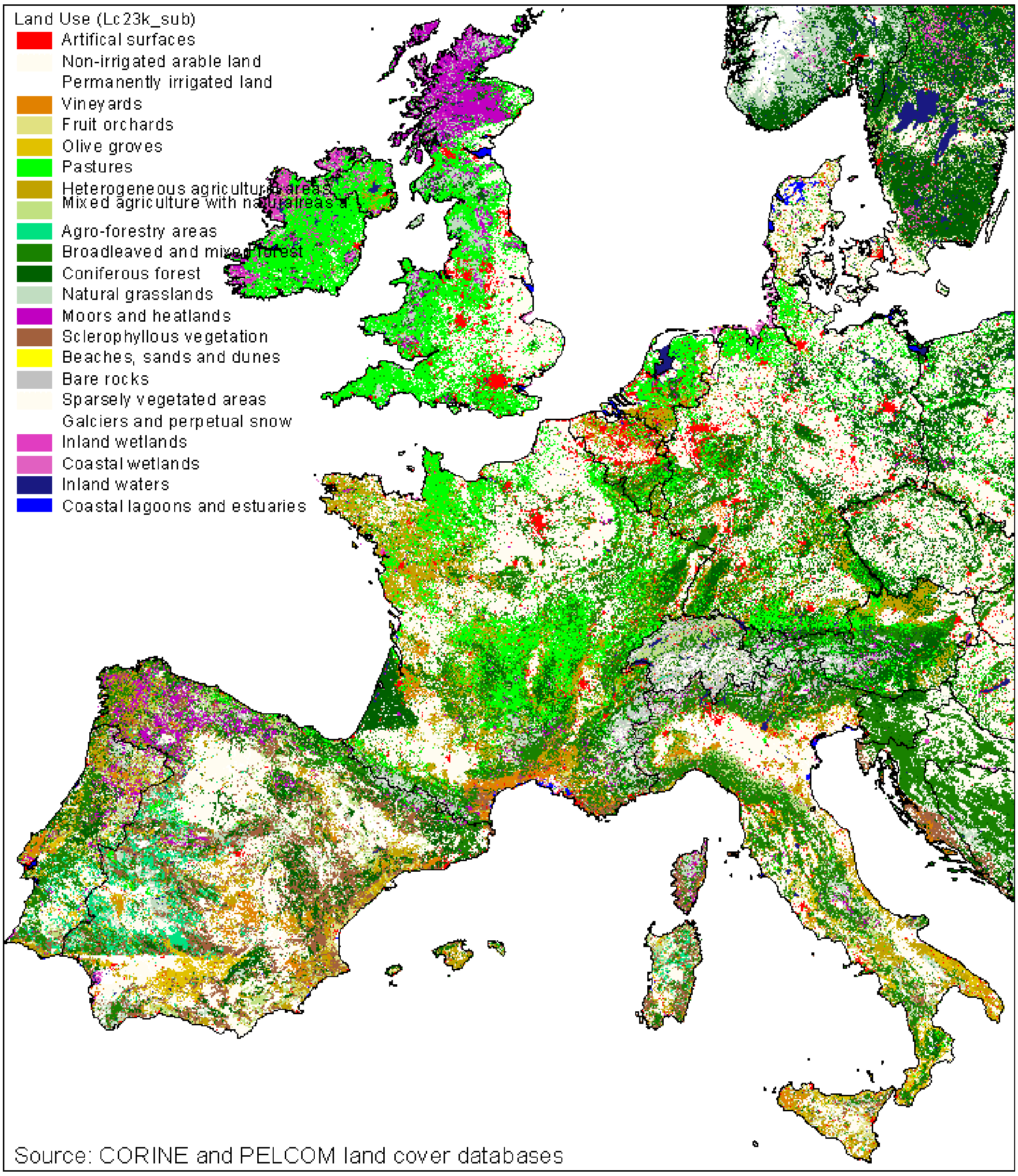


Figure 4.4 Parent material as second input layer in the segmentation process

Table 4-3 Data layer 3: Land use (Source: Corine)

	level 1	level 2		Code	Level 3 CORINE land cover class	
1.	Artificial surfaces	1.1	urban fabric	1.1.1	continuous urban fabric	1
				1.1.2	discontinuous urban fabric	1
		1.2	industrial, commercial and transport units	1.2.1	industrial and commercial units	1
				1.2.2	road and rail networks and associated land	1
				1.2.3	port areas	1
				1.2.4	airports	1
		1.3	mine, dump and construction sites	1.3.1	mineral extraction sites	1
				1.3.2	dump sites	1
				1.3.3	construction sites	1
		1.4	artificial non-agricultural vegetated areas	1.4.1	green urban areas	1
				1.4.2	port and leisure facilities	1
2.	Agricultural areas	2.1	arable land	2.1.1	non-irrigated arable land	2
				2.1.2	permanently irrigated land	2
				2.1.3	rice fields	2
		2.2	permanent crops	2.2.1	vineyards	3
				2.2.2	fruit trees and berry plantation	3
				2.2.3	olive groves	3
		2.3	pastures	2.3.1	pastures	4
		2.4	heterogeneous agricultural areas	2.4.1	annual cops associated with perm. crops	5
				2.4.2	complex cultivation patterns	5
				2.4.3	land principally occupied by agriculture with significant natural vegetation	5
				2.4.4	agro-forestry areas	5
3.	Forests and semi-natural areas	3.1	forest	3.1.1	broad-leaved forest	6
				3.1.2	coniferous forest	6
				3.1.3	mixed forest	6
		3.2	shrub and / or herbaceous vegetation associations	3.2.1	natural grasslands	7
				3.2.2	moors and heath lands	7
				3.2.3	sclerophyllous vegetation	7
				3.2.4	transitional woodland-scrub	7
		3.3	open spaces with little or no vegetation	3.3.1	beaches, sand, dunes	8
				3.3.2	bare rocks	8
				3.3.3	sparsely vegetated areas	8
				3.3.4	burnt areas	8
				3.3.5	glaciers and perpetual snow	8
4.	Wetlands	4.1	inland wetlands	4.1.1	inland marshes	9
				4.1.2	peat bogs	9
		4.2	coastal wetlands	4.2.1	salt marshes	9
				4.2.2	salines	9
				4.2.3	intertidal flats	9
5.	Water bodies	5.1	inland waters	5.1.1	water courses	10
				5.1.2	water bodies	10
		5.2	marine waters	5.2.1	coastal lagoons	10
				5.2.2	estuaries	10
				5.2.3	sea and ocean	



Source: CORINE and PELCOM land cover databases

Figure 4.5 Land use as third input layer in the segmentation process

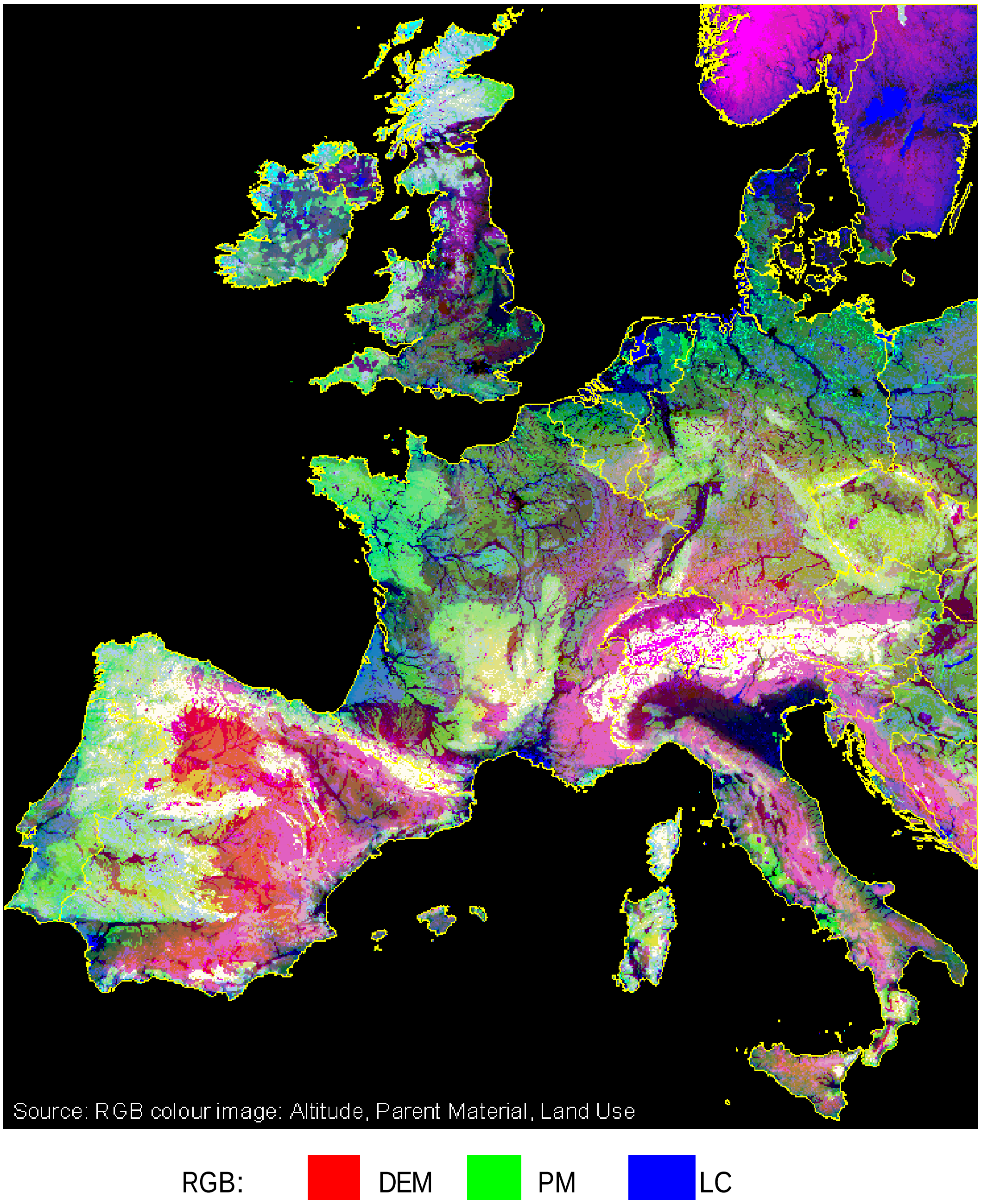

Source: RGB colour image: Altitude, Parent Material, Land Use

Figure 4.6 RGB colour composite of the 3 data layers (topography, parent material and land use). In this image the topography is shown in the Red channel, the parent material in the Green channel and land use in the Blue Channel

In the case that all three core layers have a high value the colour is towards white in the colour composite. In the case that all core layers have a low value the colour is towards black. If the colour is reddish it means that topography has a high value while the other two core layers have a low value. How the RGB colour composite is segmented will be discussed in the next paragraph.

4.5.3 Segmentation process

As has been mentioned before, eCognition is an object-oriented image classification software for multiscale analysis of Earth Observation data of all kinds. The image classification is based on attributes of image objects (semantic information) rather than on the attributes of individual pixels. After the RGB colour composite has been loaded in the eCognition several parameters can be adjusted in the “multiresolution segmentation” window. The most important parameters are the scale parameter and the weight factor for the individual layers. The parameters for colour and shape are respectively fixed to 1 and 0 (must in total always be one), because the segmentation is purely based on the values of the data layers and not on their shape (landscapes have no predefined shape). The parameter setting for the scale and weight factor went through an iterative process of trial and error. If the scale factor is set to a low value, e.g. 15 the segmentation is very detailed. Inversely, if the scale factor is set to a high value, e.g. 100, the segmentation is very coarse. If the weight factor is set to 0 the data layer is not considered in segmentation, when the factor is set to 1 the data layer counts completely. The weight factor is especially important in relation to the other layers.

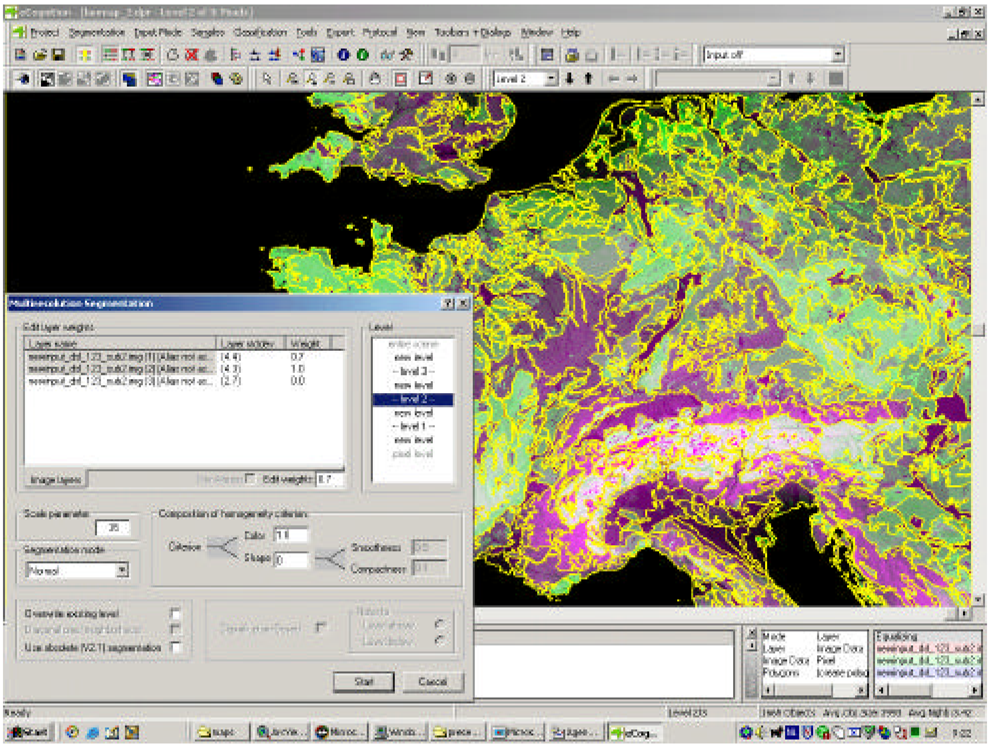
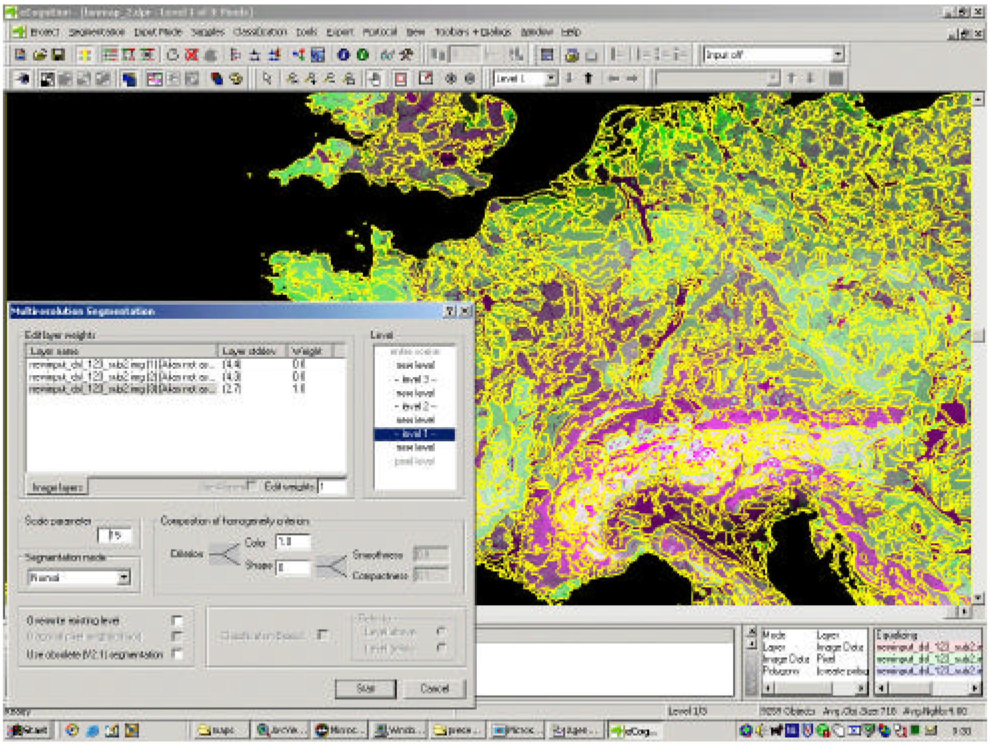


Figure 4.7 First segmentation based topography and parent material only

The segmentation itself has been implemented at various levels. At the first level the land use has been excluded (weight factor 0). At this level the segmentation result is considered to be a fixed matrix (based on the physical data layers topography and parent material). At a lower level the land use has been segmented as subsegments of the higher level segments. For the first segmentation the scale factor has been set to

35, while the land use has been segmented as subsegments on a more detailed level using a scale factor of 15. The final segmentation result, as shown in the figure below (fig 4.8), can immediately be exported to an Arcview shape file.



Scale parameter 15

Segmentation mode Normal

Color 1.0

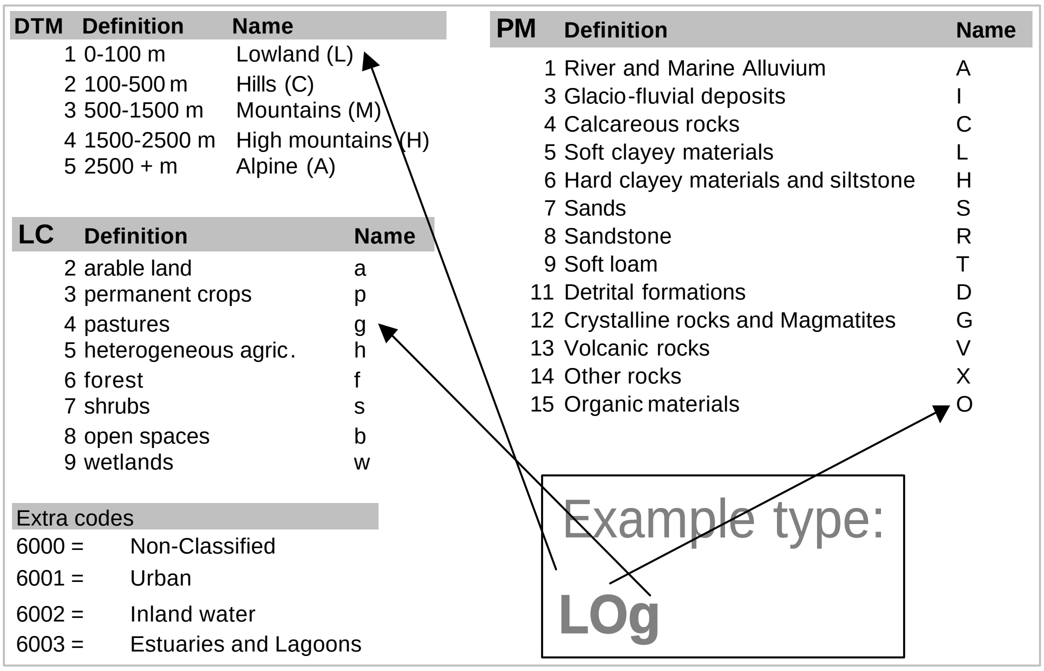
Shape 0

Figure 4.8 Second segmentation using the land use only to subdivide the higher level segments

For this landscape segmentation the dominant class (within the segment) for each data layer has been calculated again and attached as an attribute to the segments. The segments are now considered as separate landscapes but they have not been classified so far. The classification or labelling of the segments (landscape mapping units) will be based on its attributes. This will be discussed in the next section.

4.5.4 Typology

As mentioned before the landscape typology is based on the attributes of the landscape mapping units (segments). The attributes on which the first typology has been based concerns the three core layers: topography, parent material and land use. As mentioned in paragraph 4.5.2 there were 17, 15 and 10 classes for the three layers respectively. This means that in principle 17*15*10 = 2550 landscape types are possible. This is considered as impracticable and therefor the amount of classes has been reduced for the three core layers in the typology construction. In table 4.1, 4.2 and table 4.3 it is shown how the number of classes is reduced (aggregated) to a smaller number of classes. For the typology construction there are now 5 altitude classes, 13 parent material classes and 8 land use classes. For the urban, marine and freshwater landscapes the information was directly derived from the land use layer. (This was also necessary because for these landscape types there were data gaps in the soil database). So in principle there are (5*13*8)+3 = 523 combinations, however in reality there are 202 existing combinations, read landscape types.



DTM	Definition	Name
1	0-100 m	Lowland (L)
2	100-500 m	Hills (C)
3	500-1500 m	Mountains (M)
4	1500-2500 m	High mountains (H)
5	2500 + m	Alpine (A)

LC	Definition	Name
2	arable land	a
3	permanent crops	p
4	pastures	g
5	heterogeneous agric.	h
6	forest	f
7	shrubs	s
8	open spaces	b
9	wetlands	w

Extra codes	
6000 =	Non-Classified
6001 =	Urban
6002 =	Inland water
6003 =	Estuaries and Lagoons

PM	Definition	Name
1	River and Marine Alluvium	A
3	Glacio-fluvial deposits	I
4	Calcareous rocks	C
5	Soft clayey materials	L
6	Hard clayey materials and siltstone	H
7	Sands	S
8	Sandstone	R
9	Soft loam	T
11	Detrital formations	D
12	Crystalline rocks and Magmatites	G
13	Volcanic rocks	V
14	Other rocks	X
15	Organic materials	O

Figure 4.9 Construction and symbology of the typology based on topography, parent material and land use

The final typology consisting of 202 landscape types has a 3 digit code; the first capital letter is used for the topographic class, the second capital letter for the parent material and the third letter (undercast) for the land use class. This is also demonstrated in figure 4.9.

As an extra attribute the environmental zone (e.g. Alpine south, Nemoral, Pannonian) has been attached to each landscape mapping unit. The Environmental Zones (13 zones in total, see Chapter 3) have not been used in the typology, but will be used in the description of the landscape type.

For the urban landscapes the information was derived from the CORINE land cover database. However, some extra processing was done to derive only the larger urban agglomerations. For this purpose a 5km by 5 km majority filter was used in ERDAS Imagine. The resulting map with urban agglomerations is shown in the figure 4.10. This map was integrated within the landscape map. After this there were additional post-processing steps necessary to upgrade the European Landscape Map, being summarised below.

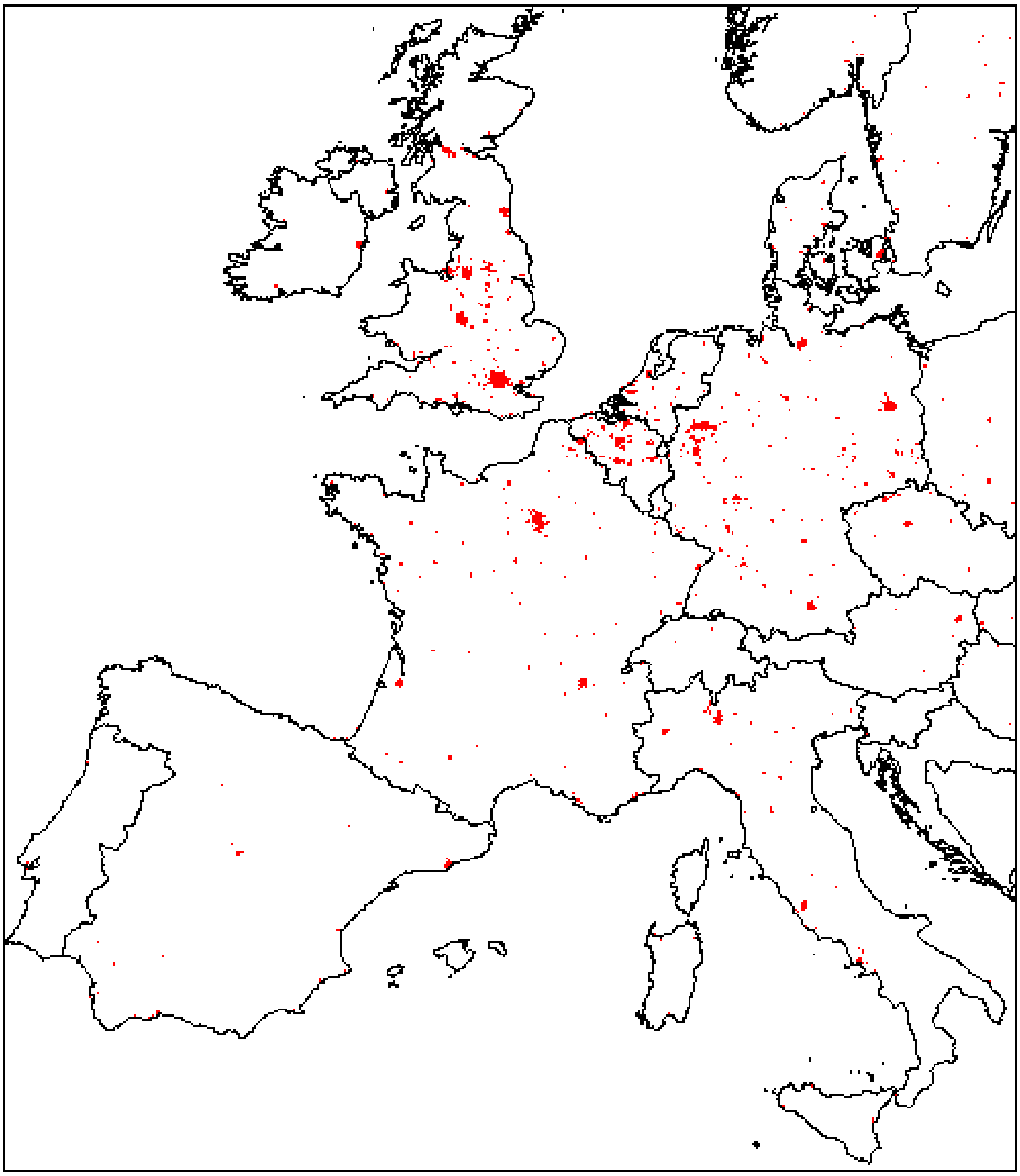


Figure 4.10 Identified urban landscapes

The additional post-processing consisted off:

- Add major urban areas (lc_1km_urban_majority_5km).
- Aggregate adjacent polygons with same landscape type (normal dissolve)
- Remove small polygons by combining them with larger adjacent polygons,
- use arcscript (dissolve_adjacent_polys),
- use option dissolve with smallest adjacent polygon and threshold of 50 km2 (5000 ha).

4.6 Results

The resulting European Landscape Map is demonstrated in figure 4.11. The landscape map (landscapemap_v12.shp) is an Arcview shape file with 2682 landscapes mapping units of which more than 2600 are larger than 2500 ha. In table 4.4 some of the main attributes of the European Landscape Classification are given. Each of the 202 landscape type has a unique code and the landscape type itself is the LCC code. The LCC code is based on the dominant altitude class, parent material class and land use class. The current landscape classification is now being distributed and revised by a limited number of landscape experts and on basis of their comments the landscape map will be improved. It is expected that a final version will be ready in 2005. If the landscape map will be extended to the rest of Europe is still under discussion. Outside the European Union and the accession countries databases like CORINE land cover and the European Soil database are not available, which limits the possibilities. No decision has been taken on this issue yet.

Table 4-4 Some of the main attributes attached to the European Landscape Map (version 12)

CODE	COUNT	LCC	LCC_nr	HECT	DEMnr	PMnr	LC nr
1	80	LAa	1012	8676100	1	1	2
2	8	LAp	1013	473800	1	1	3
3	25	LAg	1014	2294100	1	1	4
4	21	LAh	1015	818000	1	1	5
5	3	LAf	1016	108000	1	1	6
6	1	LAs	1017	53800	1	1	7
7	1	LAb	1018	10300	1	1	8
8	22	LAw	1019	534200	1	1	9
9	51	LIa	1032	7687100	1	3	2
10	13	LIg	1034	1389600	1	3	4
11	10	LIh	1035	357900	1	3	5
12	23	LIf	1036	4296200	1	3	6
13	5	LIs	1037	337200	1	3	7
14	1	LIw	1039	6700	1	3	9
15	22	LCa	1042	3794100	1	4	2
16	8	LCp	1043	345300	1	4	3
17	10	LCg	1044	3267600	1	4	4
18	12	LCh	1045	1113500	1	4	5
19	14	LCf	1046	395100	1	4	6
20	5	LCs	1047	229800	1	4	7
21	6	LCw	1049	82100	1	4	9
22	34	LLa	1052	6827600	1	5	2
23	1	LLp	1053	64500	1	5	3
24	5	LLg	1054	1111000	1	5	4
……							

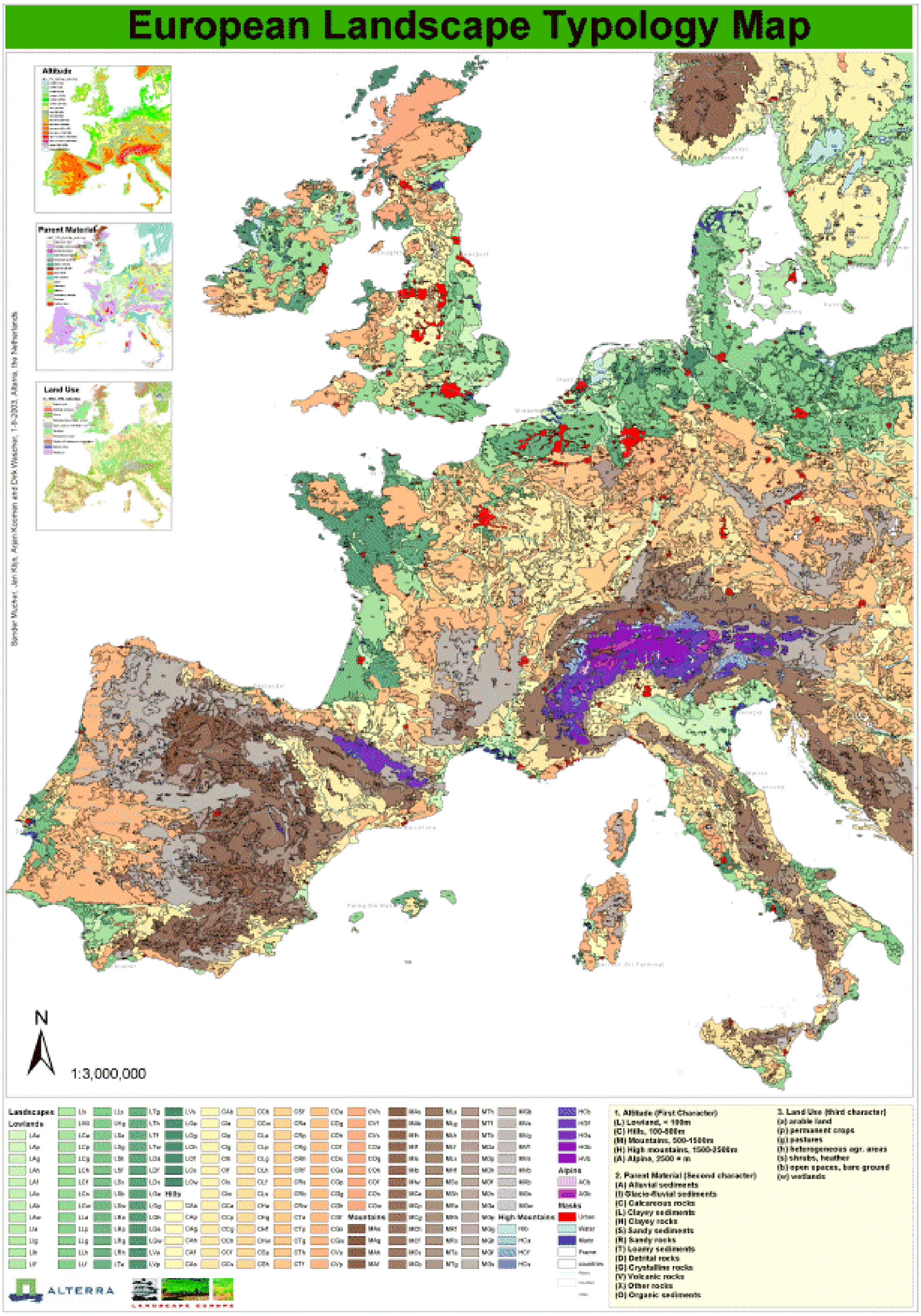


Figure 4.11 The European Landscape Map (landscapemap_v12.shp)

Table 4-5 Codes used in the legend of the European Landscape Classification

LEGEND EUROPEAN LANDSCAPE CLASSIFICATION

1. Altitude (first character)

L	< 100 m	Lowland
C	100-500 m	Hills (Collien)
M	500-1500 m	Mountains
H	1500-2500 m	High mountains
A	2500 + m	Alpine

2. Parent-material (second character)

A	Alluvial Sediments
I	Glacio-fluvial deposits (Ice)
C	Calcareous Rocks
L	Clayey Sediments (Lutum)
H	Clayey Rocks (Shale)
S	Sandy Sediments
R	Sandy Rocks
T	Loamy Sediments (silt)
D	Detrital Rocks
G	Crystalline Rocks (e.g. granite)
V	Volcanic Rocks
X	Other rocks
O	Organic Sediments

3. Land-use (third character; undercast)

a	arable land
p	permanent crops
g	pastures (grass)
h	heterogeneous agricultural areas
f	forest
s	shrubs/heather/herbaceous vegetation
b	open spaces/ bare ground
w	wetlands

Extra codes

Urban	Artificial surfaces
Water	Inland waters
Marin	Coastal lagoons and estuaries
Nodat	Non-Classified

The map has an extensive legend as given in figure 4.11. In the following section a short explanation of the legend-units is presented (limited to the first two information layers and thus first two characters)

Table 4-6 Description of landscape legend-units at the second level

	Alpine
AG	Crystalline Rocks in alpine areas (Alps)
AC	Calcareous Rocks in alpine areas (Alps)
	High Mountains
HC	Calcareous Rocks in high mountains (Alps)
HG	Crystalline Rocks in high mountains (Pyrenees, Alps)
HI	Glacio-fluvial deposits in high mountains (Alps)
HV	Volcanic Rocks in high mountains (Alps)
	Mountains
MA	Alluvial Sediments in mountains (North Central Spain)
MC	Calcareous Rocks in mountains (Southern Europe, Eastern Spain, along the Adriatic
MD	Detrital Rocks in mountains (Central Spain)
MI	Glacio-fluvial deposits in mountains (Southern Norway, Northern Switzerland)
MG	Crystalline Rocks in mountains (Spain, Southeastern France, Tjechoslowakia, Switzerland)
MH	Clayey Rocks in mountains (Southwestern Germany)
ML	Clayey Sediments in mountains (Southern Germany, Northern Italy)
MO	Organic Sediments in mountains (North England; Dinaric Alps, East of the Dinara and
MR	Sandy Rocks in mountains (Eastern Spain, Central and Southern Italy)
MS	Sandy Sediments in mountains
MT	Loamy Sediments in mountains (Few isolated patches over Europe)
MV	Volcanic Rocks in mountains (Central France: Massif Central)
MX	
	Hills
CA	Alluvial Sediments in hills (North of Pyrenees, Eastern Hungary)
CC	Calcareous Rocks in hills (Spread across Central and Southern Europe, cluster in France)
CI	Glacio-fluvial deposits in hills (Scandinavia, England, Northern-Ireland, Southern Alps)
CD	Detrital Rocks in hills (Central and Souterhn France, Central Spain, Balkan countries)
CG	Crystalline Rocks in hills (Western Portugal and Spain, France, England, Ireland, Corsica,
CH	Clayey Rocks in hills (Central Germany)
CL	Clayey Sediments in hills (Central-Northern France, Poland, Italy)
CO	Organic Sediments in hills (Northwestern Scotland and Lake District)
CR	Sandy Rocks in hills (Southern Ireland, Germany, France)
CS	Sandy Sediments in hills (Poland and Tsjechoslowakia)
CT	Loamy Sediments in hills (Spread across Central Europe)
CV	Volcanic Rocks in hills (Spread across Europe in small isolated patches)
	Lowlands
LA	Alluvial Sediments in lowland areas (Deltas of Rhine and Po)
LC	Calcareous Rocks in lowland areas (Ireland, Southwestern England, Western France,
LD	Detrital Rocks in lowlands (Southwestern France)
LG	Crystalline Rocks in lowlands (Bretagne, coastal zones of Ireland and England)
LH	Clayey Rocks in lowland areas (South England and West Ireland)
LI	Glacio-fluvial deposits in lowland areas (Scandinavia, England, Northern-Ireland,
LL	Clayey Sediments in lowland areas (Southwestern England, Northeastern Germany,
LO	Organic Sediments in lowlands (Northern Netherlands- Germany-Poland)
LR	Sandy Rocks in lowlands (Ireland, England, Portugal)
LS	Germany, Denmark, Poland, Les Landes, Southwestern tip of Iberic peninsula)
LT	Loamy Sediments in lowlands (Belgium, Northwestern France)
LV	Volcanic Rocks in lowlands (Italy near Rome and Naples)

A first check on the possibility of combinations for altitude-parent material-landuse does not give a reason to suspect that impossible combinations exist in this classification. For instance the legend-unit MOw (Mountains with Organic Sediments and land-use wetland) seems strange but is infact an area covered with organic deposits in the Dinaric Alps. In table 4.7 is a cross-matrix of the dominant land use types with the abiotic legend-units.

Table 4-7 Cross-matrix of dominant land use type for each landscape type (2nd level)

	a	p	g	h	f	s	b	w
AG							x	
AC							x	
HC	x				x	x	x	
HG					x	x	x	
HI							x	
HV							x	
MA	x		x	x	x	x	x	
MC	x	x	x	x	x	x	x	
MD	x	x		x	x	x		
MI				x		x	x	x
MG	x	x	x	x	x	x	x	
MH					x			
ML	x		x	x	x	x		
MO						x		x
MR	x			x	x	x		
MS	x			x				
MT	x		x	x	x		x	
MV	x		x		x	x	x	
MX							x	
CA	x	x	x	x	x	x	x	
CC	x	x	x	x	x	x	x	x
CI	x	x	x	x	x	x		x
CD	x		x	x	x	x		
CG	x	x	x	x	x	x		x
CH	x		x		x			x
CL	x	x	x	x	x	x		
CO	x		x	x	x	x		x
CR	x	x	x	x	x	x	x	x
CS	x			x	x			
CT	x	x	x	x	x			
CV	x	x		x	x	x		
LA	x	x	x	x	x	x	x	x
LC	x	x	x	x	x	x		x
LD	x				x	x		
LG	x		x	x		x		x
LH			x					
LI	x		x	x	x	x		x
LL	x	x	x	x	x	x		
LO	x		x	x	x	x		x
LR	x	x	x	x				
LS	x		x	x	x	x	x	x
LT	x		x	x	x			x
LV	x	x				x		

From table 4.7 it is obvious that agricultural use of the land is dominant for lowlands and hills where forests, shrubs and open categories are dominant in the high mountains and alpine areas. In the following section an example of a detailed legend description is given for the Netherlands.

Possible example of a full legend-description for the Netherlands

For the different legend-units of the European classification within the Netherlands a description is available as an example of how these may be presented. The descriptions are built up using the following order: altitude – parent material – soil type – geomorphology – landscape characteristics.

Legend-descriptions for a few selected classifications in the Netherlands may look like the following:

CTa
Hills with average elevation of 200-300 metres above msl (mean sea level). Loamy sediments with locally bedrock at shallow depth. Quite large elevation differences over short distances (slopes) from flat plateau levels to river and dry valleys. The higher elevated plateau levels are open with arable land while the slopes and valleys reflect small scale landscapes with valuable characteristics such as old hollow roads, graften and hedgerows.

LAa
Lowlands with elevations around or below msl. Clay deposited by the sea is the main parent material. Landforms that are present do not exceed altitudes of 1.5 meters and consist of sea-related landforms such as old creeks and creek-ridges developed by relief-inversion. However large areas are flat. Also men-made polders are included in this unit. Very open landscapes with arable land and a typical rational parcel pattern.

LAg
Lowland with alluvial riverine deposits several meters above msl. Parent material differs from sands to clays and intermediate deposits. Along the old and present rivers channels natural levee’s are present where further from the channel lower elevated areas are present where heavy clays were deposited. The natural levee’s are characterised by fruit trees and arable land where the lower elevated areas are characterised by pastures.

LOg
Lowlands with elevations around msl. Peat is the parent material here showing no significant elevations. Thickness of the peat-layer differs from 1 to over 10 meters. Landforms are rare but waters present usually reflect old creeks or peat-rivers. The landscape is very open with a characteristic pattern of land reclamation where parcels are narrow and very long (opstrekkende verkaveling). In some areas these pattern have remained relatively unchanged over the past 1000 years. Land-use is mainly pasture because the soil water table is just beneath the soil surface.

LSh

Lowland with sandy parent material with elevations above msl (mean sea level). The parent material consists of eolian and glacial deposits. Typical soils in this area are podzols. Landforms consist of land dunes, ice-pushed ridges and small rivers. Landscape is quite divers with arable land, pastures, heather and forest.

4.7 Validation

4.7.1 the Netherlands

A visual comparison of the European Landscape Classification with the Dutch landscape classification learns us that, taken into account the scale of the European landscape map (1 to 5.000.000), the boundaries between the major landscapes are present.

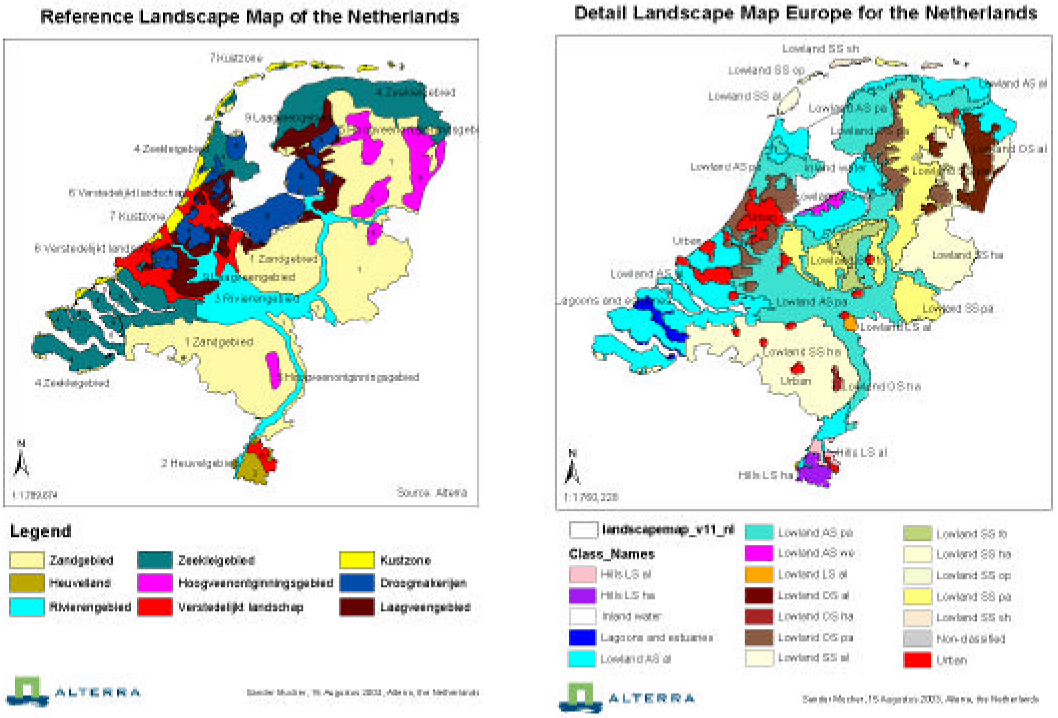


Figure 4.12 Comparison of the Dutch national landscape map (left) and a detail of the European Landscape Map for the Netherlands (right)

In the southern and eastern part the same picture exists for the sandy sediments (see figure 4.12). This also complies for the Rhine-Meuse delta in the central part of the Netherlands. A closer examination with the Dutch landscape classification also shows that there are some important boundaries not present. This is the case for the relatively high ice-pushed ridges of the Veluwe. This area is now part of the Lowland Alluvium area. Explanation for this omission is of course the altitude classes that have been used for the classification where lowland is defined as areas with elevations between 0-100 metres; the central ice-pushed ridge of the Veluwe does not exceed this elevation. The coastal dunes, also an important feature of the Dutch landscape are incomplete in the European classification; one reason is that their altitude falls within the 0-100 metres interval of the Lowland areas but an other important reason is that this landscape type was too small in the segmentation process. Moreover, the coastal dunes can not be extracted directly from the CORINE land cover database because dunes covered with forest or grassland are respectively classified as forest or grassland. The best opportunity for extraction of coastal dunes would be provided by the European Soil Database (see figure 4.12).

Another important boundary in the Dutch landscape classification that is lacking in the European Landscape Classification is the transition from the river alluvium into organic material towards the West. This is a result from the fact that these areas correspond in parent material (alluvium), however, looking in more detail the alluvial sediments in the western part of the country are covered by organic deposits. Finally, the boundaries for organic materials in the European classification do not correspond too well with the those in the Dutch classification which is partly due to the errors in the European Soil Database (see figure 4.12 and 4.13). What is better presented in the European Landscape Map than in the Dutch Landscape map are the urban agglomerations which are very roughly delineated in the Dutch landscape map and misses the large urban agglomeration outside the provinces Noord and Zuid-Holland. Moreover, the present land use is not well reflected in the Dutch landscape classification.

In general the European classification proves to be rather well connected the Dutch landscape map. For some important boundaries adjustments should be considered in the European Landscape Classification. The Dutch landscape classification is based on detailed soil and geomorphological maps with data on land reclamation and is therefore an important source for validation.

A large advantage of the European Landscape Classification is that its selection of boundaries is consistent, crisp and transparent based on the underlying layers: topography, parent material and land use. However, if misclassifications do occur in one of the three underlying layers this is reflected in the European Landscape Classification. The fact that the European Landscape Classification lacks information on the land use history is a limiting factor but was so far difficult to collect at the European scale.

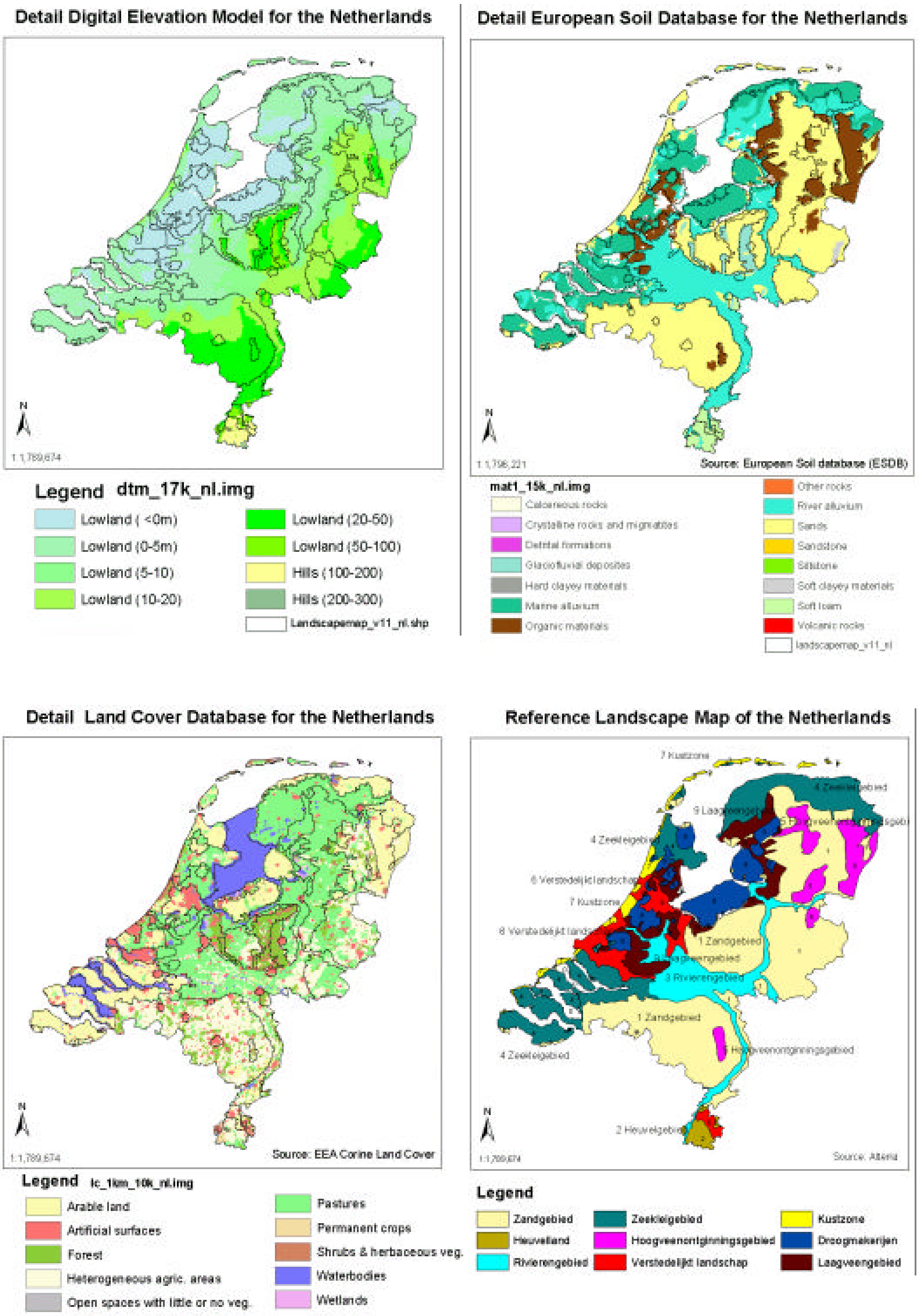
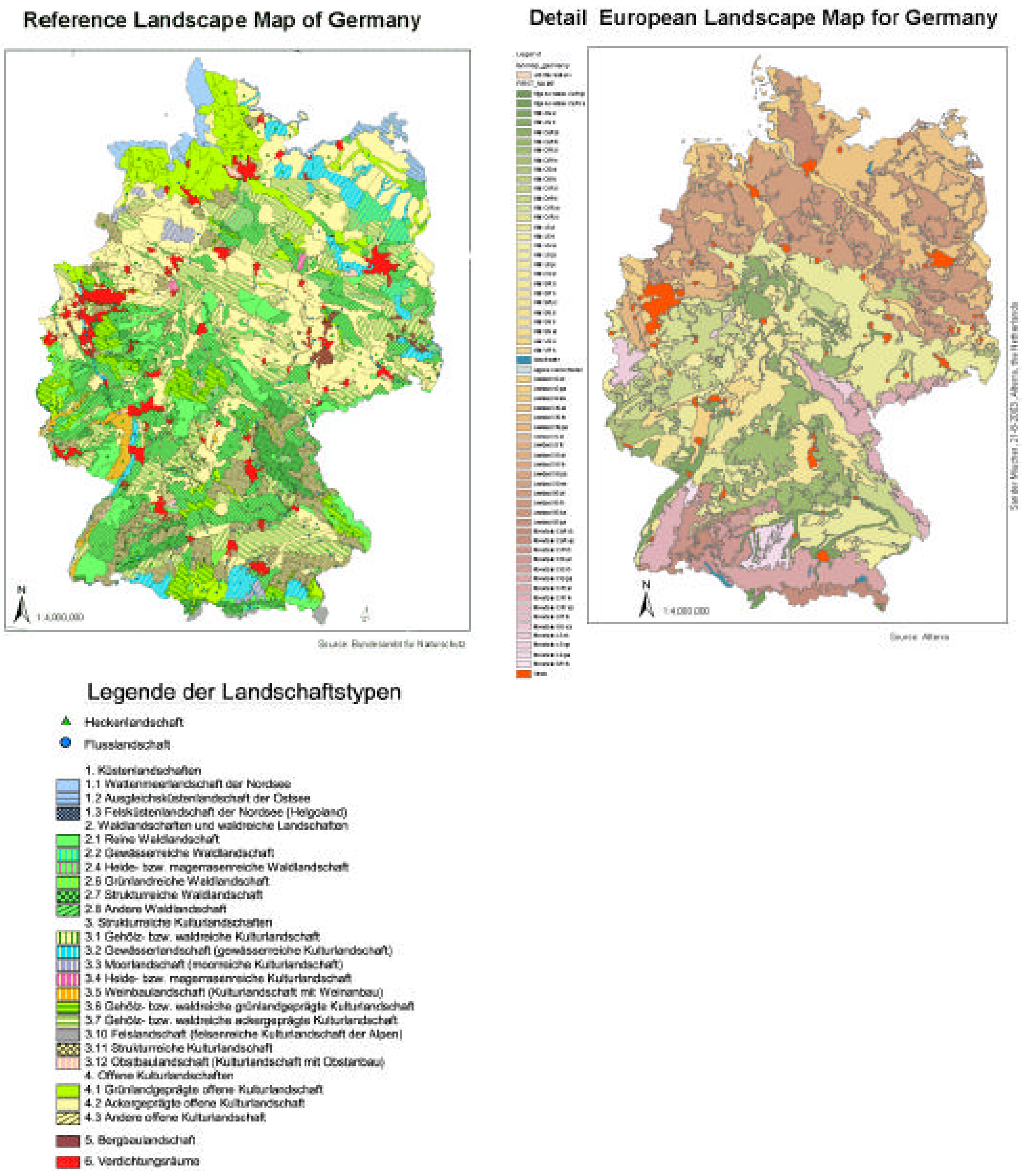


Figure 4.13 The underlying data sources for the construction of the European Landscape Classification here being shown for a detail of the Netherlands

4.7.2 Germany

For Germany a landscape map is available from the Bundesambt für Naturschutz. Unfortunately, the German landscape map is until now only available as a picture and not as a spatially-explicit GIS coverage, which limits the comparison. However, in general there is a rather good correspondence in the general patterns between the two maps.



Reference Landscape Map of Germany

Detail European Landscape Map for Germany

Source: Bundesambt für Naturschutz

Source: Alterra

Figure 4.14 Comparison of the Landscape Map of Germany from the Bundesambt für Naturschutz (left) and a detail for Germany of the European Landscape Map (right)

Where the boundaries in the European Landscape Classification deviate from the German landscape map it is difficult to explain why without a proper background knowledge of the German Landscape Map. All boundaries in the European landscape map can be explained on basis of the underlying layers: topography, parent material and land use. Probably the German landscape map is based on much more expert knowledge which is more difficult to uncover. For example in the Southern part of Germany the landscape type “Gewässerreiche Kulturlandschaft ” exists, which is a lake-rich landscape type, however, according to the CORINE land cover database (and therefore within the European Landscape Classification) there do not occur that many lakes (for example near the Bodensee). But it is also possible that there is a difference is scale, generalisation and explanation. Therefore it becomes very important that landscape experts from other countries will use the European Landscape Classification and comment on its usefulness.

4.8 Conclusions and perspectives

The construction of a European landscape classification has been and still is a major challenge. The use of a consistent framework, thematic data sources with a high spatial accuracy and new techniques in object identification can be considered as a major breakthrough in the field of European landscape mapping. However, it is still too early to conclude that we have a completed product, therefor the European Landscape Classification still has to be validated in a broader sense. Major improvements in characterisation are still needed for the landscape types in terms of its cultural history and landscape patterns and herewith the general description of the landscape types. Also extension of the European Landscape Classification to a larger part of Europe is highly required. Moreover, also improvements are needed in terms of spatial identification of certain landscape types such as the coastal dunes.

The validation of the European Landscape Classification is also considered as not being a straightforward exercise. The reason for this is that for validation use is made of national landscape classifications. However, these landscape classifications differ often very much in methodology, underlying data sets, methods of delineation and spatial scale (even within one country). For this reason they are difficult to compare and not straightforward to use in any validation. The selection of boundaries between different landscape types in a certain landscape map is difficult to see through because they are often based on expert knowledge and do not reveal the underlying data sources. This is also considered as a major advantage of the European landscape Classification which is completely consistent and transparent in its selection of boundaries between landscape types. Expert knowledge should be used in the characterisation and description of the landscape types while the delineation itself should be based on hard geographic data sets.

We hope that the European Landscape Classification will serve as a common reference framework for future landscape mapping activities and that further integration of the numerous national and regional mapping initiatives within this European framework will be considered so that in the end the European Landscape

Classification can be used as a basic reference framework for landscape assessments and monitoring of the environmental and landscape quality of the numerous and precious European landscapes.

5 Discussion and outlook

Focusing at Europe's terrestrial ecosystems at the landscape level, this SEO project was specifically designed to fill significant data gaps on the basis of the most actual state-of-the-art data and to advance our knowledge. The crucial linkage between the environmental dimension and the landscape aspects of sustainability has been created by developing two closely related spatial classifications:

- the Environmental Classification of Europe and;
- the European Landscape Classification,

both as parts of an overarching *landscape concept* that links human activities and terrestrial ecosystems.

The Environmental Classification of Europe has been constructed using and improving tried-and-tested statistical procedures using newly available data sets. It shows significant correlations with other principal European ecological data sets. As such it can serve as a statistically robust stratification and is appropriate for monitoring purpose using strategic random sampling for resource assessment, for measurement of change and for modelling. The classification is already being applied in various projects. The Environmental Classification of Europe is a finished product and minor changes can be expected. However, its descriptive statistics will still have to be made in the coming period. Unfortunately, this is not the case for the European Landscape Classification which is still being validated at this moment and needs improvements such as the description of the landscape types in terms of landscape pattern and extension to entire Europe.

The following section illustrate the applications of the environmental classification and the possible future validation and application processes that should be considered as part of the further development of both products presented in this report.

5.1 Application of the Environmental Classification

The Environmental Classification of Europe can be applied in field research, reporting and scenario building. Depending on the need it can be used as aggregated zones for environmental overviews (Jongman and Bunce, 2000, Petit et al., 1998) or in its full detail for strategic sampling and detailed reporting. The following major applications are envisaged for the EnC, with existing outputs being available from projects mainly at the national level. References are given to examples of such exercises.

- *Monitoring and Distribution and change of resources* A fundamental requirement for many planning situations is to assess where the main centres of a given resource are distributed. Haines-Young et al. (2000) have shown how the methodology can be used at a national level (in the UK) to carry out such mapping. Brandt et al. (2001) have discussed the complementary nature of surveillance and monitoring and discuss the principles involved. There is a well-established need to monitor land use change and ecological change so that appropriate policies can be developed. Monitoring needs especially strict protocols to separate real change from artefacts of sampling.

- *Integration and co-ordination with other databases.* Bunce et al. (1993) showed how the classification methodology could be used to integrate disparate data sources e.g. for moths in GB (Figure 6). At the European level Bunce et al. (1997) showed how the original ITE classification could be used to place data from various European databases into a common framework e.g. agricultural statistics, land cover and forest types. Whilst the different scales of such databases need to be taken into consideration, such exercises can be used to identify hotspots for biodiversity. Currently however, the availability of data for such exercises remains limited, but as the potential of the approach is shown this situation might change.

- *Identification of gaps within designated areas.* Bischoff & Jongman (1993) have shown how co-ordination of existing data can reveal gaps within areas designated for nature conservation. Currently a range of nine projects e.g. Natura 2000, are involved in review exercises to assess the representativeness of existing sites submitted by the member states. The present framework could assist this process by supplying a statistical comparison for the assessment of experts.

- *Assessment of resources through strategic sampling.* One of the main objectives of constructing the EnC was to produce a system of strategic sampling for Europe. The BioHab (Coordination of Biodiversity and Habitats for Europe) project within the EU-Fifth Framework Research Programme is designed as the first stage along this process. The main concept behind this project is to develop more complete, specific and user-friendly tools in support of implementing the Habitat Directive, including NATURA 2000, as well as other policy initiatives, e.g. EMERALD. The EnC provides a framework to assign regional differences to comparable habitats in Europe. By using an Environmental Classification system that has links with climate and biogeographical diversity these differences can be addressed and integrated if needed.

- *Modelling change and scenario testing of climate change and socio-economic parameters.* The environmental classification is ideal suited for modelling change. The classes can be used in linear programmes to produce optimal solutions. Parry et al. (1996) have demonstrated how this can be done for Britain and the same technique could readily be applied at a European scale. As with several applications described above such exercises could have a direct input into policy. Currently within the EU fifth framework project ATEAM (Advanced Terrestrial Ecosystem Analysis and Modelling) a scenario exercise is being carried out with the EnC and updated climatic change scenarios (Metzger, in prep).

5.2 Landscape Character Assessment

A decade of environmental reporting on the state and trends of European biodiversity has demonstrated that the protection of species and habitats in isolation does not guarantee the sustainable development of landscapes. The fragmentation of semi-natural habitats that has taken place in agricultural landscapes is a major issue in this context. It is only at the landscape level that comprehensive planning of natural resources, including their cultural values, can be adequately carried out.

An analysis of the existing monitoring programmes at the national level shows that "Landscape Character Assessments" have become an important tool for the conceptual and spatial integration of a wide range of factors relevant for the state and trends of terrestrial ecosystems. The large diversity of landscapes characteristics – especially at the European level – must be considered as a key methodological challenge when assessing the vulnerability and resilience of terrestrial ecosystems with regard to pressures from land use and land cover changes. Landscape characteristics such as topography, geomorphology, structural elements (e.g. hedges, trees) and land use patterns form the life-support systems for terrestrial ecosystems. The objective of a harmonised landscape character assessment is to develop reliable indicators and a geographic reference base that allows assessing the role and function of land management for the protection/conservation of important natural and semi-natural landscapes in Europe.

Landscape Character is a distinct and consistent pattern of elements in the landscape that makes one landscape different from another, rather than better or worse. The elements of landscape depend on the combination of factors such as geology, landform, soils, vegetation, land use, field and human settlement patterns; factors may be considered in their past, present and/or future contexts. Character definitions highlight the interrelationships of biophysical *and* cultural factors."

So, Landscape Character can be seen as an expression of the way in which the natural and cultural elements of terrestrial ecosystems combine to create unique places with specific ecological, economic as well as social functions and values.

Landscape Character Assessment is a set of tools that are scientifically sound, region-specific and stakeholder orientated, designed to describe landscape character. It can be applied at a range of scales, from the national, though to the regional and local. It may also integrate landscape character analysis with biodiversity assessments, the analysis of historical character, air, water and soil quality, and socio-economic functions such as recreation and agriculture.

Characterisation is a way of identifying areas of distinctive character, classifying and mapping them, and describing and/or explaining their character. It concentrates on what makes one area different or distinctive from another. It can result in one or both of the following:

- Landscape character types (these may be generic classifications or typologies)

- Landscape character areas (these are single and unique areas that may capture a ‘sense of place’ for people)

The end product of characterisation is normally a map of landscape character types and/or areas, together with relatively value free descriptions of the character and the key characteristics that are most important for defining this character. The characterisation of areas does not necessarily involve making quality judgements about them (except insofar as we have to decide what aspects are essential to character).

The European Landscape Classification is considered to provide a key reference framework for the further identification of landscape character types at the European level. Obviously, a number of critical fine-scale information layers such as on cultural attributes and landscape pattern are still missing to fully address landscape character as recognised as most regional or national levels. Nevertheless, the developed Landscape Character Typology can be considered a valuable first step towards integrating a wide range of more detailed parameters.

5.3 State and trend assessments

Judgements are based on the results of the characterisation process and involves making judgements about landscape character to inform particular decisions related to the application. For example landscape characterisation may be used as an input into development planning, designing special areas for protection or targeting agri-environmental measures in multifunctional landscapes. The characterisation process may also be used as a framework for, or as an input into, the identification or evaluation of ecosystem or landscape functions for wider assessment applications.

Of course, the characterisation and judgement parts of landscape study cannot be entirely separated. Landscape Character Assessment techniques try to minimise the latter, and focus mainly on the more 'factual' aspects of landscape.

As mentioned earlier (in section 2.3.9), the landscape character assessment as a third layer is crucial in terms of the future Landscape State Assessment. Though methodologically still part of the Landscape Typology, the goal is to use existing environmental and socio-economic data for projecting ‘Landscape Quality Units’ that can provide the rational for interpreting national and regional data on landscape state. The objective is to further break down or characterise the spatial units identified as ‘European Landscape Typology.

5.4 Outlook

As the project title indicates, the European Environmental Classification and European Landscape Typology is meant to mark the beginning of a Europe-wide inter-agency and network co-operation on developing a systematic approach towards assessing the environment at the landscape level. The emphasis is on “systematic” as the project is designed to go beyond a mere compilation and review process, but to contribute to the development of methodological advances in a number of fields, namely:

- *Monitoring biodiversity, landscapes and land use.*
  Development of monitoring methods and systems of surveillance for species and habitats of Community interest for Agri-environmental measures and the implementation of the Water directive require consistent methods that take European differences into account. Basis for these differences is a zoning of Europe into more or less homogeneous areas. Environmental and Landscape classifications are the basis for cost-effective and statistically reliable monitoring systems.

- *The identification of landscape indicators as tools for policy implementation*:
  During the implementation of the 5th Environmental Framework Programme, landscape indicators have received increasing attention by both the policy and research community. The European Commission, OECD, Eurostat and the Joint Research Centre started to develop candidate landscape indicator and landscape assessment prototypes. The lesson learned from these activities is that the methodological progress that has been achieved was lacking operational tools for concrete applications. Complex indicator types such as “landscape coherence”, “cultural heritage” and even “adequateness of land use type” confronted the practitioners with difficulties in terms of data harmonisation, data interpretation and geographic referencing. Though various large-scale, computer-based assessment procedures have been run, the results proved to be too generic, omitting regional characteristics and hence lacking policy relevance.
  The topologies are meant to fill this gap by putting much more emphasis on analysing the regional context and to build upon existing landscape indicators as they are already used in national programmes. Indicators deriving from this analysis are meant to be organised on the basis of agreed-upon criteria, taking into account international standards and policy requirements.

- *The validation of the European Landscape Typology and Map*:
  A recent review on existing national approaches to landscape typology and mapping has demonstrated that many countries have developed such tools and are making already active use of them for their reporting and policy implementation. While some of the developed techniques and concepts are rather sophisticated, there is a lack of integration into wider European approaches. At the European level, wider international co-operation is needed in order to achieve common standards for widely applicable spatial references. Current international approaches (e.g. the landscape map of the EEA’s Dobris State-of-the-Environment report) are rather generic (frequently lacking the cultural dimension) and stand isolated from most national approaches, blocking the exchange of data and lacking policy relevance. It is a wider set of *policy-oriented* objectives that should drive the process rather than purely technical or scientific considerations.

Through projects such as the European Landscape Character Assessment Initiative (ELCAI) it is intended to validate the European typology by initiating a bottom-up process towards European landscape mapping and typology development, guided by international data management criteria and targeting at European policy objectives. Though it cannot be expected that the project will result in a complete European map of landscapes (not all countries can participate), the adequate methodological approach will be developed and a draft map for the participating countries shall be delivered.

- *The development of early participatory decision-making techniques:*
  One of the future challenges is it to explore new avenues in inter-agency co-operation, linking activities and decision-making processes at the regional, national and international level. In the light of the growing significance of the role of the regions in the context of European policy development and implementation, this project intends to use its partnership consortium as ‘focal points’ for a wider co-operation between regional and national authorities when providing contributions to the emerging landscape character assessment. Especially the identification of suitable landscape indicators including the benchmarks for data interpretation shall go beyond the boundaries of the project network by establishing anchors in the wider policy field. It is also intended that ELCAI network partners develop a multi-disciplinary approach by consulting experts from related fields such as agriculture, regional planning, tourism or others. The goal is to create a wider sense of ownership within the regions of concern and to use network partners not only as data suppliers but also as communicators for stakeholders at the interface between regional, national and international assessment processes.

This SEO project on the Environmental Classification of Europe and the European Landscape Classification provides another step in developing indicators and area typologies towards state-of-the-art communication tools. As demonstrated through previous research project, a wide range of policy-relevant landscape issues need to be addressed – for many of which there is no existing explicit political endorsement. The amount and accuracy of data is actually a lesser limiting factor than the lack of clearly defined *implementation targets*. The term ‘implementation targets’ relates to the policy field and points at the need to set priorities and to define clear objectives when developing landscape assessment schemes. Policy choices, however, demand transparent arguments that are backed and understood by the majority of stakeholders, scientists and policy makers involved in the process. If societal groups are confronted with a wide range of random assessment procedures of different philosophies and orientation, there is little chance that messages can be communicated in constructive (policy-relevant) ways.

References

Aalen, F.H..2001. *Landscape development and change.* In: B.H.Green & W.Vos, 2001, Threatened landscapes: conserving cultural environments. Span Press, London: p.3-20.

Bailey, R.G. (1985) The factor of scale in ecosystem mapping. *Environmental Management., 9, 271-276.*

Banchmann, C.M., Donato, T.F., Lamela, G.M., Rhea, W.J., Bettenhausen, M.H., Fusina, R.A., Du-Bois, K.R., Porter, J.H., & Truitt, B.R. (2002) Automatic classification of land cover on Smith Island, VA, using HyMAP imagery. *IEEE Transactions on Geoscience and Remote Sensing, 40, 2313-2330*.

Brandt, J., Holmes E. & Agger, P., 2001. Integrated monitoring on a landscape scale - Lessons from Denmark. Pages 31-41 in Groom, G. & Reed, T. (editors) "*Strategic landscape monitoring for the Nordic countries.*" (TemaNord Series 2001:523). Copenhagen. Nordic Council of Ministers, pp. 31-41

Bishop, Y.M.M., Fienberg, S.E., & Holland, P.W. (1975) *Discrete Multivariate Analysis: Theory and Practice*. MIT Press, Cambridge, MA.

Bischoff N.T. and Jongman R.H.G. 1993. *The development of rural areas in Europe: the claim for Nature*. Netherlands Scientific Council for Government Policy Report V79.

Bohn, UU. G. Gollub and C. Hettwer, 2000. Karte der natürlichen Vegetation Europas: Maßstab 1: 2 500 000. *Map of the Natural Vegetation of Europe: scale 1: 2.500. 000.* Bundesamt für Naturschutz, Bonn-Bad Godesberg.

Bullock, P., Jones, R.J.A., & Montanarella, L. (1999). *Soil Resources of Europe*, Rep. No. EUR 18991. Office for official publication of the European Communities, Luxembourg.

Bunce, R.G.H., Howard, D.C., Hallam, C.J., Barr, C.J., & Benefield, C.B., 1993. *Ecological consequences of land use change*. (Countryside 1990 vol.1). London: Department of the Environment.

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., Clarke, R.T., Howard, D.C., & Lane, A.M.J., 1996b. ITE Merlewood Land Classification of Great Britain. *Journal of Biogeography, 23, 625-634.*

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

Bunce, R.G.H., J.W. Watkins, P. Brignall & J. Orr., 1996d. A Comparison of the Environmental Variability within the European Union States. In: R.H.G. Jongman (Ed). *Ecological and Landscape consequences of land use change in Europe*. Proceedings of the first ECNC seminar on land use change and its ecological consequences. pp 82-91. European Centre for Nature Conservation, Tilburg.

Bunce, R.G.H., Watkins, J.W., & Gillespie, M.K., 1997. *A stratification system for gathering agricultural and environmental data from different sources in the EU*. In: CAP and the regions: building a multidisciplinary framework for the analysis of the EU agricultural space, edited by C.Laurent & I.Bowler, 187-196. Paris: Institut National de la Recherche Agronomique.

Bunce, R.G.H., Carey, P.D., Elena-Roselló, 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*.

Cate, J.A.M. ten en Maarleveld, G.C., 1977. *Geomorfologische kaart van Nederland schaal 1:50000: toelichting op de legenda*.

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.

Council of Europe; UNEP & European Centre for Nature Conservation, 1996. *The Pan-European Biological and Landscape Diversity Strategy. A vision for Europe's natural heritage*.

Council of Europe, 2000. *European Landscape Convention.* Florence, 20 October 2000. European Treaty Series – No. 176.

Delbaere, B.C.W, 1998. Facts and figures on Europe's biodiversity; state and trends. ECNC, Tilburg 115 pp.

Delbaere, B.(ed.) 2003. *Enironmental Risk Assessment for European Agriculture (ENRISK) – Interim Report.* European Centre for Nature Conservation (ECNC), Tilburg, May 2003.

DMEER, 1997. *Digital Map of European Ecological Regions*. Final draft for comments (version September 1997). Produced by the Higher Institute of Statistics and Information Management IISEGI).

Easterbee, N., Hepburn, L.U., & Jefferies, D.J. (1991). *Survey of the status and distribution of the wildcat in Scotland 1983-1987*. Nature Conservance Council for Scotland, Edinburgh.

EEA (2000). *CORINE land cover technical guide - Addendum 2000*, Rep. No. 40. European Environment Agency, Copenhagen.

EEA (2002). *The Biogeographical Regions Map of Europe*. European Environment Agency, Copenhagen.

EEA, 2003. *Indicator Reporting on the Integration of Environmental concerns into Agricultural policy (IRENA)*, joint activity between DG Agriculture, DG Environment, DG Eurostat, DG JRC and the EEA to develop 35 agri-environment indicators described in Commission Communications COM(2000) 20 and COM(2001) 144.

Elena-Rosselló, R., 1997. *Clasificatión Biogeoclimática de España Peninsular y Balear.* Ministerio de Agricultura, Pesca y Alimentación, Madrid.

Embleton, C., (ed.) 1984. *Geomorphology of Europe*. MacMillan Publishers, London. 465 pp.

ERDAS, 1997. *ERDAS Field Guide*, 4th edn. ERDAS Incorporated, Atlanta, USA Georgia. 628 pp.

ESRI, 2002. *ArcGis 8.2*. Environmental Systems Research Incorporated. Redlands California.

EU Council Directive, 1992. 92/43/EEC. *Natura2000 Network on the conservation of natural habitats and of wild fauna.* COUNCIL DIRECTIVE 92/43/EEC (1) of 21 May 1992. The Council of The European Communities.

EU Council of Europe, 1987. *Biogeographic Regions*. ISBN 42-871-1047-6.

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.

Faust, N.L., 1989. *Image Enhancement.* Marcel Dekker Inc., New York.

Firbank, L.G., Barr, C.J., Bunce, R.G.H., Furse, M.T., Haines-Young, R.H., Hornung, M., Howard, D.C., Sheail, J., Sier, A., & Smart, S.M. (2003) Assessing stock and change in land cover and biodiversity in GB: an introduction to Countryside Survey 2000. *Journal of Environmental Management, 67, 207-218*.

Gasc, J.-P., Cabela, A., Crnobrnja-Isailovic, J., Dolmen, D., Grossenbacher, K., Haffner, P., Lescure, J., Martens, H., Martínez Rica, J.P., Maurin, H., Oliveira, M.E., Sofianidou, T.S., Veith, M., & Zuiderwijk, A.., 1997. *Atlas of amphibians and reptiles in*

Europe. Societas Europaea Herpetologica and Muséum National d'Histoire Naturelle, Paris.

Green, B.H. & W.Vos. 2001. *Threatened landscapes: conserving cultural environments.* Span Press, London: 161 pp.

Hagemeijer, W.J.M. & Blair, M.J. (1997) *The EBCC atlas of European breeding birds, their distribution and abundance*. Published for European Bird Census Council Poyser, London.

Haines-Young, R.H., Barr, C.J., Black, H.I.J., Briggs, D.J., Bunce, R.G.H., Clarke, R.T., Cooper, A., Dawson, F.H., Firbank, L.G., Fuller, R.M., Furse, M.T., Gillespie, M.K., Hill, R., Hornung, M., Howard, D.C., McCann, T., Morecroft, M.D., Petit, S., Sier, A.R.J., Smart, S.M., Smith, G.M., Stott, A.P., Stuart, R.C., & Watkins, J.W. (2000) *Accounting for nature: assessing habitats in the UK countryside.* London:DETR.

Hill, M.O., 1979a. *DECORANA, a FORTRAN program for detrended correspondence analysis and reciprocal averaging*. Cornell University, Ithaca, New York.

Hill, M.O, 1979b. TWINSPAN – a Fortran program for arranging multivariate data in an ordered two-way table by classifying the individuals and attributes. *Section of Ecology and Systematics.* Ithaca, New York, USA: Cornell University.

Jalas, J. & Suominen, J., eds. (1976) *Atlas Flora Europaea, distribution of Vascular Plants in Europe. Vol. 3* The Committee for Mapping the Flora of Europe & Societas Biologica Fennica Vanamo, Helsinki.

Jensen, J.R. (1996) *Introductory Digital Image Processing*: A Remote Sensing Perspective Prentice-Hall, Englewood Cliffs, New Jersey.

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 pp. 17-29.*

Jongman, R.H.G. and Bunce, R.G.H. 2000. Landscape classification, scales ad biodiversity in Europe. In Ü Mander and R.H.G. Jongman (Eds). *Consequences of Land use change in Europe pp 11-38.*

Jongman, R.H.G., R.G.H. Bunce, M.J. Metzger, C.A. Mücher and D.C. Howard, 2003. A statistical Environmental Classification of Europe: objectives and applications. *Submitted to special issue Landscape Ecology.*

Kendrew, W.G. 1953. *The climate of the continents*, 4th edition London Oxford University Press. 607 pp.

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..1995. *Hierarchical concepts in landscape ecology and its underlying disciplines; the unbearable lightness of a theory*. Report 100, The Winand Staring Centre. 144 pp.

Klijn,J.A.1999. Developments in European landscape assessment. In D.M.Wascher (Ed). Landscapes and sustainability; Proceedings of the European Workshop on landscape assessment as a policy tool. ECNC/Countryside Agency, Strassbourg. : p.58-61.

Klijn, J.A.2003. *Driving forces behind landscape transformation in Europe, from a conceptual approach to policy options: agriculture and climate change as examples*. In: R.Jongman(Ed) in prep. Proceedings of the Frontis workshop/ Kluwer.

Klijn, J.A. and Vos, W., 2000. *From landscape ecology to landscape science*: proceedings of the European congres "Landscape ecology: things to do - proactive thoughts for the 21st century", organised in 1997 by the Dutch Association for Landscape Ecology (WLO) on the occasion of its 25th anniversary. Kluwer Dordrecht, ISBN 0792369211, 163 p.

Köppen, W., 1936. Versuch einer Klassification der Klimat, Vorsuchsweize nach ihren Beziehungen zur Pflanzenwelt. *Geographische Zeitschrift, 6, 593-611 ; 657-679.*

Leathwick, J.R., Overton, J.M., & McLeod, M. (2003a) An environmental domain classification of New Zealand and its use as a tool for biodiversity management. Conservation Biology, in press.

Leathwick, J.R., Wilson, G., Rutledge, D., Wardle, P., Morgan, F., Johnston, K., McLeod, M., & Kirkpatrick, R. (2003b) Land Environments of New Zealand Bateman, Auckland.

Loveland, T.R. and Belward, A.S., 1997. The International Geosphere Biosphere Programme Data and Information System global land cover data set (DISCover). In *Acta Astronautica, Vol 41, Issues 4-10, pp 681-689.*

MacDonald, D.W., Bunce, R.G.H., & Bacon, P.J. (1981) Fox populations, habitat characterisation and rabies control. *Journal of Biogeography, 8.*

Martinez & Penas, 1996. *Biogeographic Map of Europe.*

Meeus, J.H.A., Wijermans, M.P., & Vroom, M.J. (1990) Agricultural landscapes in Europe and their transformation. *Landscape and Urban Planning, 18, 289-352.*

Meeus, J.H.A., 1995. Pan-European landscapes. In: *Landscape and Urban Planning 31. Pp. 57 – 79.*

Meeus, J.H.A., J.D. van der Ploeg and M.P. Wijermans, 1998. *Changing agricultural landscapes in Europe: continuity, deterioration or rupture?* IFLA Conference. Rotterdam.

Metzger, M.J. R.G.H. Bunce, R.G.H. Jongman, C.A. Mücher and J.W. Watkins. A statistical stratification of the environment of Europe. *Submitted to Journal of Global Ecology and Biogeography.*

Metzger, M.J. & Schröter, D. (in prep.) A spatially explicit and quantitative vulnerability assessment for Europe.

Milanova, E.V. & A.V. Kushlin, 1993. *World map of present day landscapes, an explanatory note.* Dept of World Physical Geography and Geoecology. Moscow State University, UNEP.

Mitchell, T.D. (in prep.) A comprehensive set of climate scenarios for Europe and the globe.

Mitchell-Jones, A.J., Amori, G., Bogdanowicz, W., Krystufek, B., Reijnders, P.J.H., Spitzenberger, F., Stubbe, M., Thissen, J.B.M., Vohralik, V., & Zima, J. (1999). Atlas of European mammals. In. Academic Press.

Mücher, C.A., 1992. *A discussion on land use classifications. An amalgam of methods.* Internal report, Department of Tropical Crop Science, Wageningen Agricultural University, The Netherlands.

Mücher, C.A. et al., 2001. *Development of a consistent methodology to derive information on a European scale from Remote Sensing for environmental monitoring.* The PELCOM report. Alterra-rapport 178. CGI – report 6. Alterra Green World Research, Wageningen.

New, M., Lister, D., Hulme, M., & Maken, I. (2002) A high-resolution data set of surface climate over global land areas. *Climate Research, 21.*

Ozenda, P., Noirfalise, A., Tomaselli, R., & Trautmann, W. , 1979. *Vegetation map of the Council of Europe member states.* Council of Europe, Nature and Environment.

Pan, Y., Li, X., Gong, P., He, C., Shi, P., & Pu, R. (2003) An integrative classification of vegetation in China based on NOAA AVHRR and vegetation - climate indices of the Holdridge life zone. *International Journal of Remote Sensing, 24, 1009-1027.*

Parry, M.L., Hossell, J.E., Jones, P.J., Rehman, T., Tranter, R.B., Marsh, J.S., Rosenzweig, C., Fischer, G., Carson, L.G., & Bunce, R.G.H. (1996) Integrating global and regional analyses of the effects of climate change: A case study of land use in England and Wales. *Climatic Change, 32, 185-198.*

Petit, S., B.K.Wyatt, L.G. Firbank, D. Howard, R.G.H. Bunce, M.O. Hill, R.D. Swetnam, K.R.Bull, D. Morton, J. Cooper and R.P.B. Foppen. 1998. *Mirabel, Models for Integrated Review and Assessment of Biodiversity in European Landscapes*. Report to the European Topic Centre for Nature Conservation.

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

Regato, P., Castejón, M., Tella, G., Giménez, S., Barrera, I., & Elena-Rosselló, R. (1999) Cambios recientes en los paisajes de los sistemas forestales de España. *Investigación Agraria. Sistemas y Recursos Forestales, 1, 383-398*.

Sheail, J. & Bunce, R.G.H. (2003) The development and scientific principles of an environmental classification for strategic ecological survey in Great Britain. *Environmental Conservation, 30, 147-159.*

Stanners, D. and P. Bordeaux (eds.), 1995. *Europe's Environment; The Dobríš Assessment.* European Environmental Agency, Copenhagen. 676 pp. Office for Official Publications of the European Communities, Luxembourg.

Stomph, T.J., C.A. Mücher and L.O. Fresco, 1997. Environmental Impact of Land Use: A New Basis for Analysis. *The Land, 1997, Vol 1.2, pp 129-142.*

Thunnissen, H.A.M. and H.J. Middelaar, van, 1995. *The CORINE land cover databasde of the Netherlands.* Final report of the CORINE land cover project in the Netherlands. Report 78. SC-DLO (Alterra) Wageningen, the Netherlands.

Task, G.S.D., 2000. Global Soil Data Products CD-ROM (IGBP-DIS). International Geosphere-Biosphere Programme, Data and Information System, Potsdam.

Tou, J.T. & Conzalez, R.C., 1974. *Pattern Recognition Principles.* Addison-Wesley Publishing Company, Reading, Massachusetts.

Townshend, J.R.G., (editor), 1992. *Improved global data for land applications*, IGBP report number 20. (IGBP secretariat, Royal Swedish Academy of Science, Box 50005, S-10405, Stockholm, Sweden).

Udvardy, M.D.F., 1975. *A Classification of Biogeographic Provinces of the World*. In IUCN Occasional Paper, Gland.

Vervloet, J.A.J and T. Spek, 2002. Towards a pan-European Landscape Map; a mid-term review.

Von Humboldt, A. 1867. *Ideeen zu einem Geographie der Pflanzen nebst einem naturgemälde der Tropenländer.* F.G. Cotta, Tübingen.

Wascher, D.M.(ed.), 1998. *Landscapes and Sustainability.* Proceedings of the European Workshop on landscape assessment as policy tool; 25th-26th March 1999 Strasbourg, organised by the European Centre for Nature Conservation and the Countryside Agency of England, United Kingdom, Tilburg, 94 pages

Wascher,D.M.(Ed.), 1999. *Landscapes and sustainability*. Proceedings of the European Workshop on landscape assessment as a policy tool. ECNC/Countryside Agency, Strassbourg.

Wascher, D.M.(ed.), 2000a. *Agri-environmental Indicators for Sustainable Agriculture.* Report from the EU Concerted Action Project FAIR5-PL97-3448. European Centre for Nature Conservation, Tilburg, 200 pages

Wascher, D.M. (ed.) 2000b. *"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 pages.

Wascher, D.M. and Jongman, R.H.G. (eds.), 2003. *European landscapes - classification, evaluation and conservation.* EEA, Environment Technical Reports, European Environment Agency, Copenhagen (in press).

Annex I Inventory of data sources

Introduction

During the development of the conceptual framework for the classification and characterisation of European environments, nine essential thematic layers were identified. As mentioned in section 2.2 these layers follow a functional hierarchy, showing an increased dependency at lower levels (see also Box 2), e.g. vegetation is dependant on specific soil characteristics. In most cases, the lower components in this hierarchy show more regional heterogeneity, making them especially difficult to monitor and map. Environmental scientists therefore frequently interpret primary data sources in order to create European maps of these components, e.g. Potential Natural Vegetation can be interpreted from climate and soil data. Table A1.1 lists the nine thematic layers in their hierarchy and indicates the interpretation level of available data sets.

Table A1.1 Essential thematic layers for environmental and landscape classification

Layer	Component	Dependency	Interpretation level available data	Data sets
Climate	Abiotic	↓	Primary	CRU climate data set
Geology	Abiotic		Not availbale	-
Geomorphology	Abiotic		Primary – available as topography	USGS GTOPO30 (DEM)
Hydrology	Abiotic		Not available	-
Soils	Abiotic		Primary – but some interpretation	FAO-UNESCO Soil Map, European Soil Database
Vegetation	Biotic		Interpreted	Potential Natural Vegetation
Fauna	Biotic		Not available	-
Land use and land cover	Cultural		Interpreted	CORINE, PELCOM, IGBP
Landscape history	Cultural		Not available	-

For geology, geomorphology, hydrology and landscape history no data sets were identified so far that cover Europe for a large part in a consistent way and that are available in digital format. The above mentioned data layers were already shortly discussed in Chapter 2 in terms of their value and inherent existing limitations. In this Annex available digital data sets will be discussed, along with the few existing Environmental Classification of Europe. First the primary data sets are discussed, followed by the interpreted data sets. On basis of this inventory of existing digital data sources a final selection has been made for the construction of a European environmental and landscape classification.

Climate

High-resolution climate data from the Climate Research Unit

The Climatic Research Unit (CRU) of the University of East Anglia, UK, is widely recognised as one of the world's leading institutions concerned with the study of natural and anthropogenic climate change. Together with the Tyndall Centre for Climate Change it offers several high-resolution European and global climate data sets on their website. There are data sets that give the average climate in the recent past, i.e. climatologies, data sets that offer time-series and data sets that offer scenarios of possible futures climates. Furthermore, climate data have been averaged on a country basis to allow international comparison made in conjunction with socio-economic data. Table A1.2 gives a list of the currently available data sets. Table A1.3 explains the abbreviations of the climate variables. All data-sets are limited to the land surface only; the ocean grid boxes are left blank. The 'global' domain also excludes Antarctica.

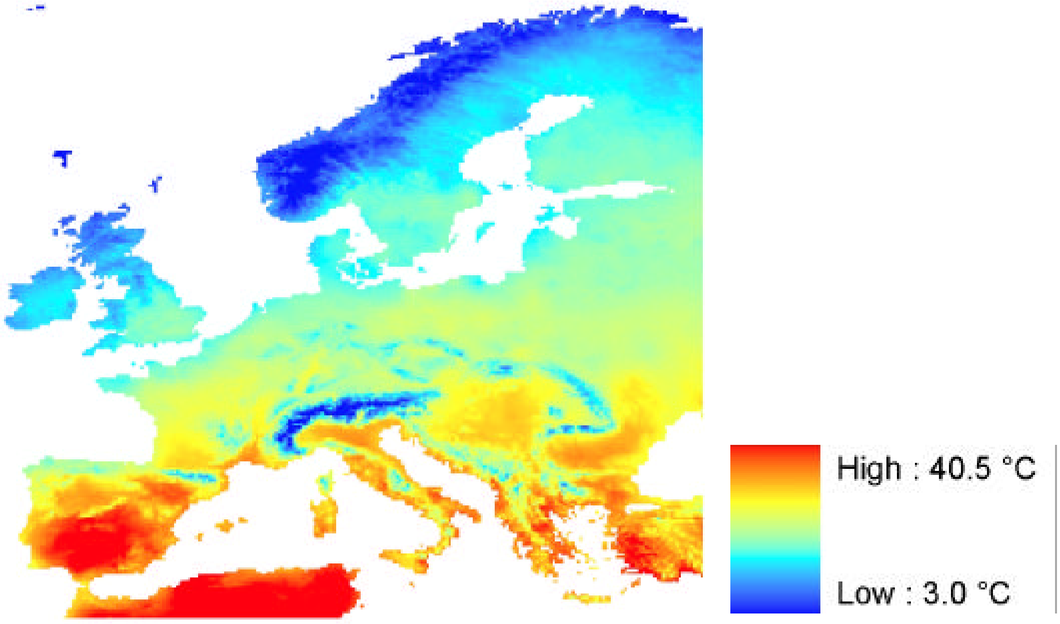


Figure A1.1 Mean maxium July temperature at 10’x10’ resolution as 1971-2000 mean from the TS 1.2 dataset

Table A1.2 Climate data sets available at CRU

Data-set	Space	Time	Variety	Variables	Reference
CRU CL 1.0	0.5°	1961-1990	Climatology	pre, wet, tmp, dtr, vap, spc, cld, frs, wnd	New et al, 1999
CRU CL 2.0	10'	1961-1990	Climatology	pre, wet, tmp, dtr, rhm, ssh, frs, wnd	New et al, 2002
CRU CL 2.1	10'	1961-1990	Climatology	cld, vap	Mitchell et al, 2003
CRU TS 1.0	0.5°	1901-1995	Time-series	pre, tmp, dtr, wet, vap, cld, frs	New et al, 2000
CRU TS 1.1	0.5°	1996-1998	Time-series	pre, tmp	New et al, 2000; extended
CRU TS 1.2	10' Europe	1901-2000	Time-series	pre, tmp, dtr, vap, cld	Mitchell et al, 2003
CRU TS 2.0	0.5°	1901-2000	Time-series	pre, tmp, dtr, vap, cld	Mitchell et al, 2003
TYN SC 1.0	10' Europe	2001-2100	Scenarios	pre, tmp, dtr, vap, cld	Mitchell et al, 2003
TYN SC 2.0	0.5°	2001-2100	Scenarios	pre, tmp, dtr, vap, cld	Mitchell et al, 2003
TYN CY 1.0	Country	1901-1998	Countries	pre, tmp, dtr, wet, vap, cld, frs	Mitchell et al, 2002
TYN CY 2.0	Country	2070-2099	Countries	pre, tmp	Mitchell et al, 2002; extended

The identifying label is made up of:

Institution of origin	Label denoting the type of data-set
CRU = Climatic Research Unit	CL = average climatology
TYN = Tyndall Centre for Climate Change	TS = time-series
	SC = set of scenarios
	CY = set of country averages

(Source: http://www.cru.uea.ac.uk/cru/data/hrg.htm)

Table A1.3 Abbreviations used for the climate variables

Label	Variable	Units	label	variable	Units
Cld	Cloud cover	Percentage	*Ssh*	sunshine duration	Hours
Dtr	Diurnal temperature range	Degrees Celsius	*Tmp*	daily mean temperature	degrees Celsius
Frs	Frost day frequency	Days	*Vap*	vapour pressure	hecta-Pascals
Pre	Precipitation	Millimetres	*Wet*	wet day frequency	Days
Rhm	Relative humidity	Percentage	*Wnd*	Wind speed	metres per sec.

Topography

GTOPO30 is a global digital elevation model (DEM) resulting from a collaborative effort led by the U.S. Geological Survey's EROS Data Center in Sioux Falls, South Dakota. Elevations in GTOPO30 are regularly spaced at 30-arc seconds (approximately 1 kilometre). GTOPO30 was developed to meet the needs of the geospatial data user community for regional and continental scale topographic data. The completion of global coverage of 30-arc second elevation data finished in 1993. The DEM is based on data from 8 different sources of elevation information, including vector and raster data sets. The data of the European continent originate almost completely from the Digital Chart of the World. Figure A1.2 shows a detail of the global elevation model USGS GTOPO30 for Europe. GTOPO30 is a global data

set covering the full extent of latitude from 90 degrees south to 90 degrees north, and the full extent of longitude from 180 degrees west to 180 degrees east. The horizontal grid spacing is 30-arc seconds (0.00833 degrees), resulting in a DEM having dimensions of 21.600 rows and 43.200 columns. The horizontal co-ordinate system is decimal degrees of latitude and longitude referenced to WGS84. The vertical units represent elevation in meters above mean sea level. The elevation values range from -407 to 8,752 meters. In the DEM, ocean areas have been masked as "no data" and have been assigned a value of -9999. Due to the nature of the raster structure of the DEM, small islands in the ocean less than approximately 1 square kilometre will not be represented. From the Digital Elevation model other parameters can be derived such as slope, aspect and relief.
(Source: http://edcdaac.usgs.gov/gtopo30/gtopo30.html).

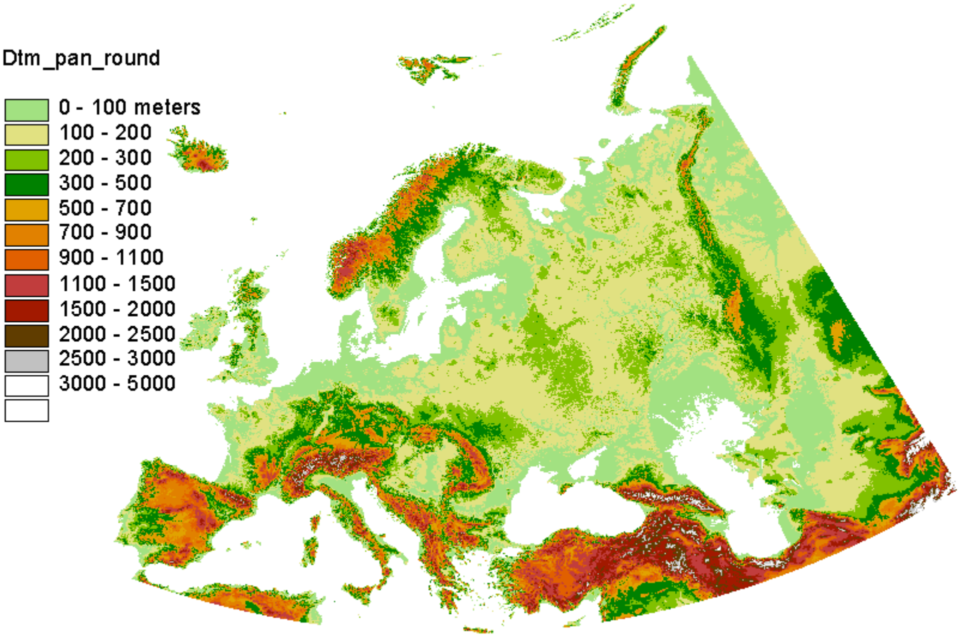


Figure A12 Detail of the global USGS GTOPO30 Digital Elevation Model for Europe

Soils

FAO-UNESCO Soil Map of the World

The FAO-UNESCO Soil Map of the World was published between 1974 and 1978 at 1 : 5.000.000 scale (FAO, 1991). The legend comprises an estimated 1650 different map units consisting of soil units or associations of soil units. The soil units (106 from Af to Zt) are grouped in 26 major soil groups. Additionally, soil texture is recognised and digitised with several characteristic classes of relative clay, silt and sand proportions. When a map unit is not homogeneous, it is composed of a dominant soil and component soils. The latter are: associated soils, covering at least 20 % of the area; and inclusions, important soils which cover less than 20 % of the area. The list of components for each mapping unit is found on the back of the maps. The data set is available in the Arc/Info vector format. A template layer containing topographic information (coastlines, islands, lakes, glaciers, double lined rivers and outer sheet boundaries) was prepared and digitised for each map sheet.

The soil associations are indicated on the map by the symbol of the dominant soil unit followed by a figure which refers to the descriptive legend on the back of the map where the full composition of the association is given. Associations in which Lithosols are dominant are marked by the Lithosol symbol I combined with one or two associated soil units or inclusions; where there are no associated soils (or not known), the symbol I is used alone. When information on the texture of the surface layers (upper 30 cm) of the dominant soil is available, the textural class (1, 2, 3) follows the association symbol, separated from it by a dash. Where two or three groups of textures occur that could not be separated on the map, two or three figures may be used, separated by a slash. Slope classes are indicated by a small (lower case) letter: a, b or c, immediately following the texture notation. In complex areas where two or three types of topography occur that cannot be delimited on the map, two or three letters may be used. If information on texture is not available, the small letter indicating the slope class immediately follows the association symbol. An example of the symbol and full composition of a soil mapping unit follows (Table A1.4):

Table A1.4 An example of the symbol and full composition of a soil mapping unit

Bk23-2/3ab:	soil mapping unit symbol
Bk	dominant soil, covering 40 % of the mapping unit
Bk23	refers to the soil components described on the back of the map (associated soils: K, and E, each covering 20 % of the mapping unit; and inclusions: Jc and Zo each covering 10 % of the mapping unit)
2/3:	texture classes of the dominant soil
ab	slope classes of the dominant soil

European Soil Database

The Soil Geographical Data Base of Europe at scale 1:1.000.000 (CEC, 1985) is part of the European Soil Data Base managed by the European Soil Bureau (ESB). It is the resulting product of a collaborative project involving all the European Union and neighbouring countries. It is a simplified representation of the diversity and spatial variability of the soil coverage. The methodology used to differentiate and name the main soil types is based on the terminology of the FAO legend for the Soil Map of the World at Scale 1:5.000.000. This terminology has been refined and adapted to take account of the specificities of the landscapes in Europe. It is itself founded on the distinction of the main pedogenetic processes leading to soil differentiation: brunification, lessivage, podzolisation, hydromorphy, etc.

The database contains a list of Soil Typological Units (STU). Besides the soil names they represent, these units are described by variables (attributes) specifying the nature and properties of the soils: for example texture, water regime, stoniness, etc. The geographical representation was chosen at a scale corresponding to the 1:1.000.000. At this scale, it is not feasible to delineate the STUs. Therefore they are grouped into Soil Mapping Units (SMU) to form soil associations and to illustrate the functioning of pedological systems within landscapes.

Table A1.5 Summary of attributes of the European Soil Database (version 3.2.8.0, 19/07/1999). Source: European Soil Bureau

VARIABLE	DESCRIPTION
AGLIM1	Dominant limitation to agricultural use.
AGLIM2	Secondary limitation to agricultural use.
AREA	Area of polygon, SMU or STU as computed by CHECK_AND_BUILD_SOILDB.AML.
BORDER_SOIL1M	State of progress of the Soil Geographical Data Base of Europe at Scale 1:1,000,000 in the neighbouring country.
CFL	Global confidence level of the Soil Typological Unit attributes description.
COUNTRY	Country code: identifier of country.
DT	Depth class to textural change.
IL	Presence of an impermeable layer within the soil profile.
MAT1	Dominant parent material code.
MAT2	Secondary parent material code. NB: if parent material is drift or residuum from various rocks, then last number (unit) is coded "9".
PM11	First character in item MAT1 (meant for pedotransfer rules)
PM12	Second character in item MAT1 (meant for pedotransfer rules)
PM13	Third character in item MAT1 (meant for pedotransfer rules)
PM21	First character in item MAT2 (meant for pedotransfer rules)
PM22	Second character in item MAT2 (meant for pedotransfer rules)
PM23	Third character in item MAT2 (meant for pedotransfer rules)
ROO	Depth class of an obstacle to roots.
SLOPE1	Dominant slope class.
SLOPE2	Secondary slope class.
SMU	Soil Mapping Unit number: identifier of Soil Mapping Unit.
SN1	First character in item SOIL (meant for pedotransfer rules)
SN2	Second character in item SOIL (meant for pedotransfer rules)
SN3	Third character in item SOIL (meant for pedotransfer rules)
SOIL	Full 1974 (modified CEC 1985) FAO-UNESCO legend soil name.
SOIL1	First level 1974 (modified CEC 1985) FAO-UNESCO legend soil name.
SOIL2	Second level 1974 (modified CEC 1985) FAO-UNESCO legend soil name.
SOIL3	Third level 1974 (modified CEC 1985) FAO-UNESCO legend soil name.
SOIL90	Full 1990 FAO-UNESCO legend soil name.
SOIL901	First level 1990 FAO-UNESCO legend soil name.
SOIL902	Second level 1990 FAO-UNESCO legend soil name.
TEXT1	Dominant surface textural class.
TEXT2	Secondary surface textural class.
USE1	Dominant land use.
USE2	Secondary land use.
WM1	Normal presence of a water management system in agricultural land (on >

VARIABLE	DESCRIPTION
	50% STU).
WM2	Purpose of the water management system.
WM3	Evident type of water management system.
WR	Dominant annual average soil water regime class of the soil profile.
ZMIN	Minimum above sea level altitude (in metres).
ZMAX	Maximum above sea level altitude (in metres).

The parent material (mat1) as derived from the European Soil Database has 127 classes at the second level (Table A1.7) and 9 classes as the first level (Table A1.6).

Table A1.6 First level parent material classes

MAT11 MAT21	First level dominant parent material code. First level secondary parent material code. *(Present in STU)*
	No information
1	Undifferentiated alluvial deposits (or glacial deposits)
2	Calcareous rocks
3	Clayey materials
4	Sandy materials
5	Loamy materials
6	Detrital formations
7	Crystalline rocks and migmatites
8	Volcanic rocks
9	Other rocks

Table A1.7 Full legend parent material classes

MAT1 MAT2 *(Present in:*	Dominant parent material code. Secondary parent material code. NB: if parent material is drift or residuum from various rocks, then last number (unit) is coded "9". *STU)*
	No information
100	Undifferentiated alluvial deposits (or glacial deposits)
110	River alluvium
111	Old fluviatile deposit (Tertiary)
112	Terraces
113	Lacustrofluvial alluvium
120	Estuarine/Marine alluvium
130	Glaciofluvial deposits
131	Till
140	Glaciofluvial drift
150	Colluvium
200	Calcareous rocks
209	Residuum from calcareous rocks
210	Limestone
211	Primary limestone (Carboniferous)
212	Secondary limestone
213	Tertiary limestone
214	Ferrugineous limestone
215	Hard limestone
216	Soft limestone
217	Marly limestone

218	Chalky limestone
219	Detrital limestone
220	Secondary chalk
230	Marl
231	Secondary marl
232	Tertiary marl
233	Gypseous marl
234	Schistose marl
240	Gypsum
250	Dolomite
300	Clayey materials
310	Old clayey sedimentary deposits
311	Primary clay and sandstone
312	Secondary clay
313	Tertiary clay
314	Pleistocene clay
319	Residuum from old clayey sedimentary deposits
320	Alluvial or glaciofluvial clay
321	Tertiary alluvial clay
322	Glacial clay (Tertiary and Quaternary)
323	Gravelly clay
324	Boulder clay
330	Residual clay from calcareous rocks
331	Clay-with-flints
332	Siderolith formations
333	Calcareous decalcification clay
340	Claystone, mudstone
350	Calcareous clay
400	Sandy materials
410	Old sandy sedimentary deposits
411	Secondary sands
412	Tertiary sands
413	Flint sands
414	Pleistocene sands
419	Residuum from old sandy sedimentary deposits
420	Alluvial or glaciofluvial sands
421	Glacial sands
422	Sandy gravelly materials
429	Residuum from alluvial or glaciofluvial sands
430	Eolian sands
431	Locally sandcover
440	Coastal sands (Dune sands)
441	Shelly coastal sands
442	Non calcareous coastal sands
450	Sandstone
451	Calcareous sandstone (Macigno)
452	Ferrugineous sandstone (Old Red sandstone)
453	Clayey sandstone
454	Soft quartzy sandstone
455	Hard quartzy sandstone
456	Quartzite
457	Schistose sandstone
459	Residuum from sandstone
500	Loamy materials
510	Residual loam
511	Old loam (Touyas)
512	Stony loam

513	Clay loam
514	Sandy loam
520	Eolian loam
521	Loess
522	Thin loess cover
523	Sandy loess
530	Siltstone
539	Residuum from siltstone
600	Detrital formations
610	Arkose
620	Breccia and Puddingstone
630	Flysch and Molasse
640	Ranas
700	Crystalline rocks and migmatites
709	Residuum from crystalline rocks and migmatites
710	Acid crystalline rocks (and migmatites)
711	Granite
712	Diorite, Quartzodiorite
719	Residuum from acid crystalline rocks
720	Non acid crystalline rocks (and migmatites)
721	Syenite
722	Gabbro
723	Serpentine
730	Crystalline metamorphic rocks
731	Gneiss
732	Embrechites
739	Residuum from crystalline metamorphic rocks
740	Schists
741	Micaschists
742	Slates
743	Shales
744	Calcschists
745	Green schists
749	Residuum from schists
750	Other metamorphic rocks
800	Volcanic rocks
809	Residuum from volcanic rocks
810	Acid volcanic rocks
819	Residuum from acid volcanic rocks
820	Basic volcanic rocks
821	Phonolites
822	Basalt
823	Andesite
824	Rhyolite
825	Volcanic tuff
830	Volcanic slag
900	Other rocks
901	Sedimentary rocks
902	Sedimentary, metamorphic and eruptive rocks
910	Organic materials

Vegetation

The production of the Potential Natural Vegetation (PNV) map was co-ordinated by the Institute für Bundesamt für Naturschutz - BfN in Germany (Bohn et al., 2000). More than 100 geobotanists from 31 European countries cooperated on this map, its legend and the explanatory text. The vector map illustrates the distribution of natural dominant plant communities and their complexes, which are adapted to existing climatic and edaphic conditions, excluding - as far as possible- human impact. It is divided into 19 fysiognomically and ecologically characterised formation- complexes, which are further, differentiated according to floristic, edaphic, climatic and phytogeographical criteria. Altogether the legend comprises 700 mapping units (Bohn et al., 2000). The Potential Natural Vegetation map of BfN includes the most important features of latitudinal and longitudinal vegetation regularities, azonal vegetation types and their differentiation as well as the edaphic, geographical and floristic varieties of the natural plant cover. The vegetation of Europe is subdivided into 19 formation units, which are sorted according to their physiognomic and structural features, dominant species and floristic composition into lower units.

Within the SynBioSys project, each mapping unit, representing specific landscape types, will be documented by a general description and information on composition and structure of the main natural vegetation types, on distribution, ecology, land use, landscape pattern, actual plant communities and nature conservation. One of the main goals of SynBioSys is to link the landscape units (in this case potential natural vegetation units) to actual vegetation types and relevés on the basis of so-called vegetation complexes.

Land use and Land cover

CORINE

The CORINE (Co-ORdination of INformation on the Environment) programme was initiated by the EU in 1985. A number of databases has been created with the aim to give information on the status and changes of the environment. One of these databases is the CORINE land cover database (Figure A1.3).

The land cover information is derived from high-resolution satellite data by computer assisted visual interpretation, in combination with ancillary information. The final CORINE land cover database consists of a geographical database describing vegetation and land use in 44 classes, grouped into a three level nomenclature (see Table A1.8) in order to cover the entire land cover spectrum of Europe (CEC 1992). The minimum mapping element is 25 hectares. For line elements the minimum width is 100 meters (Thunnissen and Middelaar, 1995). The scale of the land cover database is 1 : 100.000.

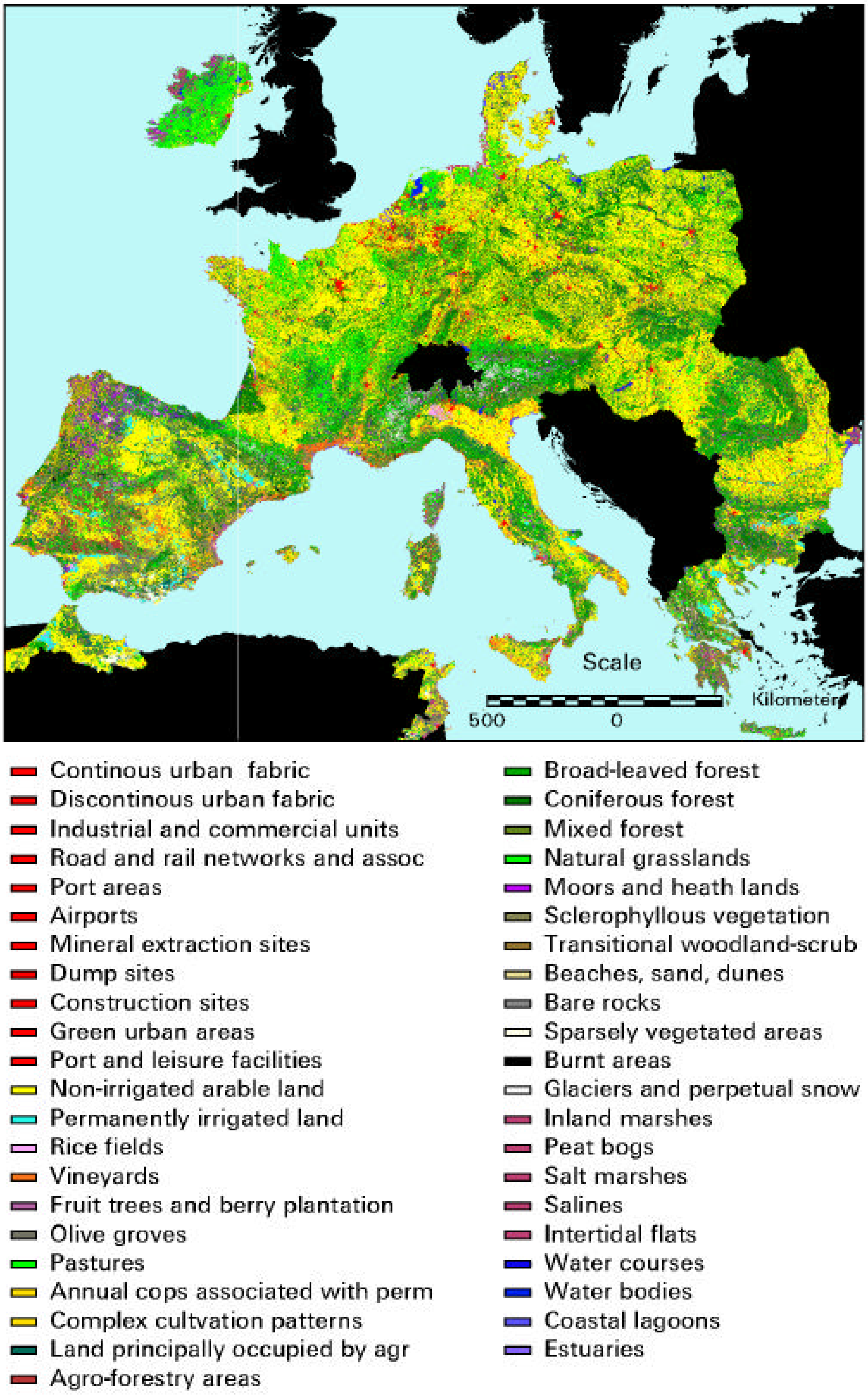


Figure A13 Extent of the CORINE land cover database in 1998 (source EEA)

Table A1.8 Nomenclature of the CORINE land cover database

Level 1	level 2	Level 3
1. Artificial surfaces	1.1 Urban fabric	1.1.1 continuous urban fabric
		1.1.2 discontinuous urban fabric
	1.2 Industrial, commercial and Transport units	1.2.1 industrial and commercial units
		1.2.2 road and rail networks and associated land
		1.2.3 port areas
		1.2.4 airports
	1.3 Mine, dump and Construction sites	1.3.1 mineral extraction sites
		1.3.2 dump sites
		1.3.3 construction sites
	1.4 Artificial non-agricultural Vegetated areas	1.4.1 green urban areas
		1.4.2 port and leisure facilities
2. Agricultural areas	2.1 Arable land	2.1.1 non-irrigated arable land
		2.1.2 permanently irrigated land
		2.1.3 rice fields
	2.2 Permanent crops	2.2.1 vineyards
		2.2.2 fruit trees and berry plantation
		2.2.3 olive groves
	2.3 Pastures	2.3.1 pastures
	2.4 Heterogeneous agricultural areas Agricultural areas	2.4.1 annual cops associated with permanent crops
		2.4.2 complex cultivation patterns
		2.4.3 land principally occupied by agriculture with significant natural vegetation
		2.4.4 agro-forestry areas
3. Forests and semi-natural Areas	3.1 Forest	3.1.1 broad-leaved forest
		3.1.2 coniferous forest
		3.1.3 mixed forest
	3.2 shrub and/or herbaceous vegetation associations	3.2.1 natural grasslands
		3.2.2 moors and heath lands
		3.2.3 sclerophyllous vegetation
		3.2.4 transitional woodland-scrub
	3.3 open spaces with little or no Vegetation	3.3.1 beaches, sand, dunes
		3.3.2 bare rocks
		3.3.3 sparsely vegetated areas
		3.3.4 burnt areas
		3.3.5 glaciers and perpetual snow
4. Wetlands	4.1 inland wetlands	4.1.1 inland marshes
		4.1.2 peat bogs
	4.2 coastal wetlands	4.2.1 salt marshes
		4.2.2 salines
		4.2.3 intertidal flats
5. Water bodies	5.1 inland waters	5.1.1 water courses
		5.1.2 water bodies
	5.2 marine waters	5.2.1 coastal lagoons
		5.2.2 estuaries
		5.2.3 sea and ocean

PELCOM

The 1km-resolution Pan-European land cover database, called PELCOM (Mücher et al., 2001), contains 16 classes with a total surface of 17.603.669 km^2 (Table A1.9). Note that the land cover classes urban areas, wetlands and water bodies have been derived from ancillary data sources.

Table A1.9 Land cover statistics of the 1km PELCOM land cover database

Nr	Class name	Code	Histogram	Area (ha)
1	Coniferous forest	11	1227641	148545000
2	Deciduous forest	12	677966	82033900
3	Mixed forest	13	424346	51345900
4	Grassland	20	1057669	127978000
5	Rainfed arable land	31	2554791	309130000
6	Irrigated arable land	32	58405	7067000
7	Permanent crops	40	96657	11695500
8	Shrubland	50	401720	48608100
9	Barren land	60	134374	16259300
10	Permanent Ice&Snow	70	72589	8783270
11	Wetlands	80	282684	34204800
12	Inland waters	91	190171	23010700
13	Sea	92	7081737	856890000
14	Urban areas	100	104335	12624500
15	Data gaps	110	2550	308550
16	Out of scope	111	180852	21883100

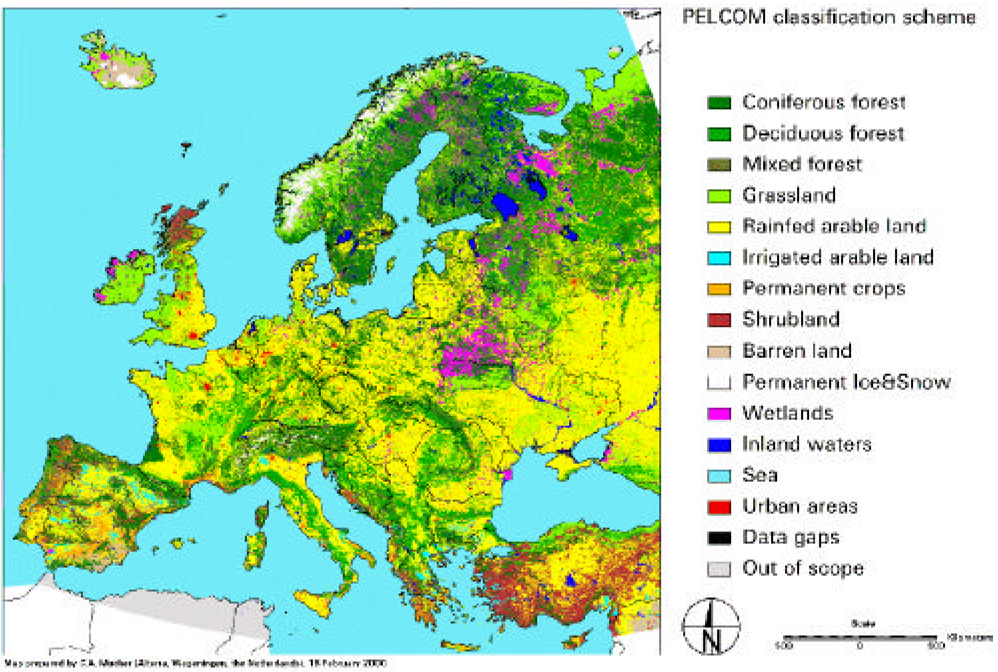


Figure A1.4 PELCOM 1km pan-European land cover database

For validation of the PELCOM land cover database high-resolution satellite images have been used. Ideas have been followed from the IGBP-DIS global land cover database validation (IGBP-DIS, 1996). Due to the amount of work the validation has been limited to confidence site mapping. IGBP-DIS provided 30 Landsat-TM images for Europe. In addition, 10 high resolution satellite images were provided by PELCOM partners. This resulted in 40 high-resolution satellite images distributed over pan-Europe that had to be interpreted. Visual interpretations of the high-resolution satellite images were done independently of the PELCOM land cover database, but use of ancillary data was allowed (topographic maps, national land cover databases). This resulted in a total area of (interpreted) confidence sites of 7700 km^2. The total average accuracy was 69,2%, which can be considered as a good result considering the mixed pixel and geo-referencing problems of AVHRR data.

IGBP-DIS

IGBP-DIS began a project in 1992 to produce a global land cover data set at a spatial resolution of 1-km, derived from the Advanced Very High Resolution Radiometer (AVHRR) onboard the US National Oceanic and Atmospheric Administration’s (NOAA) polar-orbiting satellite series (Loveland and Belward 1997). The methodology is based on unsupervised clustering of monthly NDVI maximum value composites (MVC's) on a continental basis. The MVC’s covers a 18 month period from April 1992 to September 1993 (Townshend 1992). Clusters are labelled by expert knowledge. A major limitation of the approach is that it is implemented on a continental basis without any stratification. Therefore, the result is more closely related to agro-ecological zones, i.e. zones of similar phenology, than to the different land cover types existing in each agro-climatic zone. The European landscape is heterogeneous and fragmented and requires a stratified approach. As a result the IGBP global land cover database called ‘DISCover’ does not reveal much spatial variety in land cover for Europe. Moreover, in the data set about 1/3 of the pan-European land surface is covered by the land cover class “cropland/natural vegetation mosaics”, which can cover all kind of land cover types and is therefore difficult to apply in environmental studies. However, it must be stressed that the project is unique and enormous efforts have been invested in order to establish an up-to-date global land cover database at a 1-km resolution in a consistent manner. Still, application of the database in environmental and climate studies for pan-Europe may be limited. At this moment a European project called GLC2000 is finalising a new global land cover database on basis of SPOT-Vegetation satellite data, which is expected to give much better results.

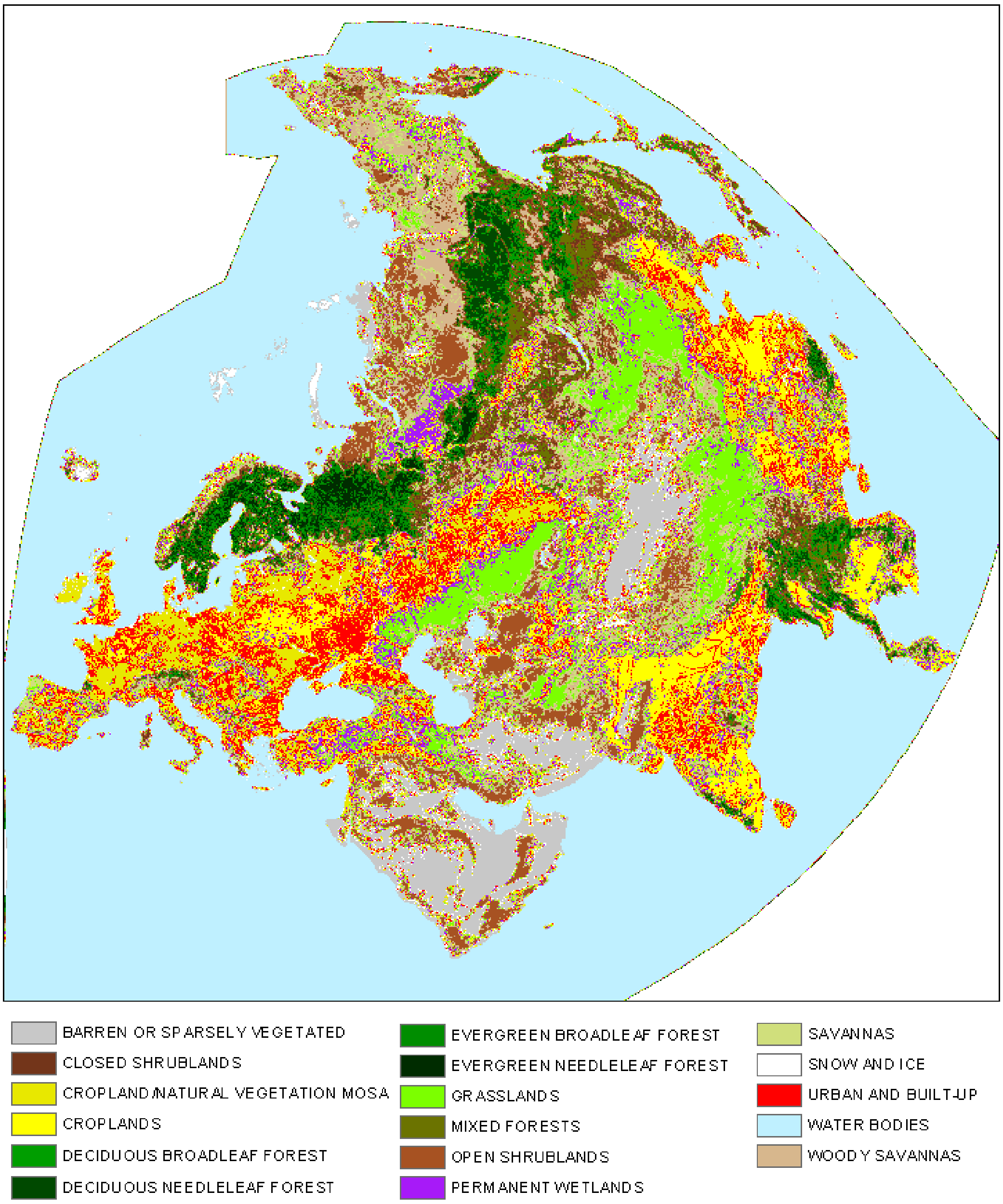


Figure A15 IGBP-DIS global land cover database <DISCOVER>

Existing European environmental classifications

There are many existing classifications of the European environment, some of which are available in a digital format. In fact the previously mentioned data sets on PNV, land use and land cover could be classified in their own right as European environmental classifications. Most of these classifications, as we have seen for PNV and land cover, are derived from expert judgement, and the critical variables describing them are not explicit. They were not intended to be used for statistical stratification, which requires classes to be relatively homogeneous and cannot be used for such purpose because of their lack of objectivity. Nevertheless, these traditional classifications of the European environment certainly do provide descriptions of the main environmental regions and have proved to be most valuable. Of the three environmental classifications that are discussed in this section, two are based on expert judgement. Until the development of the EnC the ITE European land classification was the only quantitative classification distinguishing more that a few classes.

Table A1.10 Selected examples for biogeographic maps (Wascher, 1997). Most of these maps are not digitally available

Map title	Coverage	units	No of classes	Purpose
Habitats Directive (EEC/43/92)	EU 15	Biogeographic regions	6	Assessment of Natura 2000
Emerald (Bern Secretar.)	Pan-Europe	Biogeographic regions	11	Assessment of Emerald network
Potential Natural vegetation (BfN)	Pan-Europe (1:2.5 mill)	Vegetation classes	700	Vegetation science, environm. reporting
Potential natural vegetation (BfN)	Pan-Europe (1:10 mill)	formations classes	19 75	Vegetation science, environm. reporting
European land classification (ITE, Bunce 1996c)	Pan-Europe	Areas of homog.climate	64 / 128	Land stratification for resource survey
Végétation du Cont. Européen (Ozenda,1996))	Pan-Europe (1:7 mill)	Domains: Sectors nat. veg.:	8 38	Vegetation sciences, plant biogoegraphy
Biogeographic Map of Europe (Rivas-Martinez&Penas '96)	Pan-Europe (1:20 mill)	Regions Provinces Sub-provinces:	4 27 72	Vegetation sciences, plant biogeography
Biogeographic provinces (Udvardy, 1975)	World (1:30 mill)	Biogeo. Realms: Biog. Provinces:	8 207	UNESCO
Eco-regions of the world (Bailey 1989)	World (1:30 mill)	Climat. Domains, divisions, prov.	?	Resource reporting, FAO
DMEER (1997)	Pan-Europe (1:15 mill)	Ecological regions	69	Assessment of biodiversity, EEA

Biogeographic regions of EEA – The EMERALD Zones

Biogeographic classifications have a long history, dating back to the early classifications by Von Humboldt (1867) and Köppen (1936). These scientists used their knowledge of climate and altitude to create maps that explained regional vegetation patterns. Although these maps give a clear insight into the relationships between climate and vegetation, the rules behind the classes distinguished were either not defined, as in the former, or were chosen to describe boundaries distinguished by personal judgement, as in the latter. Biogeographic classifications, such as the Emerald Zones (EEA, 2002) produced by the European Environment Agency as part of the NATURA2000 policy for European nature conservation are generally accepted and used. The Emerald Zones distinguish eleven main biogeographic regions (e.g. Boreal, Atlantic, Continental) based upon knowledge about potential natural vegetation and environment. The main problem is that the consistency of these classifications is dependent upon the expertise of the originators. No individual expert has equal knowledge about a continent the size of Europe, so local and personal biases arise, e.g. in the Emerald Zone classification the Alpine Zone is identified in Italy but not in central Spain.

The map of Biogeographic Regions was developed to be a tool for assessment of the NATURA2000 Network of EU (EU Council Directive 92/43/EEC). To the originally 5 regions (Alpine, Atlantic, Continental, Macaronesian and Mediterranean) the Boreal region was added when Finland and Sweden joined the European Union. The resulting EU15 map of Biogeographic Regions was based on the map of natural vegetation (The European Commission and The of Europe, 1987) taking climatic types into account and eliminating edaphic vegetation zones and isolated islands. It is the first time a geographical frame that differs from administrative boundaries was recognised for use for official evaluation of sites. The current Pan-European Map of Biogeographic Regions is an extension of the EU15 map by the Council of Europe (Secretariat of the Bern Convention) to be used for the setting up of the EMERALD Network. The non-EU part of the map is based on an aggregation of the units of the Pan-European Map of Natural Vegetation (Bohn, 1996). Only 5 regions were added to the EU15 map (Anatolian, Arctic, Pannonian, Black Sea and Steppic). The same interpretation principles were used as for the EU15 map. It has an equivalent objective of site assessment and reporting on a pan-European scale. (The Council of Europe, 1997)

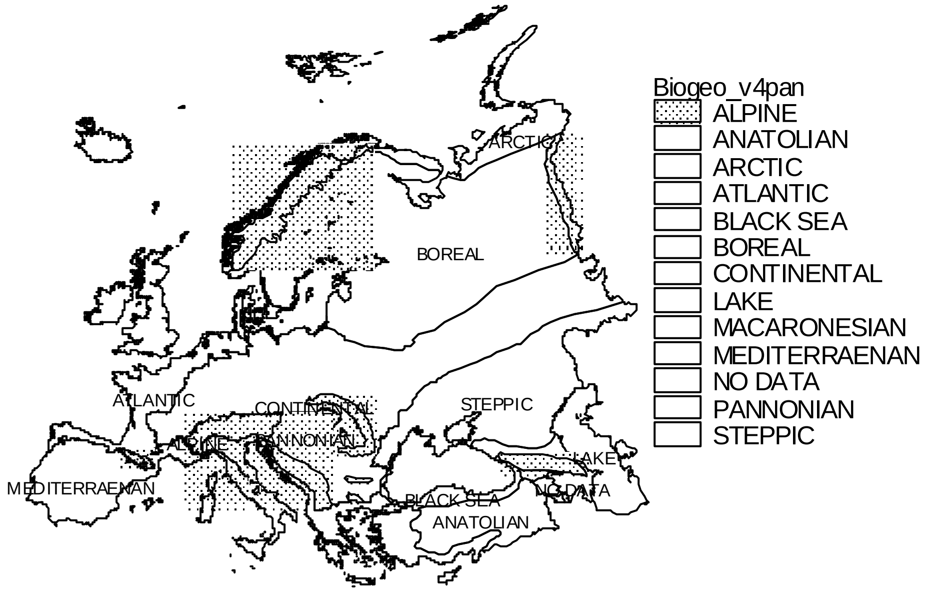


Figure A1.6 Biogeographic regions of Europe (source: EEA)

DMEER

The Digital Map of European Ecological Regions (DMEER) is a biogeographic map that illustrates the distribution of ecological regions and sub-regions, on the basis of a unified concept and updated knowledge of climatic, topographic, geobotanical European data and incorporates information from several European biogeographic experts. This map was based on a hierarchical classification, of the mapped potential natural vegetation of Europe, together with the ITE European land classification of 0.5^0 gridcells (see next paragraph). From six vector maps of DMEER that were produced, representing 6 aggregation levels off a dendrogram, reaching from 46 to 183 ecological regions, covering all Europe, a final draft of DMEER was composed according to the experts opinions. DMEER is meant to be a powerful and efficient step toward setting land management priorities. It will provide focus, direction, and accountability for conservation efforts (DMEER, 1997).

Figure A1.7 The Digital Map of European Ecological Regions (DMEER)

The ITE European Land Classification

In the 1970s field ecologists at the Institute of Terrestrial Ecology (ITE) (now Centre for Ecology and Hydrology (CEH)) in the UK recognised the need for a statistical environmental stratification. These scientists realised that strategic stratified random sampling was the only feasible way of assessing ecological resources such as habitats and vegetation and enable monitoring schemes for large, heterogeneous areas (Bunce et al., 1996a, b; Bunce et al., 1996c). Sheail and Bunce (2003) have recently described the history and development of strategic ecological survey in Great Britain. Several other countries and regions have also adopted quantitative classifications as the basis for survey, monitoring and management, e.g. Spain (Elena-Rosselló, 1997; Regato et al., 1999) and New Zealand (Leathwick et al., 2003a, Leathwick et al., 2003b). The climate variables, selected by PCA, were classified into sixty-four classes using TWINSPAN (Hill, 1979b). The complete procedure is described in Bunce *et al.*(1996d). The classes correspond to recognisable divisions of European climate, such as Mediterranean or Continental, as described by Kendrew (1953).

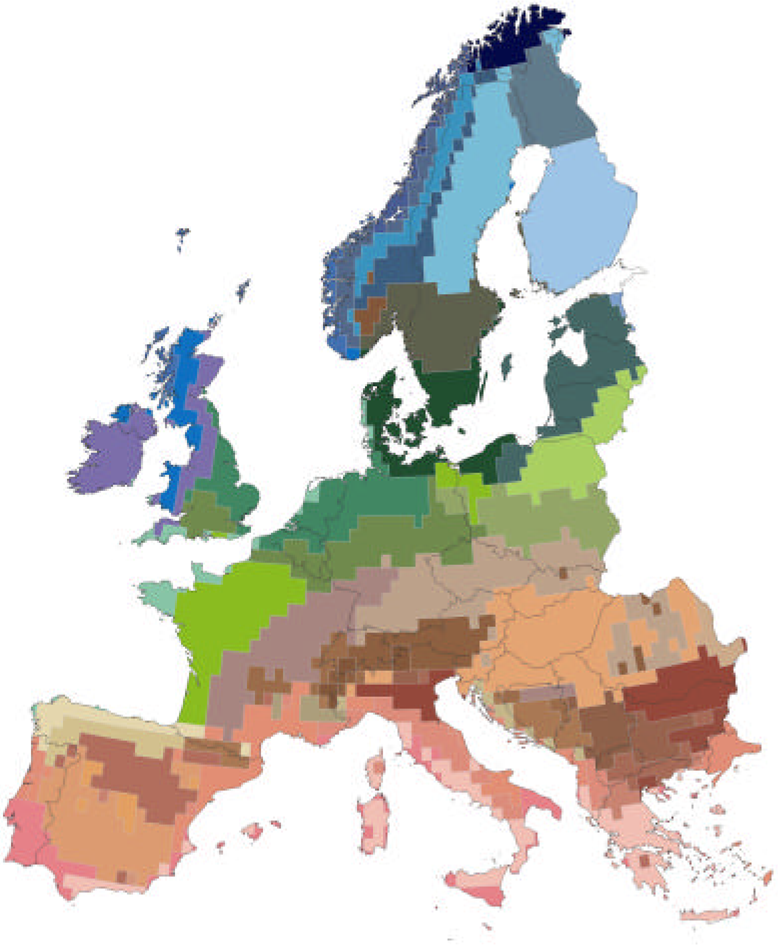


Figure A18 The European ITE Land Classification has been produced at a 0.5°x0.5° resolution. The classes correspond to recognisable divisions of European climate

The principal limitation of the ITE classification is its coarse resolution. Some of the 0.5°x0.5° grid cells are heterogeneous for climate and altitude, especially in mountain areas. For example, the grid cell with the Picos de Europa in the Cantabrian Mountains in Spain contains a range of environments from sea level to 2500m mountain summits. Because of its resolution, the classification was too coarse to be used for monitoring programmes for land-use change and to develop detailed scenarios. The ITE classification forms the basis for the Digital Map of European Ecological Regions (DMEER) which was created for the European Environment Agency (EEA) and can be obtained from their website (http://dataservice.eea.eu.int/). DMEER was used in the MIRABEL project (Petit et al., 2001) as a stratification to evaluate the consequences of environmental change for biodiversity in Europe. Within the regions, predicted impacts of environmental pressures on habitats were analysed and mapped.

A classification at a resolution of 1km2 would provide a sounder statistical basis for choosing sample sites than the ITE classification or DMEER. It could then be used for inventory and monitoring schemes for biodiversity and landscapes, as has been carried out in the UK Countryside Survey (Firbank et al., 2003; Haines-Young et al., 2000). It could also be used for scenario modelling and global change impact assessments. During the last ten years, there has been a rapid advance in computing power, GIS and statistical classification software, and in the availability of high-resolution spatial data. By making use of these new developments a new environmental classification at a 1km2 resolution can now be created that also complies with the strict requirements for reproducible and quantitative classes.

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