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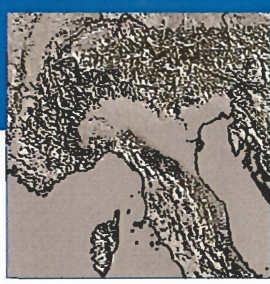
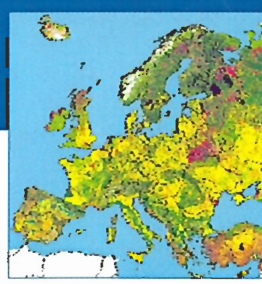
Development of a consistent methodology to derive land cover information on a European scale from Remote Sensing for environmental monitoring

The PELCOM report

C.A. Mücher, J.L. Champeaux, K.T. Steinnocher, S. Griguolo, K. Wester, C. Heunks, W. Winiwater, F.P. Kressler, J.P. Goutorbe, B. ten Brink, V.F. van Katwijk, O. Furberg, V. Perdigao and G.J.A. Nieuwenhuis





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ABSTRACT

C.A. Mücher, J.L. Champeaux, K.T.Steinnocher, S.Griguolo, K.Wester, C.Heunks, W. Winiwater, F.P.Kressler, J.P. Goutorbe, B. ten Brink, V.F. van Katwijk, O.Furberg , V.Perdigao, G.J.A.Nieuwenhuis, 2001. *Development of a consistent methodology to derive land cover information on a European scale from Remote Sensing for environmental monitoring, the PELCOM report.* Wageningen, Alterra, Green World Research/CGI-report 6. Alterra-rapport 178. 160 blz., 43 fig.; 22 tab.; 143 ref.

In the current policy frameworks the need for up-to-date and reliable information for entire Europe is well known. A step in this direction has been taken by the Pan-European Land Cover Monitoring (PELCOM) project. A concise classification methodology was established for mapping major land cover types by using regional expertise in a integrated approach of NOAA-AVHRR satellite data and ancillary information. An important result was the 1-km pan-European land cover database. An extensive accuracy assessment has been implemented on basis of 40 interpreted Landsat-TM satellite images distributed over pan-Europe. The total average accuracy was 69.2%. The PELCOM land cover database was applied successfully in various environmental and climate studies. However, the use of AVHRR satellite data has its limitations for monitoring purposes due to the fine scale at which thematic land cover changes take place. Medium resolution satellite imagery (eg. MODIS and MERIS) will play a crucial role in the near future to monitor the European landscape.

Keywords: biodiversity, change detection land cover, environmental monitoring, land use, linear unmixing, meteorological models, NOAA-AVHRR satellite data, pan-Europe, validation, VOC emissions

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Preface

This report describes the PELCOM (*Pan-European Land Cover Monitoring*) project, a shared cost project funded by Directorate General XII of the European Commission within the Environment & Climate Programme of the 4th Framework (contract No ENV-CT96-0315). The main aim of the project is to develop a consistent methodology to derive land cover information on a European scale from remote sensing for environmental modelling. Three major parts can be distinguished; methodology development, regional classification experiments leading to a pan-European land cover database and application of the database in various case studies a.o. in numerical weather prediction models, in biodiversity research and in large-scale inventories of biogenic emissions from forests. The research has been accomplished within an international research framework of universities, research institutes and private companies under co-ordination of Alterra – Green World Research. I would like to express my thanks to the following people for their scientific contributions and usefull discussions and comments: Klaus Steinnocher, Florian Kressler and Wildried Winiwater of the Austrian Research Centre Seibersdorf, Jean-Louis Champeaux and Jean-Paul Goutorbe of Météo France, Kjell Wester and Olle Furberg of the Swedish Space Corporation (Satellus), Silvio Griguolo and Ponso of the University of Venice, Vanda Perigao, Philippe Loudjani and Sten Folving of the Space Applications Institute of the Joint Research Centre, Camiel Heunks and Ben ten Brink of the Dutch Institute for Public Health and the Environment (RIVM), and Victor van Katwijk and Wideke Boersma of Geodan IT. Further, I would like to thank the following people for their mental support: Chris Steenmans from the European Environmental Agency, Michel Shouppe and Alan Cross from DGXII, Martine Michou and Gerard Szejwach of the IGBP-DIS office, Tom Loveland of the USGS EROS Data Centre, John Estes of the University of California. Moreover, I would like to thank my colleagues from Alterra, Herman Thunnissen, Henk Kramer and Susanna Azzali, for their usefull contributions. And last but not least, I would like to thank especially Rob van der Velde (DLG) and Gerard Nieuwenhuis (Alterra) who where the original initiators of the PELCOM project.

Executive Summary

Context of the Work

For many environmental and agricultural studies up-to-date and reliable information on land use and land cover is urgently needed. At the moment there are, however, no geo-referenced land use or land cover databases with a high spatial accuracy that cover entire Europe and that can be updated frequently.

During the last decades, land use has suffered dramatic changes in time and space in Europe. For example agriculture in the European Union (EU) is going through a phase of accelerating changes (WRR, 1992). The continued increase in production per unit of land area and per unit of livestock, due to improved production circumstances, better cultivation methods and external inputs, has led to significant increases in agricultural productivity. Land use intensification in one area caused marginalisation in other areas. A net gain of forest with 144980 km^2 (+10%), a net loss of arable land with 157320 km^2 (-11%), and a net loss of permanent pasture with 102280 km^2 (-11%) are some examples of land use changes in Europe over the 3 last decades (source FAO statistics, Russian federation was not included).

In the mid-nineties, the ten-minutes pan-European land use database of the Dutch National Institute for Public Health and the Environment was a first step towards meeting the demands of environmental models on a European scale (Van de Velde *et al.* 1994, Veldkamp *et al.* 1995). A major drawback of this database was that it was based on statistical and spatial data from different sources that differ in spatial accuracy, reliability, age and nomenclature. Use of remotely sensed data decimates this problem, as actual land cover data can be derived in a consistent manner with a high spatial accuracy.

Relevant activities on the derivation of pan-European land cover databases from remotely sensed data including all major land cover classes are: the CORINE (Coordination of Information on the Environment) land cover project (CEC 1993), now under supervision of the European Environment Agency (EEA) and the recently developed 1-km global land cover product, 'DISCover' (Loveland and Belward 1997), under the co-ordination of the International Geosphere and Biosphere Programme (IGBP-DIS). These are described briefly below.

The CORINE land cover database is produced by visual interpretation of high-resolution satellite images, e.g. Landsat-TM and SPOT-XS, at a scale of 1 : 100 000, with simultaneous consultation of ancillary data (CEC 1993). The CORINE legend distinguishes 44 classes grouped in a hierarchical nomenclature and is landscape and ecology oriented. The CORINE land cover database is the most detailed database at the moment that covers a large part of Europe. Despite the uniqueness of the CORINE land cover database its use is still limited for pan-Europe because a complete coverage is still not accomplished.

IGBP-DIS began a project in 1992 to produce a global land cover data set at a spatial resolution of 1-km (scale ~ 1:5M), 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 on a continental basis. The clusters are labeled by expert knowledge. 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. Moreover, experiences indicate that clustering techniques do not identify forests satisfactorily (Champeaux et al. 1998 a). An additional limitation is that the 1-km database according to the DISCover legend contains complex classes, e.g. cropland/natural vegetation mosaics (about 27 per cent of the pan-European land surface), which are difficult to apply in environmental studies. However, it must be stressed that the project is unique and enormous effort had to be invested in order to establish an up-to-date global land cover database at a 1-km resolution in a consistent manner. Application of the database in environmental and climate studies for pan-Europe may be limited.

Besides the detailed CORINE land cover database and the global DISCover database with their own advantages and disadvantages, there is a need for additional land cover data sets derived from remotely sensed data that fulfils the needs for pan-European environmental and climate modeling. These needs comprise a consistent land cover database that covers pan-Europe, that can be easily updated, and that contains main land cover classes such as arable land, grassland, urban areas, water bodies, wetlands, barren land and the various forest types with sufficient regional detail (Van de Velde et al. 1994). Therefore a study was initiated to investigate the applicability of AVHRR satellite data for Pan-European Land Cover Monitoring (PELCOM, http://cgi.girs.wageningen-ur.nl/cgi/projects/eu/pelcom/).

Objectives

The PELCOM project aimed at establishing a 1-km Pan-European Land Cover Database that can periodically be updated based on the integrative use of multi-spectral and multi-temporal NOAA-AVHRR satellite imagery and ancillary data. PELCOM was a three-year project of a shared cost action under the Environment & Climate section of the European Union 4th Framework RTD Programme. The project started in September 1996 and finished in November 1999. Major goals were:

- Establishment of a land cover classification scheme for the European continent
- Development of a consistent classification methodology, based on NOAA-AVHRR satellite data and ancillary data
- Creation of the Central Project Information Server (CPIES) and a metadata information system
- Development of a methodology for monitoring land cover changes at a European scale
- Establishment of a 1-km Pan-European Land Cover Database

- Application of the established land cover database in various environmental and climate studies

Partnership
The consortium was co-ordinated by Alterra, Green World Research, and consisted of a group of scientists from various countries working in various disciplines. They were represented by six research institutes, one university and one private company: Space Applications Institute (SAI/JRC), Austrian Research Center Seibersdorf (ARCS), Centre National de Recherches Météorologiques (CNRM), Instituto Universitario di Architectura (IUAV), Swedish Space Corporation (SSC), Dutch National Institute for Public Health and the Environment (RIVM) and Geodan IT

Project Organisation
The PELCOM project was divided into three main phases. Phase 1 concerned the development of the methodology to produce and update a 1-km Pan-European Land Cover Database. In phase 2, regional land cover classifications were executed based on the standardized methodology. Each partner was responsible for carrying out a classification experiment within their specific region. Subsequently, the results were compiled into the 1-km Pan-European Land Cover Database. In phase 3, several case studies were performed in which the 1-km Pan-European Land Cover Database was used as input for several environmental and climate studies. The outcomes from these studies are expected to lead to sustainable applications of Earth Observation data for environmental modelling at a European scale.

End Users
The PELCOM project focused on land cover mapping and monitoring activities for establishing a consistent Pan-European Land Cover Database, which is useful for national, European, and international environmental agencies. In this project, end users were actively involved in the development of the methodology as well as the applications. The Pan-European Land Cover Database was applied in various environmental and climate models by end users. The first case study was performed by RIVM on applying the land cover database in biodiversity reasearch. The second case study was performed by ARCS on large-scale inventories of biogenic emissions from forests. An a third case study was performed on the improvement of boundary conditions for meteorological modelling by CNRM.

The European Environmental Agency (EEA) was also envisioning the strategic use of this database for the protection and improvement of the European environment. Likewise, IGBP-DIS was a potential end user of this database. In addition, contacts have been established with IGBP's Land Use and Land Cover Change (LUCC) core project. The LUCC Scientific Steering Committee agreed that the PELCOM project addresses questions that are strongly related to the LUCC science plan.

Data Sources
One of the AVHRR data sources was the MARS (Monitoring Agriculture by Remote Sensing) archive provided by the Space Applications Institute (SAI) of the Joint

Research Institute (JRC). This archive contains pre-processed daily multi-spectral mosaics of AVHRR (Advanced Very High Resolution Radiometer) images covering the Europe. Normalised Difference Vegetation Index (NDVI) composites are also available in these archives, but were considered inadequate due to the low geometric accuracy of the single AVHRR images. As a result, NDVI monthly maximum value composites of 1997 obtained from DLR (Deutches Zentrum für Luft und Raumfahrt) were used as the main data source for the classification process. Various ancillary data sources have also been used as reference data sets in the PELCOM Project. Some examples are the Digital Chart of the World (DCW) and the CORINE (Coordination of Information on the Environment) land cover database.

Methodology

The classification methodology was based on a regional and stratified approach. The FIRS strata were used for the stratification with a 10-pixel boundary buffer. The classifications were implemented per stratum with thematic maps for urban areas, water bodies and forest as optional for masking.

Around 10 clusters/classes were defined in each classification and for each startum. Assessment of the adequate number of clusters/classes was based on analysis of AVHRR scenes, CORINE, and/or statistical data. Depending on the complexity of the region, a supervised classification or clustering was performed on the NDVI composites, not including the masked areas. For each pixel the spectral distance to each class/cluster was determined and were labelled to two classes with the smallest distances. In a third layer the ratio between the two distances is given. This ratio can be used as a measure for the homogeneity of the single pixel and is valuable information to the end-user. So, with each classification three layers are produced: a first-best classification (highest 'probability'), a second-best classification (second-highest 'probability') and a distance ratio. These components offer also the possibility to calibrate the classification results with statistical information. If for example, according to the statistics insufficient grassland is found for a certain administrative region, the second-best classification can help to identify more grassland areas.

For each stratum the results from the classification of the NDVI composites was compared interactively with the visual information in the multi-spectral AVHRR scenes. The information in either the multi-temporal or multi-spectral AVHRR data will be strongly influenced by the quality of the concerned data and the specific land cover features present in the specific stratum. If specific features, e.g. linear features, and specific land cover classes were only visible in the multi-spectral AVHRR scenes they were derived from these scenes by a supervised classification.

Concerning forests, classification of NDVI maximum value composites often fails to correctly discriminate forests from grasslands (Champeaux *et al.* 1998a). In a supervised classification forests can be identified on individual multi-spectral scenes using AVHRR channels 1, 2 and 3 (ESA 1992, Mücher *et al.* 1994). However, such an approach is often hampered for pan-Europe due to frequent occurrence of clouds. Therefore Champeaux *et al.* (1998 a, b) proposed another method to improve forest mapping. Advantage was taken of the photosynthetic efficiency of the forest canopy that results in low visible reflectances. This is particularly true in summertime for northern Europe and in spring and autumn for southern Europe. The identification of forests was therefore implemented on basis of thresholding the synthesis of visible reflectance of AVHRR channel one. Because north-eastern Europe was not covered by the threshold forest map, the map was merged with the ESA forest map (ESA 1992) for this part.

Results

For the compilation of the final database only the first-best classification results have been used due to time constraints. Because for each stratum a 10-pixel boundary zone was used, there was an overlap between all classifications. On basis on visual interpretations it was decided which regional classification should overrule which adjacent classification. Irregularities in terms of unclassified pixels were removed by a majority filter. Eastern-Europe (east of Poland) was not considered within the defined regional classification experiments. This problem was solved with another project, called INDAVOR - a Dutch collaboration of Resource Analysis, TNO-MEP and Alterra (Boer et al., 2000). Within this project there was also need for a 1km pan-European land cover database for application within a tropospheric ozone model (LOTOS). It was decided to follow the classification methodology of the PELCOM project, using the same data. Main differences with the PELCOM project were that the classification was not performed per stratum but per region – largely reducing the number of classifications and that no regional expertise was used. The 1-km pan-European land cover database established within the INDAVOR project has been called PELINDA database (referring to PELCOM and INDAVOR). In the PELCOM project the part that has not been covered within the regional classification experiments has been retrieved from the PELINDA database.

The PELCOM database contains 16 classes with a total surface of 17,603,669 km^2 (Table 1). Note that the land cover classes urban areas, wetlands and water bodies have been derived from ancillary data sources.

Table 1 Land cover statistics of the 1km PELCOM land cover database

Nr	Class name	Area (ha)	Nr	Class name	Area (ha)
1	Coniferous forest	148545000	9	Barren land	16259300
2	Deciduous forest	82033900	10	Ice&Snow	8783270
3	Mixed forest	51345900	11	Wetlands	34204800
4	Grassland	127978000	12	Inland waters	23010700
5	Rainfed arable land	309130000	13	Sea	7081737
6	Irrigated arable land	7067000	14	Urban areas	104335
7	Permanent crops	11695500	15	Data gaps	2550
8	Shrubland	48608100	16	Out of scope	180852

Validation

For validation various methodologies have been used, based on CORINE land cover data, statistiscal information and on basis of high-resolution satellite images. The last one is considered as the most independent validation method. The results of this validation are explained below. Here, ideas have been followed from IGBP-DIS for their global land cover database validation (IGBP-DIS, 1996). It was decided to limit the validation to the confidence site mapping due to the amount of work. 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 were 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).

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. The mixed pixel problem is especially present in heterogeneous areas such as the Mediterranean region. Accurate geo-referencing is a general problem of AVHRR data, which reduces the apparent spatial resolution when multi-temporal AVHRR series are used. Major classes such as arable land and coniferous forest still have a high reliability and accuracy of around 80%, while small and fragmented classes such as shrubland and wetlands have a very low accuracies. Exceptions are barren land and permanent ice and snow. The validation results show the same trends as in those cases that the PELCOM database was validated using CORINE land cover database and statistical data.

Conclusions

An improved stratified and integrated classification methodology has been developped to map major land cover types of pan-Europe using NOAA-AVHRR satellite and additional geographic data in a consistent manner. Both multi-temporal NDVI profiles and multi-spectral AVHRR scenes were used as input in the classification procedure exploiting the advantages of both data types. Due to the limited accuracy of identifying forests on basis of unsupervised clustering of NDVI timeseries, the identification of forests was implemented on basis of thresholding the synthesis of the visible reflectance of AVHRR channel one. This resulted in a pan-European forest map. Additionally, urban areas and inland water, which were derived from ancillary data, were masked optionally. The validation results showed reasonable results for major classes. In general land cover classes that were very fragmented and had complex spectral signatures were more difficult to identify using AVHRR satellite data. But an overall classification accuracy 69.2% could be seen as a good result considering the mixed pixel and geo-referencing problems of AVHRR satellite data. The spatial resolution limits also the possibilities to identify land cover changes in the European landscape. Comparison of two AVHRR derived land cover maps will result in identifying many spurious changes. Medium resolution satellite sensors with a spatial resolution between 150-250 meters (eg. MODIS and MERIS) will play a major role in the near future to identify land cover changes in the European landscapes. Nevertheless, the 1-km PELCOM land cover database is a unique product, that has been applied succesfully in various studies, for example, biodiversity research by RIVM, emission modelling of volatite organic components of forests by ARCS, and in improving surface boundary conditions of numerical weather prediction models of Météo France.

1 Introduction

1.1 Background

In the current environmental policy plans there is an increasing need for up-to-date and reliable information on land use and land cover (LULC) that covers the whole of Europe (Stanners and Bourdeau 1995). Many environmental policies rely greatly on the outcome of environmental models, which themselves are significantly influenced by the areal and spatial accuracy of LULC data.

The ten-minute pan-European land use database (ELU-1) of the Dutch National Institute for Public Health and the Environment (RIVM) was a first step towards meeting the demands of environmental models on a European scale (Van de Velde et al. 1994, Veldkamp et al. 1995). The database was made by combining non-spatial statistical information with spatial information from available land cover maps. The calibration procedure consisted of an iterative process by which the regional land use was calculated and compared with the available statistics, and consequently adjusted. The resolution (administrative level) of the statistical database determined the areas for which the land use is summed and adjusted. A major drawback of the database was that the statistical and spatial data are derived from many sources that differ in spatial accuracy, reliability, acquisition date and class definitions. Most statistical data were collected on NUTS (Nomenclature d'Unités Territoriales Statistiques) level 0 and 1 (Van de Velde et al. 1994) offering a low spatial detail. Use of Earth Observation (EO) data eliminates this problem, as up-to-date land cover data may be inferred with a high spatial accuracy in a consistent manner. This has resulted in the definition of the PELCOM project.

PELCOM aimed at establishing a 1km pan-European land cover database based on multi-spectral and multi-temporal AVHRR satellite and ancillary data, which can be easily updated. PELCOM was a three years' project that started in September 1996 and finished in November 1999. End users were actively involved in the PELCOM project: both dealing with the development of the methodology and with applications. RIVM, ARCS and CNRM applied the established 1km land cover database as input in different environmental and climate models.

One of the international end users was the European Topic Centre Land Cover (ETC-LC) as part of the European Environmental Agency (EEA). Alterra is a National representative of ETC-LC, ensuring close contacts. In 1995 the Topic Centre organised a workshop in Copenhagen discussing amongst others the experiences and lessons learned during the CORINE land cover project (CEC 1993). Some major conclusions and recommendations from the ETC-LC workshop, Copenhagen on 7th and 8th of November 1995, were:

- *up-to-date and reliable information on land cover and land use are urgently needed for environmental studies on national, continental and global scales;*
- *despite the uniqueness of the CORINE land cover database its use is still limited because a complete coverage of Europe is still not accomplished, users do not know its existence or because users have other specific requirements;*
- *at the same time there is a need for more detailed and coarser LC information;*
- *there is a need for shorter update frequencies, than is now the situation for CORINE, to enable the estimation of the actual situation of the environment at a certain moment.*

Other international contacts were establshed with IGBP-DIS (International Geosphere and Biosphere Programme – Data Information System). In April 1992 IGBP-DIS started a fast-track 1-km global land cover project (Loveland and Belward 1997). A 1-km global land cover database was produced based on clustering of monthly NDVI. Members of the PELCOM team were present as an expert at the global land cover database validation workshop 7-18 September 1998 in Sioux Falls. In addition, contacts have been established with IGBP's Land Use and Land Cover Change (LUCC) core project. The LUCC Scientific Steering Committee agreed that the PELCOM project addresses questions that are strongly related to the LUCC science plan. Finally, the Global Terrestrial Observing System (GTOS) project could benefit from the results of the PELCOM project, since one of their key global development issues is related to land use change.

1.2 Objectives

As mentioned before, for many environmental and climate studies up-to-date and reliable information on land use and land cover was urgently needed. Unfortunately, such a database that covers Europe entirely with a high spatial accuracy and that can be updated easily did not exist. The 'Pan-European Land Cover Monitoring' (PELCOM) project was formulated to fill this gap.

The main goal of PELCOM was *to assess different methodologies to map and monitor the land cover of the European Continent using AVHRR data to arrive at a consistent methodology for the establishment and regular update of a 1-km Pan-European land cover database as an input for environmental impact studies and climate research.*

The general objectives can be summarised as:
- set-up of a commonly agreed land cover nomenclature ;
- set-up of a consistent classification methodology based on AVHRR data and ancillary data;
- set-up a central project information server and a meta-information system;
- set-up of a methodology to detect land cover changes;
- to apply the agreed classification methodology to various vast regions;
- Demonstrations of the 1-km land cover database as input in different environmental and climatic models.

Three sequential phases were defined to arrive at the stated goals:

- *Phase 1*, Development of a consistent methodology for mapping and monitoring land cover on a continental scale
- *Phase 2*, Regional classification experiments
- *Phase 3*, Case-studies of environmental and climatic applications

1.3 Brief description of the consortium

The consortium contained a group of scientists from various countries in Europe and from various disciplines. They were represented by six institutes, one university and one private company:

- Alterra, Wageningen, the Netherlands
- Swedish Space Corporation, Solna, Sweden (SSC)
- Austrian Research Center Seibersdorf , Seibersdorf, Austria (ARCS)
- Météo France, Centre National de Recherches Météorologiques, Toulouse, France (CNRM)
- Instituto Universitario di Architectura, Venice, Italy (IUAV)
- Space Applications Institute, Ispra, Italy (SAI/JRC)
- Dutch National Institute for Public Health and the Environment, Bilthoven, the Netherlands (RIVM)
- Geodan IT, Amsterdam, the Netherlands

In general, all partners were actively involved in the PELCOM project during the whole period, and were not only concerned with their own core activities but participated actively in all discussions that leaded to the successful completion of the project.

1.4 Contents of the report

This report describes the results of the PELCOM project (official project title '*development of a consistent methodology to derive land cover information on a European scale from remote sensing for environmental modelling*'), a shared cost project funded by Directorate General XII of the European Commission within the Environment & Climate Programme of the 4th Framework (contract No ENV-CT96-0315). Chapter 1 and 2 are introductory chapters. Chapter 1 gives a general introduction followed by a description of major land use changes that took place in Europe in Chapter 2. Chapter 3 describes the main satellite and thematic data sources that have been used in the project. The classification methodology is described in Chapter 4. The regional expert knowledge within the PELCOM team made it possible to optimise the classification results for the various regions in Europe. Chapter 5 illuminates the results of the regional classification experiments being compiled in one database: the PELCOM 1-km pan-European land cover database. The chapter also discusses the validation of the database. In principle, two large data sets have been used for comprehensive validation; the CORINE land cover database and a set of 40 interpreted TM images over Europe. Only the last one is discussed in Chapter 5. A methodology for monitoring on the European scale based on the linear unmixing technique is discussed in chapter 6. Chapters 7, 8 and 9 contain the three major case studies that applied the PELCOM database in various environmental and climate studies. The first case study is an extensive study of RIVM investigating the possibilities of the PELCOM land cover database in biodiversity research. The second case study is a study of CNRM investigating the use of the PELCOM land cover database in meteorological models by improving the descriptions of the boundary conditions. It discusses the use of land cover data in soil-vegetation-atmosphere transfer schemes, in numerical weather forecasting and in limited area models. The last case study is a study of ARCS dealing with the estimation of forest emissions in Europe on basis of the PELCOM land cover database. Chapter 13 highlights the main conclusions of the PELCOM project.

2 Land use changes in Europe

2.1 Introduction

Land use and land cover are strongly related. The land cover is the result of land use at a certain moment in time (Mücher et al., 1994). However, the terms land cover and land use are too often intermingled, with descriptions and definitions being written partly in terms of land cover and partly in terms of land use (UNEP/FAO, 1994). Land cover can be defined as the attributes occupying a part of the earth's surface, such as human artefacts, crops, grassland, forests and bare soil, which can be 'seen' from a distant and so by remote sensing. Land use often refers to, "man's activities which are directly related to the land" (Anderson et al., 1976). Examples of such land use classes are: industrial area, grazing land, recreation area, forestry, fishing area, etc. Such land use classes define the purpose for which the land is used (Mücher et al. 1994). In Stomph et al. (1997) a new concept is proposed for the description of land use to improve our understanding of the way agro-ecosystems function and, especially, to assess the environmental impact of land use.

The scale in time and space of land use changes increased dramatically during the last decades. According to the ECNC (European Centre for Nature Conservation) seminar on land use changes (Jongman, 1996), three processes should be distinguished clearly: intensification, marginalisation and extensification. Intensification is considered as a key activity in the development of modern society. The use of fertilisers, machinery and fossil fuel made it possible to increase production levels. For example agriculture in the European Union (EU) is going through a phase of accelerating changes. The continued increase in production per unit of land area and per unit of livestock, due to improved production circumstances, better cultivation methods and external inputs, has led to significant increases in agricultural productivity. Land use intensification in one area might cause marginalisation in other areas. Marginalisation indicates the process of disappearing functions because of its unprofitability. It can be found in all kind of activities from industry to forestry and agriculture. Marginalisation must be distinguished from extensification because that process indicates only changes in the way of using the land, but does not imply a socio-economic context. Both marginalisation and intensification are seen as threats to the landscapes of Europe.

2.2 Land Use statistics

In order to quantify the processes of land use change, the FAO website (http://apps.fao.org) was browsed for land use statistics over the last decennia (1961-1995) in Europe. Some examples of land use changes in Europe (Russian federation excluded) over the past decennia are (source: FAO statistics 1961-1994):

- A net gain of forest of 144,980 km^2 (+10%)
- A net loss of arable land of 157,320 km^2 (-11%)
- A net loss of permanent pasture of 102,280 km^2 (-11%)

For most countries land use statistics have been investigated to get insight into the trends in land use. Some interesting remarks are drawn from the FAO land use statistics in the following sections.

2.2.1 Arable land

During the last decennia the total amount of arable land has been relatively large in all concerned countries. However, there is an overall decrease during the last 35 years (see Figure 1). Countries in Western Europe, like the Netherlands and France, show a sharp decrease of total arable area till the early seventies. Since then the area of arable land in these countries recovered partly up to 85 % of the total arable area in 1961. The decrease of total arable land is largest in Sweden (more then 20 percent). The total amount of arable land in Spain shows a relatively irregular trend of decrease. Since the early nineties the total amount of arable land stabilised abruptly in Greece.

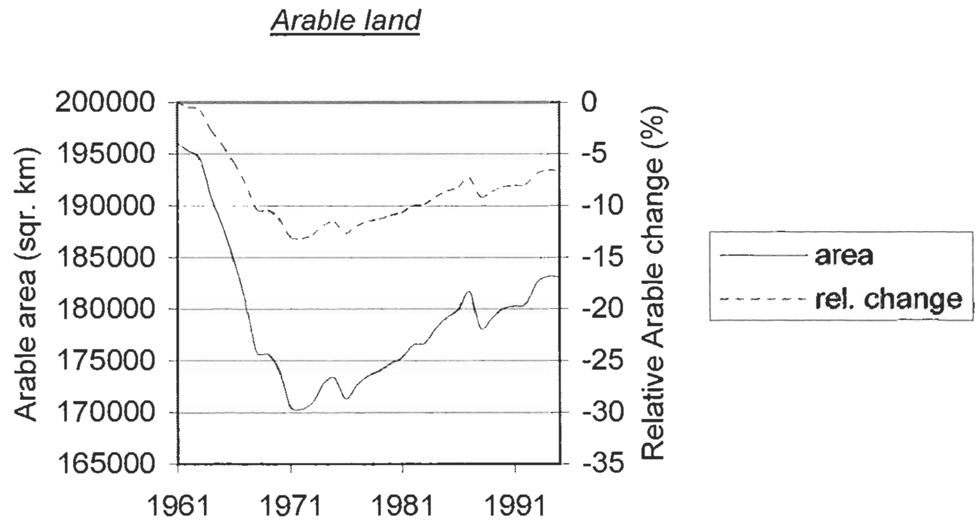

Figure 1 FAO land use statistics for arable land in France for the period 1961 to 1995. The solid line indicates the changes in the absolute acreage of arable land. The dotted lines indicated the relative change using 1961 as point of departure.

2.2.2 Permanent crops

The acreage of permanent crops increased most prominently in Poland, to 155 percent comapred with the acreage in 1961. Since the early sixties, Greece has the same steady increase in the amount of permanent crops to 120 percent of the initial amount in 1961.

On the contrary, countries like France and Hungary show a considerable and steady decrease of respectively 50 and 35 percent. In other countries like Spain and the Netherlands the total amount of permanent crops seems fluctuating through time.

2.2.3 Forest and Woodland

The total amount of forest/woodland has increased considerably in all concerned countries during the last three decennia (to 130 percent of the initial acreage in 1961). In most countries the amount of forest has increased especially during the sixties. However, in countries like Spain (Figure 2) and Hungary the total acreage of forest/woodland is still increasing. Although the increase of forest is relatively low in Sweden, the Scandinavian countries exceed all other countries in absolute terms.

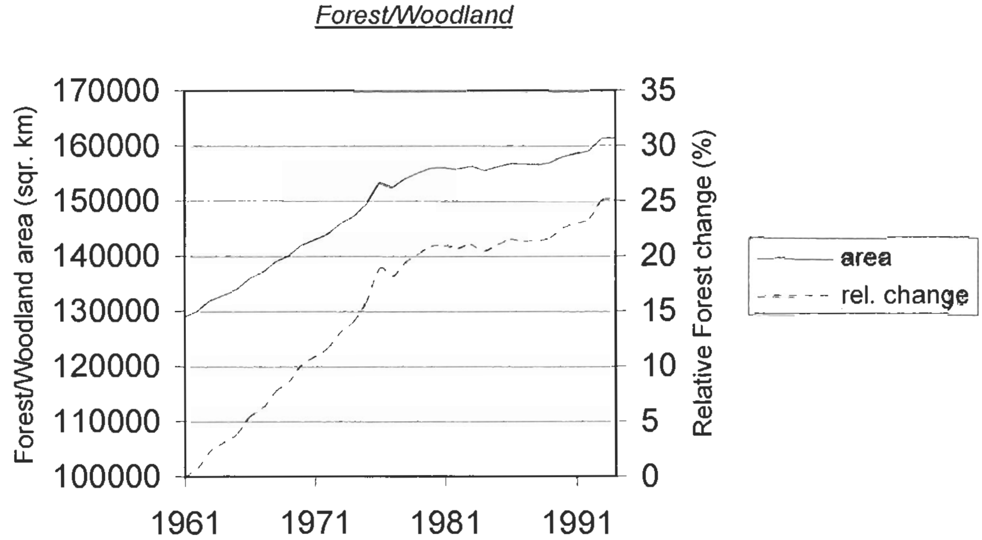

Figure 2 FAO land use statistics for forested and wooded land in Spain for the period 1961 to 1995. The solid line indicates the changes in the absolute acreage of arable land. The dotted line indicates the relative change taking 1961 as point of departure.

2.2.4 Permanent pasture

The total amount of permanent pasture was relatively large in all countries during the last decennia, except for Sweden. In Greece it's even the largest proportion of land use. In France and the Netherlands the total amount of permanent pastures equals the amount of arable land. During the last decennia, countries like Spain and Hungary showed a decrease of approximately 20 percent in acreage. Other countries like Poland, the Netherlands and France show the same decrease (a maximum was reached in the late 1960's). Sweden differs from this pattern with a maximum reached in the late 1970's. Greece on the contrary showed almost no change, except a strange drop in 1964. Apparently this is an artificiallity in the statistics.

3 Data sources

3.1 Satellite data

3.1.1 Introduction

Europe can be covered by two full scenes of the AVHRR (Advanced Very High Radiometric Resolution) sensor on board of the meteorological polar orbiting satellite NOAA (National Oceanic and Atmospheric Administration). In comparison with the METEOSAT satellite sensor, the AVHRR sensor has a high spatial resolution. In comparison with the high resolution satellite data, such as SPOT and Landsat TM, AVHRR satellite data has a high temporal resolution, which makes it more likely to find a cloud-free image for a specific area at a certain time period (see Table 2). In finding an equilibrium in a high spatial resolution, a high temporal resolution and covering large areas, the AVHRR sensor seems to be a very suitable sensor for mapping and monitoring the European continent.

Table 2 Characteristics of various satellite sensors

	METEOSAT	NOAA/AVHRR	LANDSAT-TM	SPOT-XS
Spatial resolution	2.5 km (VIS) 5 km (TIR)	1.1 km (nadir)	30 meter	20 meter
Temporal resolution	½ hr	1/2 day	16 days	26 days
Swath width	-	2400 km	185 km	120 km
Altitude	35,900 km	805 - 870 km	715 km	832 km

3.1.2 Technical description

The Advanced Very High Resolution Radiometer (AVHRR) is a broad-band, four or five channel (depending on the model) scanner, sensing in the visible, near-infrared, and thermal infrared portions of the electromagnetic spectrum. This sensor is carried on NOAA's Polar Orbiting Environmental Satellites (POES), beginning with TIROS-N in 1978. AVHRR data are acquired in three formats:

- High Resolution Picture Transmission (HRPT)
- Local Area Coverage (LAC)
- Global Area Coverage (GAC)

HRPT data are full resolution image data transmitted to a ground station as they are collected. The average instantaneous field-of-view of 1.4 milliradians yields a HRPT ground resolution of approximately 1.1 km at the satellite nadir from the nominal orbit altitude of 833 km. LAC are full resolution data that are recorded on an onboard tape for subsequent transmission during a station overpass. The average instantaneous field-of-view of 1.4 milliradians yields a LAC ground resolution of approximately 1.1 km at the satellite nadir from the nominal orbit altitude of 833 km

(517 mi). GAC data are derived from a sample averaging of the full resolution AVHRR data. Four out of every five samples along the scan line are used to compute one average value and the data from only every third scan line are processed, yielding 1.1 km by 4 km resolution at the subpoint.

Extent of Coverage

The AVHRR sensor provides global (pole to pole) on board collection of data from all spectral channels. Each pass of the satellite provides a 2399 km (1491 mi) wide swath. The satellite orbits the Earth 14 times each day from 833 km (517 mi) above its surface.

Spatial Resolution

The average Instantaneous Field-Of-View (IFOV) of 1.4 milliradians yields a LAC/HRPT ground resolution of approximately 1.1 km at the satellite nadir from the nominal orbit altitude of 833 km. The GAC data are derived from an on board sample averaging of the full resolution AVHRR data yielding 1.1-km by 4-km resolution at nadir.

Temporal Coverage

NOAA aims at maintaining two near polar orbiting, sun synchronous satellites, with equatorial crossing times of 7.30 at descending node and 19.30 at the ascending node for even numbered satellites and 14.30 at the ascending node and 2.30 at the descending node for odd-numbered satellites. The times being approximate mean local solar times (Buiten, 1993). An ascending node would imply a northbound Equatorial crossing while a descending node would imply a southbound Equatorial crossing. NOAA-B launched May 29, 1980, failed to achieve orbit. NOAA-13 launched August 9, 1993, failed due to an electrical short circuit in the solar array (see Table 3).

Table 3 Operational characteristics of NOAA satellites (source: NOAA)

Satellite Number	Launch date	Ascending Node	Descending Node	Service Dates
TIROS-N	10/13/78	1500	0300	10/19/78 - 01/30/80
NOAA-6	06/27/79	1930	0730	06/27/79 - 11/16/86
NOAA-7	06/23/81	1430	0230	08/24/81 - 06/07/86
NOAA-8	03/28/83	1930	0730	05/03/83 - 10/31/85
NOAA-9	12/12/84	1420	0220	02/25/85 – Present
NOAA-10	09/17/86	1930	0730	11/17/86 – Present
NOAA-11	09/24/88	1340	0140	11/08/88 - 09/13/94
NOAA-12	05/14/91	1930	0730	05/14/91 – Present
NOAA-14	12/30/94	1340	0140	12/30/94 – Present
NOAA-15	05/13/98	19.30	0730	5/13/98 - Present

NOAA-13 launched at August 9, 1993, failed due to an electrical short circuit in the solar array.

Spectral Range

The AVHRR is a radiometer measuring reflected and emitted radiation in five or four channels, depending on the satellite (see Table 4).

Table 4 Radiometric characteristics of AVHRR sensors

Band	Satellites: NOAA-6,8,10	Satellites: NOAA-7,9,11,12,14	IFOV
1	0.58 - 0.68	0.58 - 0.68	1.39
2	0.725 - 1.10	0.725 - 1.10	1.41
3	3.55 - 3.93	3.55 - 3.93	1.51
4	10.50 - 11.50	10.3 - 11.3	1.41
5	band 4 repeated	11.5 - 12.5	130
	(micrometers)	(micrometers)	(milliradians)

The five channels have the following characteristics:

AVHRR channel 1. Visible light (0.58-0.68 μm). This band corresponds to the green reflectance of healthy vegetation and is important for vegetation discrimination.

AVHRR channel 2. Near-infrared (0.72-1.0 μm). This band is especially responsive to the amount of vegetation biomass present in a scene.

AVHRR channel 3. Infrared (3.55-3.93 μm). In this band both reflected and emitted thermal radiation is measured. This band is of importance especially to discriminate snow and ice, monitoring of forest fires, fire fuel mapping.

AVHRR channel 4. Thermal infrared (10.3-11.3 μm). This band is useful for the determination of temperatures, the monitoring of cloud formation and for soil moisture studies.

AVHRR channel 5. Thermal infrared (11.5-12.5 μm). See AVHRR channel 4.

3.1.3 AVHRR data sources

One of the AVHRR data sources was the MARS (Monitoring Agriculture by Remote Sensing) archive which is maintained by the Space Applications Institute (SAI) of the Joint Research Centre (JRC). This archive contains unique pre-processed daily multi-spectral mosaics of AVHRR images covering Europe. NDVI composites are also available in this archive. However, these composites were not considered in the project, due to blurring effects. This is mainly caused by the automatic georeferencing (chip mathing) based on a limited amount of ground control points along the coastline. If these ground contol points are covered by clouds the automatic georeferencing fails and causes shifts between individual images. Therefore, NDVI maximum value composites for 1997 were selected from the DLR (Deutches Zentrum für Luft und Raumfahrt) archive and were used as the main data source within the classification process (see Figure 3). In addition, other AVHRR data sources, such as the IGBP-DIS (EROS Data Center) and Lannion archive, were used in specific cases. For a complete description of the used NOAA archives is referred to Appendix B.

Figure 3 NDVI monthly composites from the DLR Archive (Colour composite, Red: May 1997, Green: July 1997, Blue: September 1997.

3.1.4 Geographic Projection

All AVHRR and ancillary data has been georeferenced to the 'Albers Conical Equal Area' projection and was used as the standard PELCOM projection (see Table 5). Integration of all data is only possible after referencing all data to the same projection. This projection was selected because the MARS archive uses this projection as a standard. All AVHRR data from this archive have a spatial resolution of 1100 meters. Therefore, all other raster data obtained in the PELCOM project were resampled to 1100 meters spatial resolution.

Table 5 The standard "PELCOM" projection

Projection type:	Albers Conical Equal Area
Spheroid:	WGS72
Latitude of 1st standard parallel:	32: 30: 00 N
Latitude of 2nd standard parallel:	54: 30: 00 N
Longitude of central meridian:	22: 39: 00 E
Latitude of original projection:	51: 24: 00 N
False easting:	0
False Northing:	0

3.2 Thematic data

3.2.1 Introduction

State of the art in land cover mapping activities

The ten-minute pan-European land use database (ELU-1) of the Dutch National Institute for Public Health and the Environment (RIVM) was a first step towards meeting the demands of environmental models on a European scale (Van de Velde et al. 1994, Veldkamp et al. 1995). The database was made by a combination of non-spatial statistical information with spatial information from available land cover maps using a calibration procedure. The procedure consisted of an iterative process by which the regional land use is calculated and compared with the statistical figures, and consequently adjusted. The resolution (administrative level) of the statistical database determines the areas for which the land use is summed and adjusted. A major drawback of the database is that the statistical and spatial data are derived from many sources that differ in spatial accuracy, reliability, acquisition date and class definitions. Moreover, most statistical data have been collected on NUTS (Nomenclature d'Unités Territoriales Statistiques) level 0 and 1 (Van de Velde et al. 1994) causing a low spatial accuracy. Use of remotely sensed data eliminates this problem, as up-to-date land cover data may be inferred with a high spatial accuracy in a consistent manner.

Current activities on the derivation of pan-European land cover databases from remotely sensed data include the CORINE (Co-ordination of Information on the Environment) land cover project (CEC 1993), now under supervision of the European Environment Agency (EEA), and the development of a 1-km global land cover product, DISCover (Loveland and Belward 1997), under the co-ordination of the International Geosphere and Biosphere Programme's Data and Information System (IGBP-DIS). These are described briefly below. Other activities that use remotely sensed data for European land cover mapping, such as for example the ESA forest map (ESA, 1992) and the Forest Inventory by Remote Sensing (FIRS) project (Roy et al. 1997), are confined to a limited number of classes.

Importance ancillary data sources

During the last two decades, significant advances have been made in developing techniques for the use of satellite data jointly with ancillary data to improve the results of satellite image analysis (Brown et al. 1993; Palacio-Prieto and Luna-Gonzalez 1996). Ancillary data are now considered as being of crucial importance for methodology improvement of land cover mapping on a European scale. Ancillary data may exist as discrete, thematic or continuous data (Brown et al. 1993). Topographic features from the Digital Chart of the World (DCW) and Bartholomew Euromaps, e.g. rivers, lakes, coastlines, played a major role in the PELCOM project, e.g. when additional geometric corrections were necessary. Together with the CORINE land cover database some important masks for *water*, *urban areas* and in a later stage (after validation) *wetlands* were extracted from these data sources. One of the most important ancillary data sources in the PELCOM project was the CORINE land cover database that provides highly detailed land cover information for a large part of Europe. For training the classification homogeneous samples from the CORINE database were used as reference. For the stratification data were used from the Forest Inventory by Remote Sensing (FIRS) project of SAI-JRC. In Veldkamp et al. 1998 the role of ancillary data for improving classification results at a European scale has also been investigated. Their main conclusion was that the use of ancillary data for entire Europe is severely hampered due to large variation in thematic and spatial accuracy of the data sets. The digital elevation model GTOPO30 was encountered the most suitable data set for the definition of exclusion-rules (e.g. above a certain height it is very unlikely to encounter deciduous forests). However, these rules of exclusion can be very complicated because it depends not only on height but also on characteristics such as slope direction and climate zone. Moreover, such rules of exclusion can only be applied to very small parts of the European continent (mountainous regions) and mistakes are easily made.

In this chapter several thematic ancillary data sources are described that were used in the PELCOM Project.

3.2.2 RIVM 10 Minutes pan-European Land Use database

The Dutch National Institute of Public Health and the Environment (RIVM) initiated the construction of a '10 Minutes' pan-European land use database in 1994 (Van de Velde et al. 1994, Veldkamp et al. 1995). The database distinguishes eight classes: grass land, arable land, permanent crops, inland water, urban areas, extensive agriculture and natural areas, coniferous/mixed forest and deciduous forest. The database comprises three parts: LuStat, LuVec and LuGrid. LuStat is a tabular database, containing land use statistics on NUTS-2 or -1 (regional, if available) or NUTS-0 (National) level. LuStat is a compilation from various sources of land use statistics (e.g. FAOstat and Eurostat). LuVec is a land use map in vector format, prepared by SEI (Swedish Environment Institute), which is compiled from various map sources. LuGrid is produced by combining LuVec and LuStat using a calibration routine which combines the locational accuracy of LuVec with the correct areal totals of LuStat (Veldkamp et al. 1995). LuGrid consists of two parts: a vector-format fishnet grid used for geographical reference, consisting of cells measuring 10 geographical minutes (which equals about 10×15 km on average for the area covered), covering pan-Europe, and an attribute table in which for all fishnet cells the distribution of the various land use classes is stored, as a percentage of the area of the entire cell.

3.2.3 CORINE

The CORINE (Co-ordination of Information on the Environment) programme was initiated by the EU in 1985. A number of databases is being 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 (see Figure 4). 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 land cover and land use in 44 classes, grouped in a three level nomenclature (see Appendix C) in order to cover the entire land cover spectrum of Europe (CEC 1993). 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.

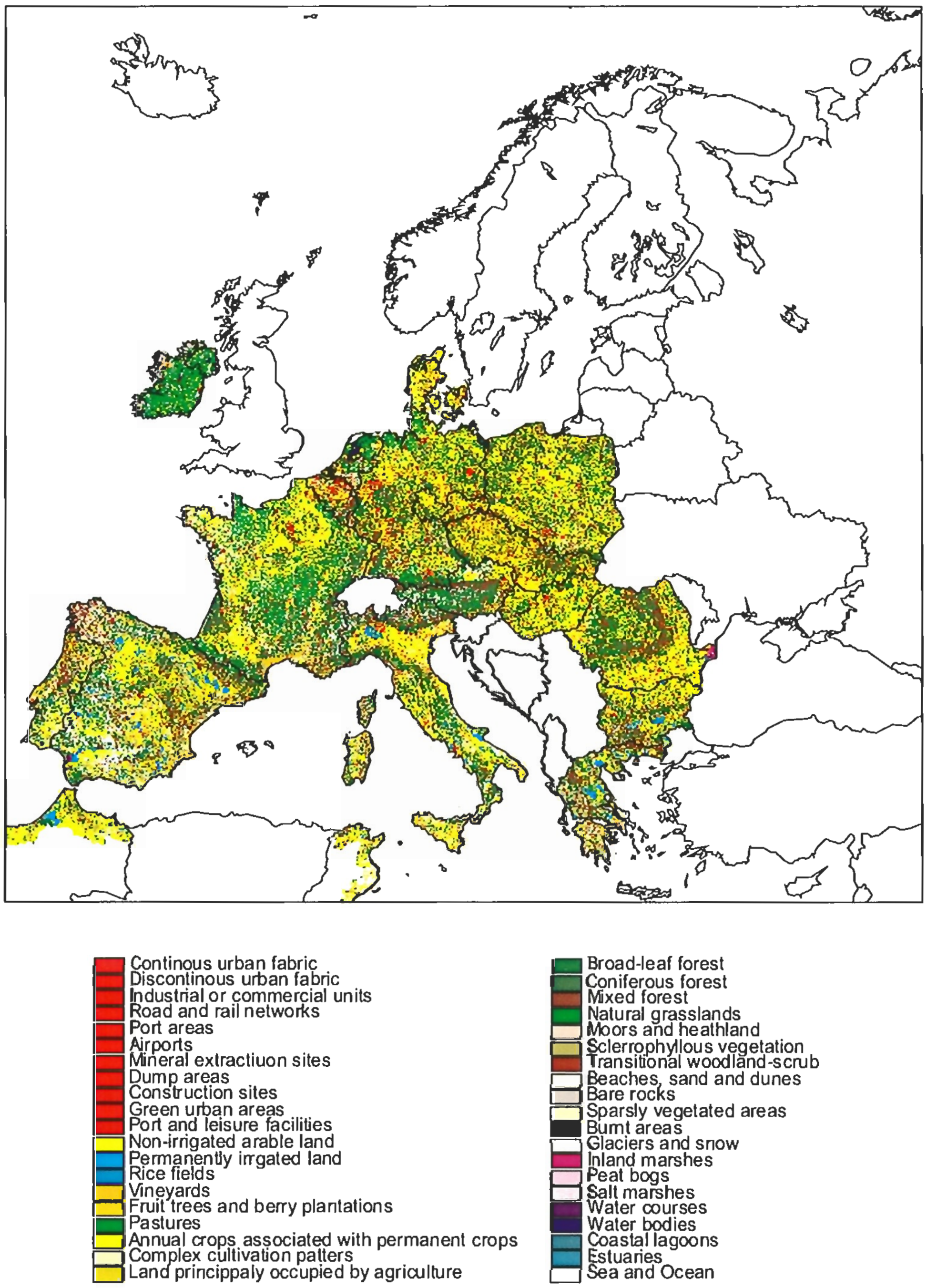

Figure 4 Extent of the CORINE land cover database in 1998 (source: EEA)

3.2.4 IGBP-DIS global 1-km land cover data set

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. 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, experiences indicate that the clustering technique does not identify forests satisfactorily (Champeaux et al. 1998 a). An additional limitation is that the 1-km database according to the DISCover legend contains complex classes, e.g. cropland/natural vegetation mosaics, which are difficult to apply in environmental studies. In the DISCover data set about 27 per cent of the pan-European land surface is covered by this land cover class. However, it must be stressed that the project is unique and enormous effort had to be invested in order to establish an up-to-date global land cover database at a 1-km resolution in a consistent manner. Application of the database in environmental and climate studies for pan-Europe may be limited.

3.2.5 FIRS regions and strata

In the framework of the FIRS (Forest Inventory from Remote Sensing) project of SAI/JRC a regionalization and stratification was made for European forest ecosystems (EC 1995, Kennedy et al. 1996). On the first level Europe has been divided into a small number of ecosystem regions based on *geofactors*, such as climate, soil and topography. On the second level the division has been guided by *biofactors* (e.g. potential forest species) to identify the various forest ecosystems (see also http://www.egeo.sai.jrc.it/forecast/firs/).

In spring 1998, both FIRS regions and strata were provided by the Environment and Geo-Information Unit of SAI-JRC. In a first instance, CNRM and Alterra tried to produce a stratification on basis of a.o. the IIASA climate database (provided by RIVM) that contains mean monthly values for a/o temperature, precipitation and sunshine hours for gridcells of 0.5 by 0.5 degree. However, the results did not meet the needed requirements. Most difficult was that the climate criteria and their class boundaries are regional depended which hampers a general clustering on basis of a few climate parameters for entire Europe. All PELCOM partners involved in the regional classification experiments confirmed that the 115 FIRS strata were preferred over other stratifications. The 115 strata have an average surface of 84,663 km^2 per stratum. In regions like the Alps, having a large variance in topography, the strata are smaller, while in eastern Europe the strata are much larger. When required the strata were aggregated or subdivided into several strata depending on the expert knowledge of the interpreter in the regional classification experiment.

3.2.6 ESA digital forest map of Europe

The ESA Digital Forest Map (DFM) was prepared by the European Space Agency (ESA, 1992), as a contribution to the World Forest Watch project of the International Space Year 1992. Classification accuracy was evaluated by comparing AVHRR classification results with Landsat MSS. Overall accuracy was found to be 82.5% with an average surface area accuracy of 93.8% (Häusler et al., 1993). The classified images were vectorized and compiled into a single dataset. The legend contains the classes forest, non-forest, water and data-gap. The maximum feasible scale is 1 : 2,000,000.

3.2.7 Digital Chart of the World (DCW)

The Digital Chart of the World (DCW) is a comprehensive 1 : 1,000,000 scale vector base map of the world. It consists of 17 thematic and topographic layers (see Table 6) with 31 feature classes of cartographic, attribute and textual data.

Table 6 Thematic layers of the Digital Chart of the World.

Thematic Layer	Description	Thematic Layer	
1.	Aeronautical Information	10.	Land Cover
2.	Cultural	11.	Ocean Features
3.	Landmarks	12.	Physiography
4.	Data Quality	13.	Political
5.	Drainage	14.	Populated Places
6.	Supplemental Drainage	15.	Railroads
7.	Utilities	16.	Roads
8.	Vegetation	17.	Transportation Structures
9.	Supplemental Hypsography		

The DCW was digitised under contract of the US Defense Mapping Agency (DMA) from their Operational Navigation Chart series in the Vector Product Format. The layers include, among other items, political boundaries, coastlines, cities, transportation networks, hydrography, land cover and hypsography. All are at 90% confidence as defined by the DMA.

3.2.8 Bartholomew Euromaps

Bartholomew Euromaps contains virtually the entire vector data set that is used to produce printed maps such as road atlases at scales of about 1 : 1,000,000. The data set is updated continuously. It is appropriate for viewing on a computer screen at scales of up to about 1 : 250,000. The data set generally extends from 13°W (Atlantic Ocean) to 47°E (Caspian Sea) and from 35°N (Mediterranean) to 72°N (Barents Sea). Iceland, Madeira, the Canarian Islands and the Azores are also included. Towards the south-eastern corner, especially beyond the Black Sea, some features are incomplete. The objects in the vector data set include attributes, such as town names and natures of tourist sites. Indexed names for more than 77,000 towns, 3,000 mountain peaks and passes, 60 countries and 730 administrative divisions are included. The various features are organised into about 40 individual layers (see appendix D).

3.2.9 USGS GTOPO30 Digital Elevation Model

GTOPO30 is a global digital elevation model (DEM) resulting from a collaborative effort led by the USGS EROS Data Center. 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 originates almost completely from the Digital Chart of the World. Elevations are regularly spaced at 30-arc seconds (approximately 1 kilometre). Figure 5 shows a detail of the global elevation model USGS GTOPO30 for the Alps.

Figure 5 Relief detail of the global USGS GTOPO30 Digital Elevation Model for Europe

3.2.10 FAO 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, which consist of soil units or associations of soil units. The soil units (106 from Af to Zt) are grouped in 26 major soil groupings. Additionally, soil texture is recognised and digitised with several characteristic classes of relative clay, silt and sand proportions. The dataset 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.

3.2.11 Some National land cover databases

Witin the PELCOM project various national land cover databases have been used as reference. Three national land cover databases are described briefly, respectively the Dutch, Swedish and Austrian land cover database.

3.2.11.1 Dutch National land cover database

The land use database of the Netherlands (LGN-2, an update of the first version LGN-1) was created by Alterra in 1995 using Landsat Thematic Mapper images of 1992 and 1994 (Thunnissen and Noordman, 1996). With respect to the production of LGN-1, newly developed classification methods were applied. Especially the new possibilities of integrating data from satellite imagery and geographical information systems have improved the quality of the database. Topographic maps, land use statistics, aerial photographs and ground reference data were used for the production of LGN-2. A multi-temporal approach provided important means for an improved classification accuracy. The resolution of the database is 25 meters. The country is covered entirely. Each pixel contains information on land use in a two level, 26 class legend. LGN-3 was created by Alterra in 1998 using Landsat Thematic Mapper images of 1995 and 1997 (De Wit et al., 1999). With respect to the production of LGN-3, the classification methodology used a multi-temporal approach and was strongly based on visual interpretation. The recently available digital 1:10.000 topographic database of the Netherlands was used to add some classes which are difficult to obtain from satellite imagery. The entire country is covered with the database using a resolution 25 meters. Each pixel contains information on land use in a two level, 43 class legend. The accuracy of the database is in the order of 90% on the first level and for most classes between 70 and 90% on the second level (http://cgi.girs.wageningen-ur.nl/cgi/projects/lgn/index_uk.htm).

3.2.11.2 Swedish National land cover database

The Swedish land cover database, created in 1992 by Satellitbild (today Satellus AB, Swedish Space Corporation Group), is one of the most extensive digital mapping projects based on satellite imagery carried out within Europe. The database is based on satellite data from the period 1988 to 1990, and was used for comparison with the PELCOM classification. The National database includes a total of 900 map sheets, each covering an area of 25 by 25 kilometres, in total about 500 000 sq. km. The classification was derived from Landsat TM satellite images complemented by SPOT imagery using supervised classification. The classification of the satellite images is combined with digital map data showing wetlands and built-up areas. The final result is presented in 13 classes with a resolution of 25 by 25 metre pixels.

Land cover classes in the Swedish National database:

• Water	• Forest, deciduous	• Open land, rock
• Wetland/mire, wet type	• Forest, scrub	• Open land, snow.ice
• Wetland/mire, dry type	• Forest, new clearcuts	• Open land, other
• Forest, dense coniferous	• Built-up area, urban	•
• Forest, sparse coniferous	• Built-up area, other	•

Before the classification process, the satellite images have been geometrically corrected to correspond to the Swedish National Grid. Aerial photos were used as reference and for verification of the classification results. During a period between 1995 and 1999 all mapsheets, excluding the mountainous area, were updated with data from 1994 to 1998. In total 30 Landsat TM scenes and 1 SPOT scene have been utilised. In the update one class was added, namely young coniferous forest.

3.2.11.3 Austrian land use database

The land use data base of Austria was created by the Austrian Research Center Seibersdorf (ARCS) in 1994. It is based on mono-temporal Landsat TM data from 1991, that were geocoded with respect to a 50m Digital Terrain Model. The classification was carried out in two steps. First a per-pixel classification was performed resulting in a land cover map. In the second step the land cover map was generalised applying a rule-based postclassification technique. This postclassification analyses the spatial composition of land cover types in a local environment and assigns generalised land use classes according to predefined rules. Topographic maps and KFA images were used as reference. The resulting land use model is raster based and has a spatial resolution of 100 meters. The nomenclature includes 15 land use classes related to level 2 of the CORINE land cover nomenclature. Comparison with selected parts of the CORINE land cover map and detailed analysis of conflicting areas proved the reliability of the land use model.

4 PELCOM classification methodology

4.1 General concept

Using only daily multi-spectral AVHRR scenes in the classification process is not feasible for pan-Europe. The most important reason is the frequent occurrence of clouds over many regions in Europe which implies that a huge amount of multi-spectral scenes need to be selected (from the MARS archive of JRC) and these images all have to be processed (eg. cloud masking and additional geometric corrections) individually. Therefore, decision keys should be developed that exploit both the uses of multi-temporal (NDVI) composites and multi-spectral AVHRR scenes at specific dates. The methodology developed in the PELCOM project is a stratified approach exploiting regional expert knowledge and is based on combining both unsupervised and supervised classification approaches. NDVI maximum value composites for 1997 obtained from DLR were the main data source within the PELCOM project.

A forest map has been produced by CNRM on basis of timeseries of AVHRR albedo (see section 4.4.1). Several other thematic maps have been derived from additional geographic sources, amongst others for water, urban areas and wetlands (in the post-classification). All thematic maps could be used to mask the AVHRR data.

The training samples are derived from selected homogeneous areas of the CORINE land cover database or additional national land cover databases. The spectral characteristics of each training sample are used to determine class boundaries and pixel assignments in the supervised classification. In the PELCOM project, the developed algorithm calculates the first and second minimum distances for each AVHRR image pixel based on the training samples, and as a result, it derives the first best class and the second best class for each pixel. The ratio between the distances is also calculated and can be used as a measure for the homogeneity of a single pixel and it is a valuable information to the end user. Using the first minimum distances, the regional classification experiments were compiled into a single database. Inconsistencies between various regional classification experiment were eliminated based on visual interpretation. After this classification, specific improvements are expected to be obtained by combining thematic ancillary data in a post-classification procedure. In the following sections the classification methodology is described in more detail.

4.2 Nomenclature

Set-up of the nomenclature needs much care, because it determines which land cover classes are identified in the classification process and will directly determine the usefulness of the AVHRR derived land cover database for the various applications. Below the classification scheme is given (Table 7) as it has been defined for the

PELCOM project. The PELCOM classification scheme consists of ten major land cover classes and nine sub-classes. A few remarks can be made about the nomenclature. First of all, the nomenclature is quite ambiguous and during the projcet it was investigated if all land cover types could be identified with an high accuracy. A main problem is that most land cover classes have a rich variety in reflectance that differs in time and in space. A second remark is that natural and cultivated grassland are not pure land cover classes, but do relate to land use. However, it was expected that both classes differ significantly in reflectance especially for the mountainous regions. A last remark can be made about the fact that the nomenclature does not contain complex classes. The reason for this is that complex classes are difficult to handle within for environmental and climate models. However, many regions are very heterogeneous, especially within the Mediterranean area, and that it was difficult to separate the different classes as defined within the nomenclature. In general, most AVHRR pixels are mixed pixels but it is assumed that the pixel can still be assigned to a land cover class that is dominant within the pixel.

Already in the first year of the PELCOM project the nomenclature has been defined. However, in autumn 1998 after the first preliminary classification results came available it was necessary to adjust the nomenclature slightly. For example, for the forest types the distinction in sublasses of dense and spare forest have been removed from the nomenclature. In addition, the codes for the land cover classes have been standardised at the fifth PELCOM meeting in Venice. The revised nomenclature is given below.

Table 7 PELCOM classification scheme

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(10) FOREST
Lands dominated by trees and shrubs.

> (11) Coniferous forest
> Lands dominated by coniferous trees and shrubs.
> (12) Deciduous forest
> Lands dominated by deciduous trees and shrubs.
> (13) Mixed forest
> Lands dominated by coniferous and deciduous trees and shrubs.

(20) GRASSLAND
Lands with herbaceous types of cover. Tree and shrub cover is less than 10%.

> (21) Natural grassland
> Natural lands with herbaceous types of cover. Tree and shrub cover is less than 10%.
> (22) Cultivated grassland
> Lands that have introduced grass species and has been improved for grazing. Tree and shrub cover is less than 10%.

(30) ARABLE LAND

> Cultivated areas that has been tilled.
> (31) Non-irrigated arable land
> Cultivated crops for which the land is tilled.
> *(33) Winter crops*
> Cultivated areas with winter crops regularly ploughed under a rotation system.

(34) Summer crops
Cultivated areas with summer crops regularly ploughed under a rotation system.
(32) Irrigated arable land
Crops irrigated permanently and periodically, using a permanent infrastructure.

(40) PERMANENT CROPS
Crops not under a rotation system which provide repeated harvests and occupy the land for long period before it is ploughed and replanted; e.g. vineyards and orchards.

(50) SHRUBLAND
Lands with woody natural vegetation less than 2 meters tall. Includes vegetation types such as maquia.

(60) BARREN LAND
(61) Rocks
Areas dominated by cliff scarps, rocks and outcrops.
(62) Bare soil
Areas dominated by exposed soil, beaches, dunes and littoral expanses of sand and pebbles.

(70) PERMANENT ICE AND SNOW
Lands under snow and/or ice cover throughout the year. Glaciers and permanent snowfields.

(80) WETLANDS
Lands with a permanent mixture of water and herbaceous or woody vegetation that cover extensive areas. The vegetation can be present in either salt, brackish, or fresh water.

(90) WATER BODIES
Oceans, seas, lakes, reservoirs and rivers.

(100) URBAN AREAS
Land covered by buildings and other man-made structures.

(110) DATA GAPS
Clouds, dim, fog or lack of AVHRR data

4.3 Regionalization and stratification

Working over compex landscapes for a extensive region as pan-Europe makes stratification a prerequisite. The purpose of any stratification is to divide the area of interest in strata that are more homogeneous in land use and land cover and in phenology than the area as a whole and to reduce the impact of climatic gradients (Thunnissen *et al.* 1993, Mücher et al. 1996, DeFries et. al. 1994). Successive classification of different strata enables improvement of the discrimination process on difficult classes and reduces the number of misclassifications due to spectral confusion (Thunnissen *et al.* 1993). A stratified approach improves the accuracy and detail of the classification. In the framework of the FIRS (Forest Inventory by Remote Sensing) project of SAI/JRC (Space Applications Institute of the Joint Research Centre), a regionalization and stratification was made for European forest ecosystems (EC 1995, Kennedy *et al.* 1996). Within the PELCOM project the FIRS regions and strata have been used for regionalization and stratification (see also section 3.2.5).

In the regional classification experiments 5 PELCOM partners were involved: SSC, CNRM, IUAV, ARCS and Alterra. Figure 6 shows how Europe has been divided between the partners on basis of the FIRS regions. The expert-knowledge at the various institutes are exploited in the regional classification experiments using a regional approach. All regional classification experiments are done within the general framework of the PELCOM classification methodology. For the stratification within the regional classifications the FIRS strata have been used. When required the strata were aggregated or divided into several strata depending on the expert knowledge of the interpreter in the regional classification experiment (see also section 3.2.5).

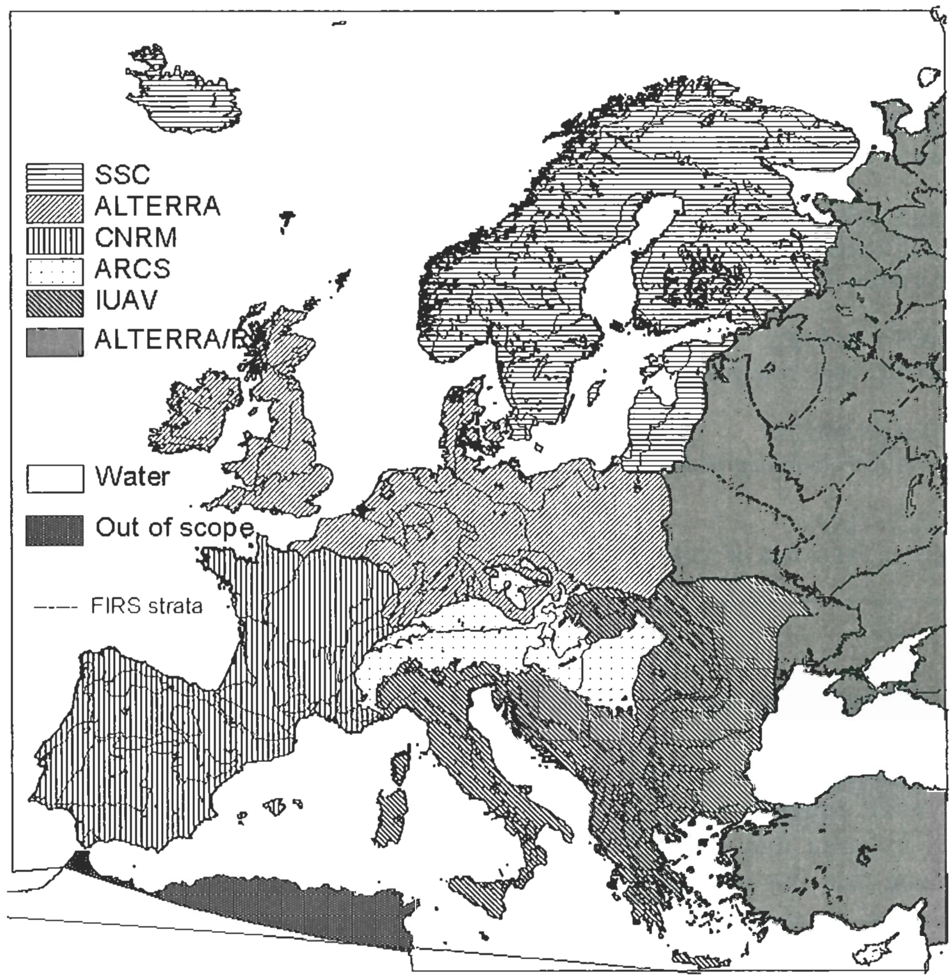


Figure 6 Areas of interest concerning the regional classification experiments

4.4 Masks

Before the regional classification experiments started three thematic maps have been produced: for forests, water bodies and urban areas (Figure 7). The forest map is based on NOAA-AVHRR satellite data, while the other two are based on ancillary geographic data sources. These thematic maps were optionally for masking the AVHRR satellite data within the regional classification experiments.

Masking is often necessary because the above mentioned classes have often a strong spectral overlap with other land cover classes and causes therefore confusion and decreases the classification accuracy. One known example is the spectral confusion between barren land and urban areas. The ancillary data sources that have been used for the urban areas and the water bodies are o.a. the DCW and Barthomew Euromaps. The various masks (thematic maps) are discussed below in more detail.

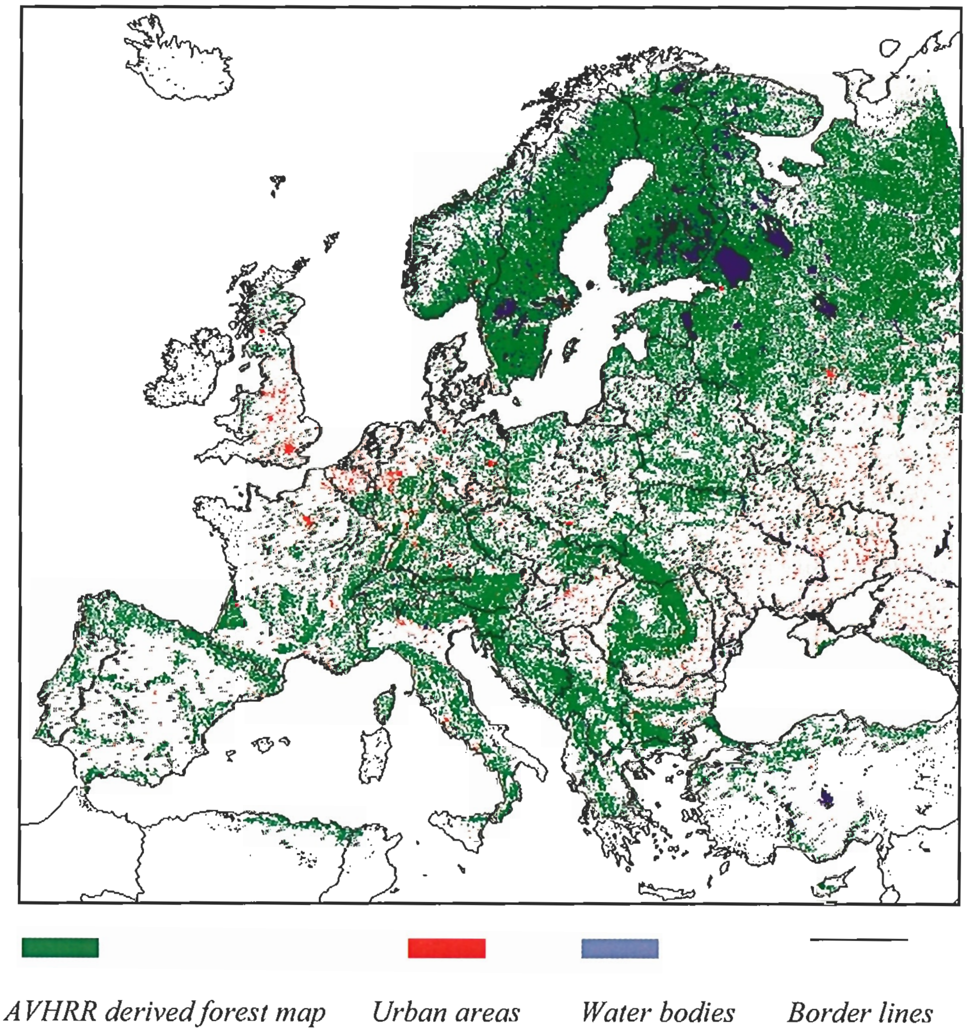


Figure 7 PELCOM masks

4.4.1 Forest Map

Classification of NDVI maximum value composites often fails to correctly discriminate forests from grasslands (Champeaux *et al.* 1998). In a supervised classification forests can be identified on individual multi-spectral scenes using AVHRR channels 1, 2 and 3 (ESA 1992, Mücher *et al.* 1994). However, such an approach is hampered for pan-Europe due to frequent occurrence of clouds.

Therefore, CNRM proposed another method to improve forest mapping (Champeaux and Legleau, 1995). Advantage was taken of the photosynthetic efficiency of the forest canopy that results in low visible reflectances. This is particularly true in summertime for northern Europe and in spring and autumn for southern Europe. The identification of forests was therfore implemented on basis of thresholding the synthesis of visible reflectance of AVHRR channel one (Champeaux *et al.* 1998 a, Champeaux *et al.* 1998 b). Ten climate areas were selected where the forests are identified by applying specific thresholds in the range between 3.8% and 5.1% of visible reflectances; the thresholds are selected with the help of ground-truth maps. This resulted in a new forest map.

In order to complete the mapping for eastern Europe, not covered by the AVHRR data from the Lannion archive, Alterra has merged the CNRM forest map with the ESA forest map (ESA 1992, Häusler *et al.* 1993). The final forest map is shown in Figure 7. In a first validation the accuracy of this combined forest map has been assessed by using the CORINE land cover database (recoded and aggregated to 1100 meters with a 75% majority threshold). The confusion matrix gave an accuracy of 74% and a reliability of 67%. This result proves that the use of the reflectance thresholds (for AVHRR channel 1) leads to a better discrimination of forests than the clustering of NDVI composites. The forest map is used as a mask in the sequent classifications.

In a later stage, subclasses for forest (coniferous, decideous and mixed forest) were identified on basis of thresholding the maximum NDVI for the area with the forest mask. The thresholding values have been selected per FIRS region on bais of homogeneous CORINE samples.

4.4.2 Water and urban mask

The masks produced for water bodies and urban areas (Figure 7) were obtained by integration of various ancillary sources, such as the Digital Chart of the World (DCW). In a later stage it was decided to derive this information from CORINE land cover database – as far as the extend of the database allowed this.

4.5 NOAA classification

The PELCOM classification methodology is based on regional expertise using a stratified approach. All regional classification experiments (Figure 6) were implemented within the general classification framework (Figure 8). For stratification the FIRS strata (Figure 7 and section 3.2.5) were used. The classifications were implemented per stratum (including a ten pixel boundary area). The thematic maps for urban areas, water bodies and forest (see section 4.4 and Figure 7) were optional for masking. The principle AVHRR data sources that have been used are: NDVI (monthly) maximum value composites for 1997 from DLR (Figure 3) and a selection of about 40 'optimal' (minimum cloud coverage) AVHRR multi-spectral mosaics over the period 1995-1997 from the MARS achive. For referencing, the CORINE land cover database (see section 3.2.3) has been used as principle information source. For this purpose the CORINE database has been aggregated to a spatial resolution of 1100 meters. In principle, only 100% homogeneous CORINE pixels (at the aggregated scale) have been used for training or labeling. When national land cover databases were used the same procedure was followed. In Figure 8 a flowchart is demonstrated which represents the general classification methodology. The classification of the satellite data itself is described below in more detail.

For each stratum around 10 clusters/classes were defined depending on the size and the diversity of land cover types present in a stratum. Assessment of the adequate number of clusters/classes was based on visual interpretation of multi-spectral AVHRR scenes, reference samples derived from the CORINE land cover database and/or region data. Depending on the complexity of the region, a supervised classification or clustering was performed on the NDVI composites of 1997. Each classification resulted in a set of spectral signatures. For each pixel the spectral distance to each class/cluster was determined and were labelled to the two classes with the smallest distances. To achieve this, the individual signatures from the signature file are used for successive supervised classifications and the main output of these classifications are the spectral distance files (minimum distance is used as parametric rule). These distance files contain the minimum distance to the respective signature of a cluster on a pixel basis. For each pixel the two smallest distances were retrieved and the related signatures/cluster numbers were assigned to two image layers, i.e. each pixel will receive a first and a second 'probability' cluster number. In addition, the ratio between the first and second distance is computed as D1/D2 and assigned to a third layer. The idea is that the distance ratio can be used as a measure for homogeneity of the single pixel and is valuable information to the end-user.

For each stratum the results from the unsupervised classification of the NDVI composites were compared interactively with the visual information in the multi-spectral AVHRR scenes. The information in either the multi-temporal or multi-spectral AVHRR data will be strongly influenced by the quality of the concerned data and the specific land cover features present in the specific stratum. If specific features, e.g. linear features, and specific land cover classes were only visible in the multi-spectral AVHRR scenes they were derived from these scenes by a supervised classification.

Much discussion went about if a supervised or unsupervised classification algorithms had to be used. Therefore, it was decided that this choice was made by the regional expert himself. In principle, all classifications are based on the same data which should lead to similar results. The choice of using supervised or unsupervised classification depended much on the complexity of the region. In heterogeneous areas it was more convenient to use clustering techniques. In both cases, signatures, spectral minimum distances and distnace ratios were obtained.

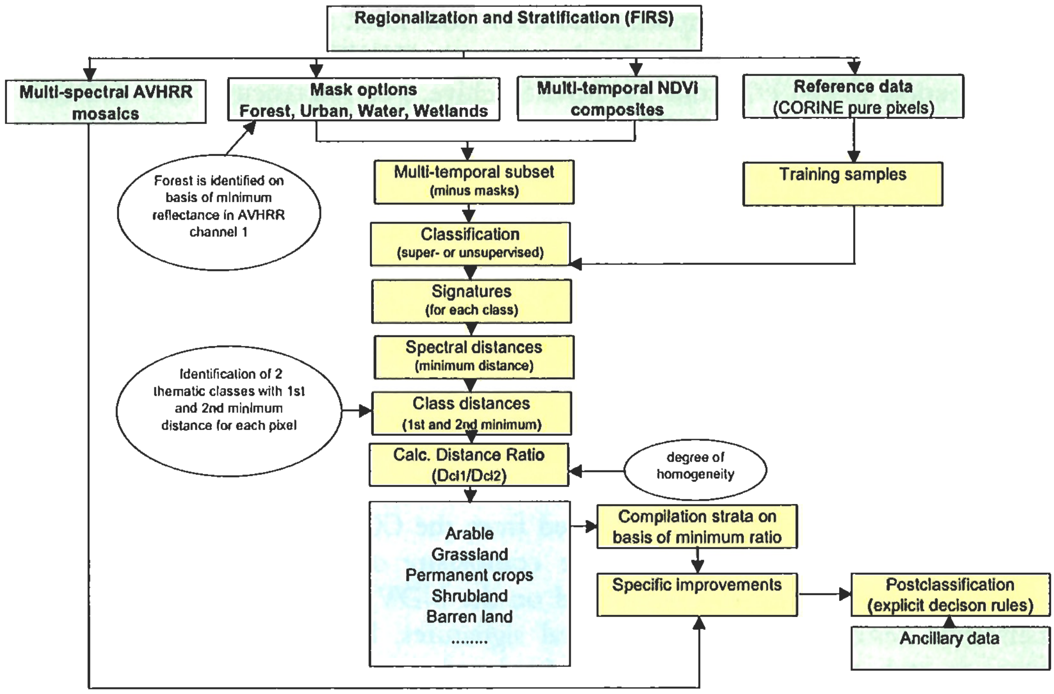


Figure 8 Flowchart of the PELCOM classification methodology

The result, the final 1km pan-European land cover database, and its validation will be discussed in the next chapter.

5 The PELCOM land cover database

5.1 Results

For the compilation of the final database the first-best classification results have been used for each stratum. Because for each stratum a 10-pixel boundary zone was used, there was an overlap between all classifications. On basis on visual interpretations it was decided which regional classification should overrule which adjacent classification. Some irregularities, in terms of unclassified pixels, were removed by a majority filter. Eastern-Europe (east of Poland) was not considered within the defined regional classification experiments. This problem was solved with another project, called INDAVOR - a Dutch collaboration of Resource Analysis, TNO-MEP and Alterra (Boer et al., 2000). Within this project there was also need for a 1km pan-European land cover database for application within a tropospheric ozone model (LOTOS). It was decided to follow the classification methodology of the PELCOM project, using the same data. The only difference now was that the classification was not performed per stratum but per region – largely reducing the number of classifications. The 1-km pan-European land cover database established within the INDAVOR project has been called PELINDA database (referring to PELCOM and INDAVOR). In the PELCOM project the part that has not been covered within the regional classification experiments has been retrieved from the PELINDA database. The PELCOM land cover database is demonstrated in Figure 9.

The final version of the PELCOM database contains 16 classes with a total surface of 17,603,669 km^2 (Table 2). Note that the land cover classes urban areas, wetlands and water bodies have been derived from ancillary data sources.

Table 8 Land cover statistics of the 1km PELCOM land cover database

Nr	Class name	Area (ha)	Nr	Class name	Area (ha)
1	Coniferous forest	148545000	9	Barren land	16259300
2	Deciduous forest	82033900	10	Ice&Snow	8783270
3	Mixed forest	51345900	11	Wetlands	34204800
4	Grassland	127978000	12	Inland waters	23010700
5	Rainfed arable land	309130000	13	Sea	7081737
6	Irrigated arable land	7067000	14	Urban areas	104335
7	Permanent crops	11695500	15	Data gaps	2550
8	Shrubland	48608100	16	Out of scope	180852

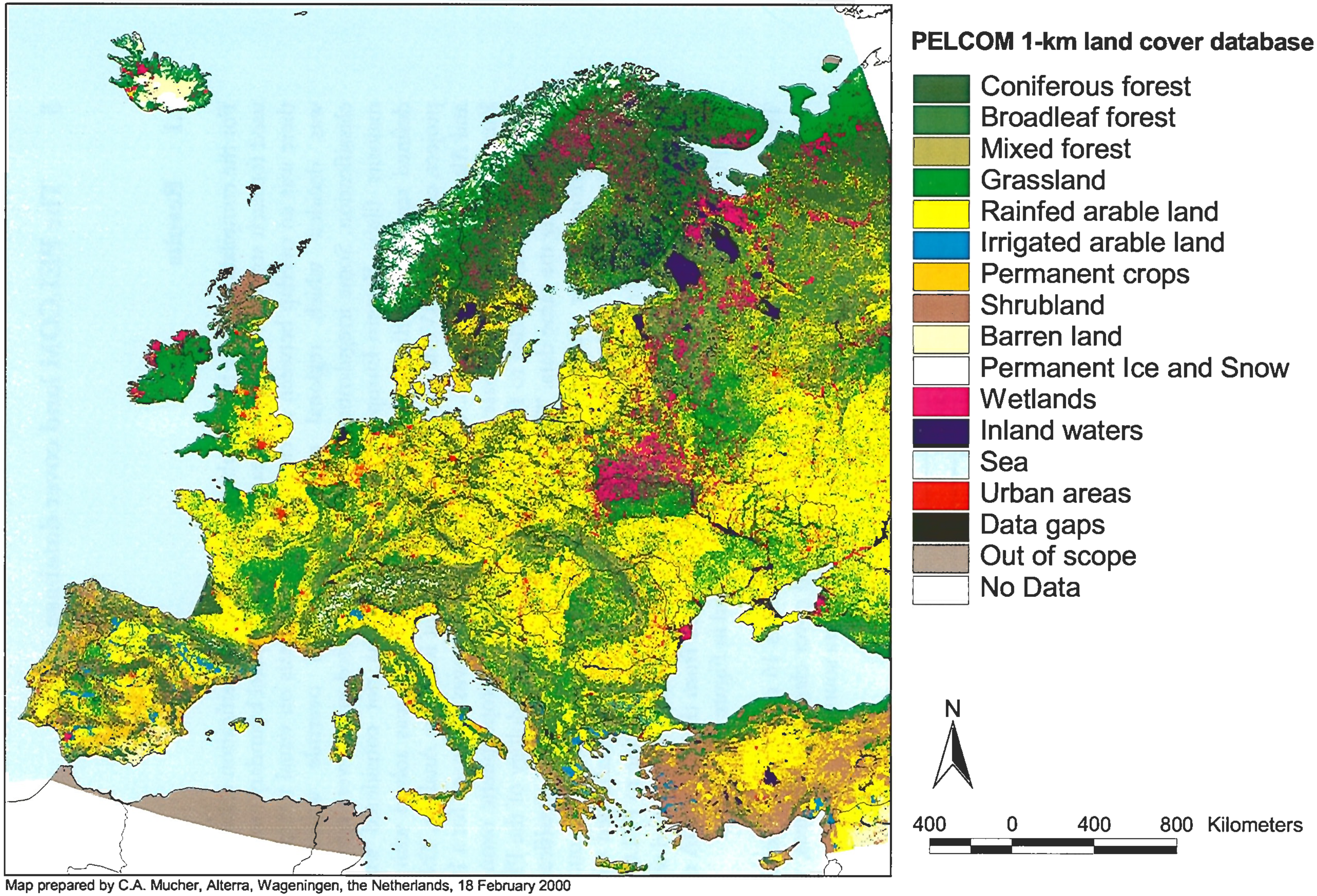


Figure 9 The PELCOM database: a 1km pan-European land cover database

5.2 Validation

Validation of the PELCOM land cover database followed various methodologies, based on CORINE land cover data, statistiscal information and on basis of high-resolution satellite images. The last one was considered as the most independent validation method. The result of this validation is explained below.

Here, ideas have been followed from the IGBP-DIS global land cover database validation (IGBP-DIS, 1996). It was decided to limit the validation to the confidence site mapping due to the amount of work. 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). In the ideal situation one identifies on each TM image polygons with a homogenous land cover for each PELCOM class. The polygons should be large enough meaning polygons of at least 4 km^2. Each polygon got a label (code) according to the PELCOM classification scheme. Before using the confidence sites for validating the PELCOM database, the coverages had to be converted from polygon to raster format. Next, there was an aggregation process (from the 25 meter spatial resolution of the Landsat-TM data to a spatial resolution of 1100 meters of the PELCOM land cover database). For this purpose a majority rule was used with a 80% threshold. So, only those 1100 meter pixels (PELCOM pixels) were accepted for validation that were covered for more than 80% with interpreted 25 meter pixels (Landsat-TM) of one specific class. This resulted in a total area of (interpreted) confidence sites of 7700 km^2. As can be seen in Figure 10 not all PELCOM classes are equally represented within the confidence sites. Moreover, for permanent crops no confidence sites were identified within the available images. Land cover classes such as arable land and coniferous forest are more common in Europe, less fragmented and easier to interpret than classes such as permanent crops and wetlands and this is reflected in the interpreted confidence sites. Of course, this distribution affects the validation results. Figure 11 demonstartes the results from the contingency table. It shows the accuracies and reliabilities of the various land cover classes.

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. The mixed pixel problem is especially present in heterogeneous areas such as the Mediterranean region. Accurate geo-referencing is a general problem of AVHRR data that reduces the apparent spatial resolution when multi-temporal series of AVHRR data are being used. Major classes such as arable land and coniferous forest still have a high reliability and accuracy of around 80%, while small and fragmented classes such as shrubland and wetlands have a very low accuracy and reliability. Exceptions are barren land and permanent ice and snow. These validation results show in general the same trends as in those cases that the PELCOM database was validated using CORINE land cover database and statistical data.

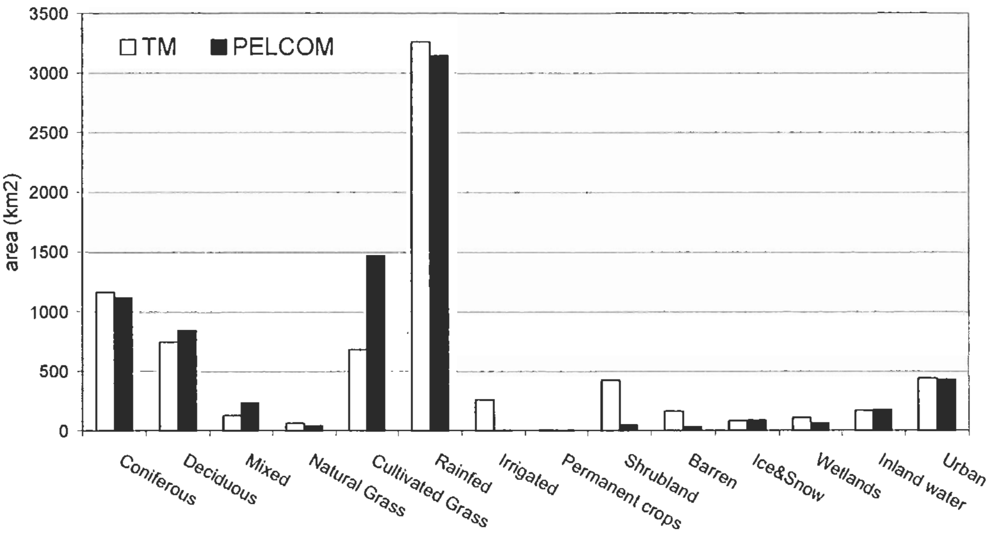
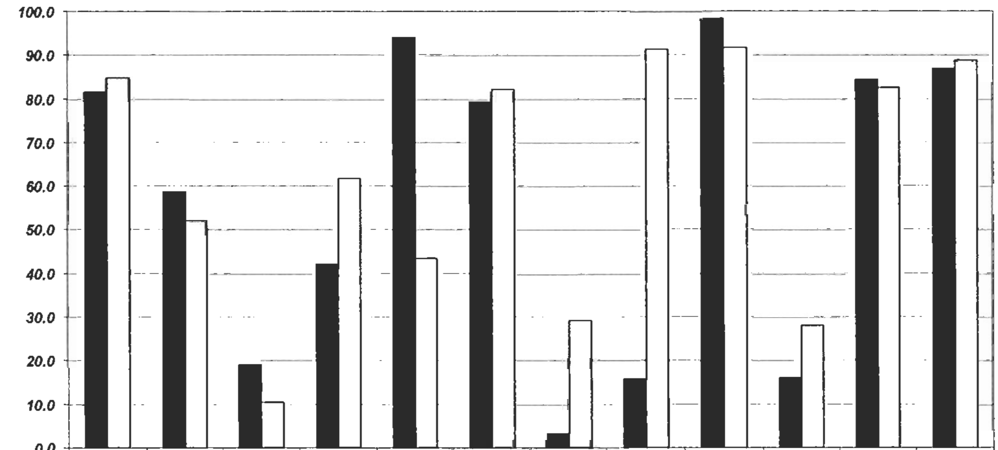


Figure 10 Overall statistics (acreages) of the confidence sites and related PELCOM areas



	Conif.	Decid.	Mixed	Nat. Grass	Cult. Grass	Arable	Shrubl.	Barren	Ice&Snow	Wetlands	Inl. water	Urban
■ Accuracy	81.5	58.7	19.0	41.9	94.0	79.2	3.2	15.8	98.5	16.0	84.3	86.8
□ Reliability	84.8	51.8	10.4	61.6	43.5	82.1	29.0	91.1	91.8	28.1	82.5	88.7

Figure 11 Validation results for the 1km PELCOM land cover database using the confidence sites of 40 high resolution satellite images distributed over Europe.

5.3 Conclusions

An improved stratified and integrated classification methodology to map major land cover types of pan-Europe using NOAA-AVHRR satellite and additional geographic data in a consistent manner. Both multi-temporal NDVI profiles and multi-spectral

AVHRR scenes were used as input in the classification procedure exploiting the advantages of both data types. Due to the limited accuracy of identifying forests on basis of unsupervised clustering of NDVI timeseries, the identification of forests was implemented on basis of thresholding the synthesis of the visible reflectance of AVHRR channel one. This resulted in a pan-European forest map. Additionally, urban areas and inland water, which were derived from ancillary data, were masked optionally.

The validation results showed reasonable results for major classes. In general land cover classes that were very fragmented and had complex spectral signatures were more difficult to identify using AVHRR satellite data. But an overall classification accuracy 69.2% could be seen as a good result considering the mixed pixel and geo-referencing problems of AVHRR satellite data. The spatial resolution limits also the possibilities to identify land cover changes in the European landscape. Comparison of two AVHRR derived land cover maps will result in identifying many spurious changes.

Medium resolution satellite sensors with a spatial resolution between 150-250 meters (eg. MODIS and MERIS) will play a major role in the near future to identify land cover changes on a European scale. Nevertheless, the 1-km PELCOM land cover database can be considered as a unique product, next to the CORINE land cover database, that fills a gap in environmental and climate studies for pan-Europe.

6 Monitoring

6.1 Digital techniques for change detection

Digital change detection algorithms can be summarised in two broad categories to which different definitions have been attached that vary in complexity and, to a certain extent, in coverage (Coppin and Bauer 1996). Singh (1989) differentiates these approaches as follows:

1. comparative analysis of independently produced classifications for each of the image dates (often known as 'post-classification change detection') and,
2. simultaneous analysis of multi-temporal data.

In terms of change-detection analysis, post-classification techniques are perhaps the easiest to implement because two independently produced information layers are compared on a pixel-by-pixel basis at a thematic level. Change maps can be derived quickly, as 'confusion' (or 'contingency') matrices can show a summary of all changes. The accuracy of such a change map is, however, dependent on the accuracy of each of the single-date classifications — it is the product of these two values. Since an error on either date will give a false indication of change, a large number of erroneous change indications will typically be produced.
The alternative to post-classification change detection is the use of the original image data. Changes are detected by comparing either multi-date channels or transformed image data. The simplest method is image differencing, where an image at time *t1* is subtracted pixel by pixel from an image at time *t2*. The resulting 'difference' image is assumed to show high absolute pixel values in areas of change, whereas pixels representing unchanged areas should have values around zero. This method is easy to apply but has a number of drawbacks. First, the resulting differences might not only be due to land-cover/land-use change, but also to external influences caused by differences in atmospheric conditions, differences in sun angle or differences in soil moisture. Second, the nature of change is difficult to detect, as the method provides only differences of the radiance in different wavelengths. Third, the decision which threshold to use to separate 'change' from 'no change' is highly subjective and scene-dependent. Application of similar approaches such as regression analysis of the two images, image rationing and comparison of image indices can reduce the impact of the external influences. However, a clear interpretation of the detected changes is still difficult to achieve (Lambin and Strahler 1994, Green *et al.* 1994).

We therefore propose to use a different technique that offers many of the advantages of the traditional approaches without their attendant disadvantages. This technique is a linear unmixing algorithm, which applies a linear transformation to the multi-spectral channels of an image to derive continuous thematic layers, each pertaining to one, and only one, land-cover type (Adams and Smith 1986, Settle and Drake 1993). Differencing of multi-temporal fraction images representing the same land cover type will result in thematic change images.

Unmixing has already been applied to coarse resolution data in a number of studies, especially for vegetation monitoring. While some were based on the first two channels (Hlavka and Spanner 1995, Quarmby *et al.* 1992) others used the reflective part of the third channel as well (Holben and Shimabukuro 1993, Shimabukuro *et al.* 1994). The first four AVHRR channels were used by Cross *et al.* (1991) for unmixing to differentiate tropical forest from non-forest, with satisfactory results when compared with TM images. More recent studies (DeFries et al. 1997, Bastin 1997) reflect the ongoing interest in subpixel analysis using coarse resolution satellite imagery.

6.2 Linear unmixing

Aim of linear unmixing is to estimate how each ground pixels' area is divided up between different cover types. The results are a series of images, each the size of the original image, and each giving a map of the concentration of a different cover type across the scene (Settle and Drake, 1993). Before these proportions can be calculated a set of spectra is defined called 'image endmembers', representing the spectral reflectance of the different cover types. These may be defined by selecting appropriate pixel vectors, examining laboratory data or derived from a principal component analysis. When mixed using the appropriate rule, these endmembers reproduce all of the pixel spectra. The maximum number of endmembers is limited by the number of spectral bands of the satellite image.
Once the endmembers are defined the fractions of each endmember in each pixel may be calculated by applying the appropriate mixing rule. A general equation for mixing is (Adams, et al. 1989):

$$DN_c = \sum_{n=1}^{N} F_n \cdot DN_{n,c} + E_c \quad (1)$$

where

$$\sum_{n=1}^{N} F_n = 1 \quad (2)$$

with

DN_c	radiance in channel c,
N	number of endmembers ,
F_n	fraction of endmember n,
$DN_{n,c}$	radiance of endmember n in channel c,
E_c	error for channel c of the fit of N spectral endmembers.

Equation (1) converts the DN value of each pixel in each channel to the equivalent fraction (F_n) of each endmember as defined by the endmembers ($DN_{n,c}$). The error (E_c) accounts for that part of the DN-value which is not described by the mixing rule. Equation (2) introduces the constraint that all fractions of a pixel must sum to one.

Three ways exist to evaluate the results of the spectral mixture analysis. These are the visual analysis, the calculation of the root-mean-squared (rms) error, and the calculation of the fraction overflow (Adams et al. 1989).
With the visual analysis of the fraction images, the analyst determines whether they are consistent with other information existing about the area in question. If the patterns do not correspond with the additional information obtained by ground truthing or other sources then the model constructed may not be correct.
The second test is the calculation of the rms error. It is based on the E_c term of equation 1, squared and summed over all M image channels (see (3)) (Adams et al. 1989) .

$$\varepsilon = \left| c^{-1} \sum_{c=1}^{M} E_c^{\,2} \right|^{1/2} \qquad (3)$$

with

E_c^2 root-mean-squared (rms) error
M number of Channels

The rms error is calculated for every pixel individually and can also be visualised as an image. It may also be calculated for the whole image, showing the overall rms error. A small rms error is an indication of a mathematically good model. A high rms error indicates that the model has not been set up correctly.

The third test is the computation of the fraction overflow. The fractions of the land cover components should lie between zero and one, but if the model in not constructed correctly fractions may fall outside this range. As the SMA is based on the assumption that the selected endmembers represent 100 % of the land cover in question, any pixel having a higher portion of the land cover compared to the endmember pixel, will have a fraction higher than one. To satisfy the constraint that all the fractions of a pixel must sum to one, another fraction of this pixel will be below zero.

If the model is not satisfactory according to the tests described above, the endmembers must either be changed, deleted, or additional endmembers defined. The following rules aid in the selection of new endmembers. An overflow in a fraction image is an indication for a pixel, which represents the land cover better then the pixel used for the definition of this endmember up to now. An overflow and a high rms error in a pixel may be due to an unconsidered endmember which is represented by that pixel (Adams et al. 1989).

In the following case study, the unmixing procedure described above will be applied to two AVHRR images. Although some bands used by this sensor lie in spectral regions that do not follow the underlying assumption of linearity, it will be shown that the method is still suitable to attain basic land cover information.

6.3 Case study for the Netherlands

For this study two NOAA-AVHRR-14 images were available, recorded on May, 4th 1995 and July, 25th 1995. Only the first four bands were used for the analysis as the fourth and fifth band, both in the thermal region, have a correlation greater than 99 per cent. Pre-processing was carried out by SAI-JRC (SAI-JRC, 1996) and included atmospheric correction, masking and automatic coastal chip matching.

The study area lies in the north of the Netherlands, covering the western part of the province Friesland. It is an agricultural area with mainly grassland and arable land. The area measures approximately 70 x 110 km^2, 35 per cent of which is covered by water. Water was masked on basis of a mask supplied by SAI-JRC, and will only be considered if it appears in pixels, not defined as water by the pre-processing routine.

The unmixing procedure was carried out for both images separately. Endmembers were defined by selecting appropriate pixel vectors from the images, one for each land cover type and image. They represent grassland, urban areas, arable land and forest. These endmembers were used to transform the satellite image, resulting in four fraction images, one for each land cover type defined. As only four channels were available for each image and as many endmembers defined, no root mean square error was calculated. One way to determine, whether the fraction images are likely to represent the same cover type is to examine the endmembers, defined for each image. What is of interest here is more the general shape rather than the absolute values, as these will change from image to image. It can be expected, that spectral plots for certain land cover types will change more than for others, depending on whether their spectral properties change over time or not.
Figure 12 shows the spectral plot of the endmembers for arable land. As can be expected, the curves differ from each other significantly. It can be seen that the reflectance in the near infrared parts of the spectrum (bands two and three) was stronger in July than in May, indicating the presence of more vegetation in July.

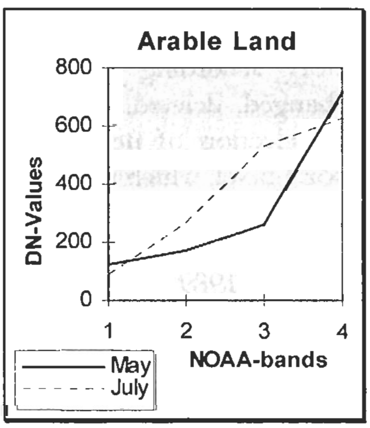


Figure 12 Spectral plot of arable land endmembers

In contrast to arable land, the endmembers for grassland have a stronger near infrared reflection (band two and three) in May than in July. This may be due to grassland being more vigorous in the growing season in May than in July as well as to variations in rainfall. Nevertheless, the difference is much lower than that for arable land and the general shape of the curve is much better preserved

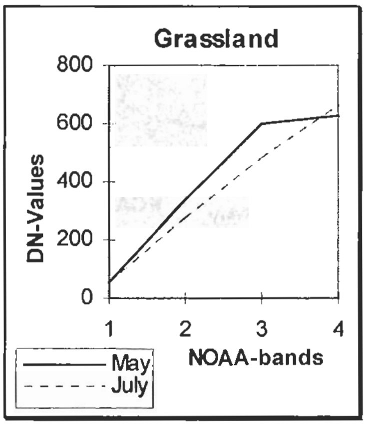


Figure 13 Spectral plot of grassland endmembers

In contrast to the plots for grassland and arable land are the plots for forest (Figure 14) and urban areas (Figure 15). Whereas the first two represent cover types which are subjected to human influences in the form of planting, harvest, irrigation, fertilising, and so forth, the following are much less influenced by short term variations and thus change less in respect to their spectral reflectance.

For forest (Figure 14) the shape of the May endmember is very similar to that of July. As the development of forest is in general more stable after the initial growing period in spring than that of other vegetation types, this is an indication of the suitability of both endmembers to represent the same land cover type.

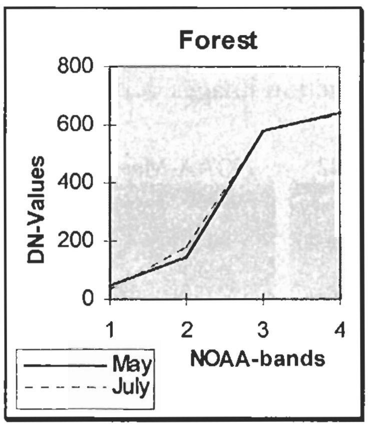


Figure 14 Spectral plot of forest endmembers

The same similarity can be seen in the urban endmember (Figure 15), showing only very small variations. This again allows the assumption, that both endmembers pick up the same cover type.

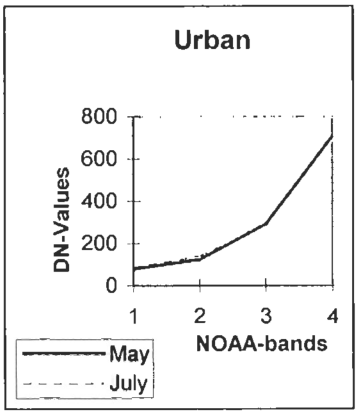


Figure 15 Spectral plot of urban endmembers

Applying these endmembers to the respective NOAA images results in two fraction images for each endmember. They have the same format of the original image and give the abundance of the defined cover types.

In order to examine the validity of the results, the fraction images were compared with the National Land Cover Database of the Netherlands, LGN-2 database (Thunnissen and Noordman 1996). The data set covers 24 different classes (excluding water) with a spatial resolution of 25 x 25 m^2. The classes were aggregated to four main classes representing grassland, urban areas, forest and arable land. To visually compare the fraction images with the LGN-2 database, pseudo fraction images were created by resampling the database to 1.1 x 1.1 km^2 and calculating the proportion of each class within each pixel. Figure 16 to Figure 19 show the fraction images derived from the AVHRR image as well as the pseudo-fraction images, derived from the LGN-2 database. Light shades signify a high proportion within a pixel, dark shades signify a low proportion of the specific class (endmember).
Figure 16 shows the fraction images for arable land. According to the LGN-2 database, fields are concentrated in the North and Southwest of the study area. This trend is also reflected in the fraction images derived from the NOAA-data.

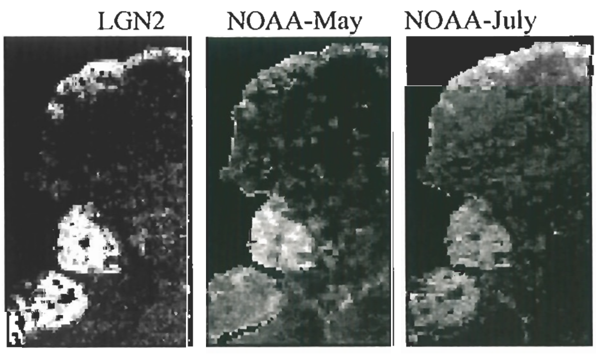


Figure 16 Fraction images for arable land. Dark shades indicate a low fraction of arable land, light shades a high fraction.

Grassland is also consistent within all three fraction images (Figure 17). It can be seen that grassland is the main cover type in this area, but also clearly visible are those areas, defined as arable land according to the former fraction images.

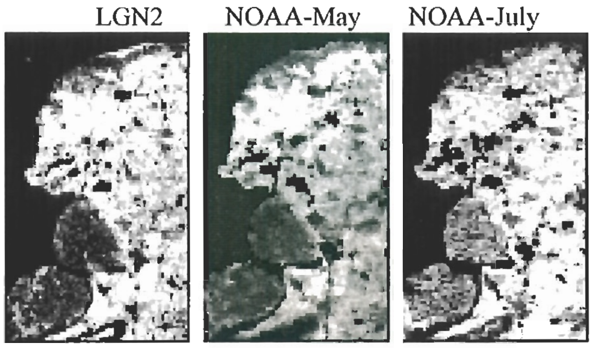


Figure 17 Fraction images for grassland. Dark shades indicate a low fraction of grassland, light shades a high fraction.

As opposed to arable land and grassland, the fraction images for forest (Figure 18) show larger differences. Further analysis revealed that those pixels containing water and were missed by the water mask. As water was not defined as an endmembers, pixels which contain water are assigned by the SMA to the endmember, which has the most similar reflectance of all the defined endmembers. This can be seen very well along the shore lines and in the North, where a number of lakes are present.

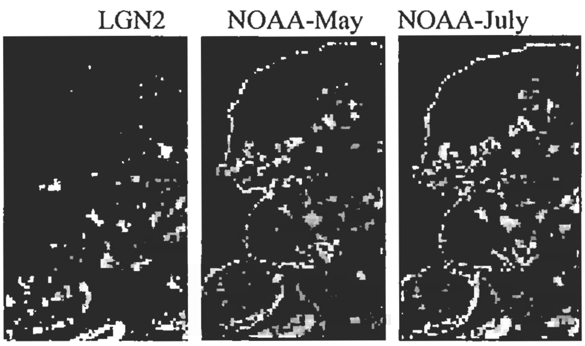


Figure 18 Fraction Images for Forest. Dark shades indicate a low fraction of forest, light shades a high fraction.

The fraction images for urban areas also show very notable differences (Figure 19). The LGN-2 and the July fraction image are more consistent than the LGN-2 and the May image. The most notable difference is in the center of the May image and in the South of both the May and July image, showing an urban area not present in the other images. According to the LGN-2 data these are areas with natural vegetation. The fact that some urban areas, visible in the Southwest of the LGN-2 and July image do not appear in the May image is due to georeferencing and thus the subset definition, indicating the limited accuracy of the technique based on coastal chip matching by SAI-JRC.

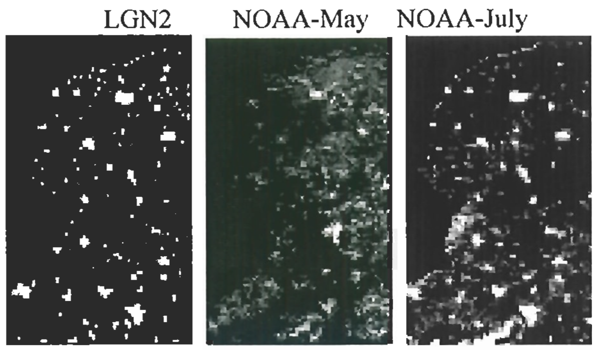


Figure 19 Fraction images for urban areas. Dark shades indicate a low fraction of urban areas, light shades a high fraction.

Another way to evaluate the fraction images is to use them as a basis for a classification. In our example, each pixel was assigned the land cover class, which has the highest proportion (Figure 20).

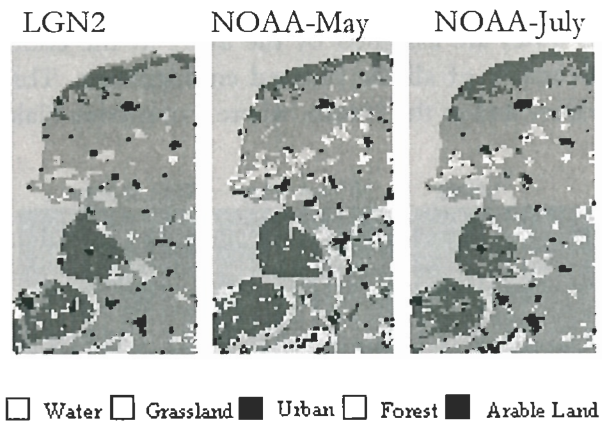


Figure 20 Classification of fraction images classes assigned according to maximum fraction of each endmember.

Again the general trend is confirmed and the distribution patterns of the classes are very similar. Also apparent is the overestimation of forest near those areas where water occurs, as well as the overestimation of agricultural areas in the North and urban areas in the South of the July image. The May classification image also overestimates forest but improves on identifying agriculture in the North and Southwest.

In order to carry out a quantitative evaluation, fraction images produced from the LGN-2 data base and the ones for the May-NOAA-image were classified according to the same decision rule. Each pixel was assigned to the land cover type, which has the highest proportion in this pixel thus allowing the calculation of a error matrix (Table 9).

Table 9 Error matrix showing the results of the linear unmixing. The Dutch national land cover database (LGN-2) was used as reference and has been recoded to four main classes and has been aggregated to a spatial resolution of 1100 meters. Numbers in the matrix express number of pixels.

	Reference data					
Classified data based on fraction images derived from July NOAA-image	Grassland	Urban	Forest	Agriculture	Total	Reliability (%)
Grassland	*2865*	40	109	66	3080	93,02
Urban	40	*59*	2	2	103	57,28
Forest	175	4	*116*	12	307	37,79
Agriculture	312	29	31	*701*	1073	65,33
Total	3392	132	258	781	4563	
Accuracy (%)	84,46	44,70	44,96	89,76		
Overall Accuracy (%)		**81,99**				

The overall accuracy of the classification is 82.0 per cent, with the highest accuracy for grassland of 84.5 per cent and the lowest accuracy for urban areas with 44.7 per cent. Grassland has also the highest reliability with 93.0 per cent, forest the lowest with 37.8 per cent. The largest confusions occur between grassland and agricultural areas and between forest and grassland.

Overall, it can be seen that the results of the unmixing procedure are very consistent when compared with the reference data. The linear unmixing procedure allows quick recovery of basic information about the distribution of different cover types in the form of thematic layers. These layers may be the starting point for a number of different applications, ranging from determining overall proportion to classification and change detection.

6.4 Potential of fraction images for change detection

Fraction images are the result of a transformation showing the proportions of spectrally pre-defined land cover types for each pixel. A direct comparison of fraction images calculated from satellite images recorded at different dates makes it possible to highlight those areas where the proportion of the different land cover types has changed. Using precisely georeferenced images, areas of change may be highlighted by a pixel-per-pixel comparison (Kressler and Steinnocher 1996). But even without this kind of agreement, basic information about broad developments may already be gained by a visual comparison of fraction images calculated from images recorded at different dates. A more detailed analysis may then be limited to those areas highlighted as change. This focus on those areas where changes are most likely to have occurred allows a more efficient use of available resources.

As some of the AVHRR channels do not follow the underlying assumption of linearity, quantitative information going beyond the statement that a certain class occurs or does not occur within a pixel, cannot reliably be made. The full potential of fraction images for monitoring changes may be realised with the development of new coarse resolution sensors, which not only utilise channels in the visible and near and middle infrared part of the spectrum (e.g. SPOT Vegetation) but also have improved geo-referencing capabilities.

7 Case study A - RIVM: Applications in biodiversity research

7.1 Introduction

For years the Dutch Institute for Public Health and the Environment (RIVM) was confronted by the lack of accurate, up-to-date, pan European land cover data. The CORINE land cover database meets this lack of information in terms of spatial accuracy. However, its methodology to derive land cover data from satellite imagery is very time consuming and, unfortunately, after more than 10 years the database is still not complete for the entire Pan European area. Moreover, the CORINE land cover database remains a snapshot as long as no effort has been made towards accurate land use change detection. Therefore, RIVM initiated in 1992 the establishment of a land cover database for entire Europe, including Eastern Europe. Unfortunately, the result (the ten-minutes database) was a database with largely varying qualities. Especially for Eastern European countries it was difficult to obtain accurate and up-to-date information (Van der Velde et.al. 1994). Other methods were searched to be developed to solve the imperfections of the RIVM land use database (Mücher et al. 1993, Van de Velde et al. 1994, Mücher et al. 1994, Mücher et al. 1996, Veldkamp et al. 1998). The result of these initiatives is the NOAA-AVHRR derived, PELCOM, land cover database, which is regarded as a most promising source of input data for environmental models.

The aim of this workpackage is to investigate whether the PELCOM database could be applied within real world policy frameworks such as the European Environmental Outlook (EEO 98) of the European Environmental Agency (EEA) and the Economic Assessment of Priorities for an European Environmental Policy Plan (PEEP) of DGXI. The environmental assessment framework in which the PELCOM land cover data were tested is the Natural Capital Index framework (NCI) (Ten Brink, 1997). The NCI framework is developed for UNEP's Global Environment Outlook (UNEP, 1997a) and later further developed under the Convention on Biological Diversity (UNEP,1997b; UNEP, 1999).

The NCI framework enables to describe current and future state of nature in relation to various possible socio-economic developments in an integrated, policy-oriented manner. Land cover data are essential within this framework. Consequently three questions arises when investigating the applicability of the PELCOM database for environmental modelling within the NCI framework. First, is the PELCOM land cover database accurate enough to derive current Natural Capital Indices on EU country level? Second, is the PELCOM methodology accurate enough to monitor Natural Capital Indices over time on policy relevant time intervals? Third, Is the PELCOM based NCI framework useful and suitable to support environmental policy at EU level?

The outcome of RIVM's contribution to workpackage 11 consists of (i) maps showing all natural areas (derived from the best FTA results) and current pressures to biodiversity, (ii) future pressures in 2010 according to the baseline EU-policy scenario, (iii) summary tables for current and future NCI statistics on EU country level, (iv) tested against CORINE derived statistics and (v) finally the applicability of the PELCOM land cover database for monitoring purposes will be discussed in comparison with long term land use statistics. Subsequently it was analysed which improvements of PELCOM LC data would be necessary to make them more applicable.

7.2 Methodology

7.2.1 Natural Capital Index framework

Motivation of NCI framework

According to the Dobris Assessment of the European Environmental Agency (Stanners and Bourdeau, 1995), the decline of Europe's biodiversity in many regions derives from: i) highly intensive, partially industrial forms of agricultural and ii) silvicultural land use, from iii) an increased isolation of remaining natural habitats by infrastructure and urbanisation and the iv) exposure to mass tourism as well as v) pollution to water and air. Given the projected growth in economic activity, the rate of loss of biodiversity is far more likely to increase than stabilise (European Community Biodiversity Strategy[1]). However, the problem is that the state and decline of biodiversity in Europe is difficult to measure because discussions on a proper assessment framework are still going on and a monitoring system is still lacking.

However, to make an assessment of Europe's nature that meets the purpose of this report the Natural Capital Index framework or NCI-framework has been applied. The NCI framework enables to describe the past, current and future state of nature and establish relations to various possible socio-economic developments in an integrated, policy-oriented manner. The NCI concept was previously developed for and applied on UNEP's Global Environment Outlook (RIVM/UNEP, 1997; UNEP, 1997a). The NCI-framework has been further adapted and improved by the Liaison Group on Indicators of Biological Diversity of the Convention on Biological Diversity (UNEP, 1997b; UNEP, 1999). The framework was accepted as starting point for further discussions at the Conference of the Parties in Bratislava, May 1998 in Bratislava.

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1 'Communication of the European Commission to the Council and to the parliament on a European Community Biodiversity Strategy', February 1998. Presented as Background document at the Electronic Conference on Research and Biodiversity (4th May to 14th June 1998).

General Natural Capital Index (NCI) framework

The NCI is defined as the product of the remaining area (ecosystem quantity) and its quality (ecosystem quality). Ecosystem quantity is defined as the percentage remaining area in a considered region. Ecosystem quality is defined as the ratio between current state of the ecosystem and the baseline state. Ecosystem quality is the average of a representative core set of quality variables such as abundance of various species, structure variables, or species richness. These quality variables are region specific. The NCI for natural areas and man-made areas ranges from 0 to 100 per cent. If e.g. 50% of a country is still natural area and the quality is 50%, than the $NCI_{natural}$ is 25% (Figure 21). An NCI of 0% means that the entire ecosystem is deteriorated either because there is no area left, or the quality is 0% or both. 100% means that the entire ecosystem is at its maximum value.

Man-made and natural areas[2] are assessed differently. The quality of natural areas is compared with a less affected, more natural state: the postulated baseline, set in pre-industrial times (UNEP, 1997b). Man-made areas (mainly agricultural areas) are compared with a pre-industrial agricultural baseline, usually a species-richer state. Baselines are used as a calibration point or benchmark to quantify the extent of change in natural and man-made areas due to human activities in modern times. This is the period in which man's impact on ecosystems rapidly accelerated. This assessment focuses on natural areas. For a more comprehensive description of NCI is referred to the document of the Convention on Biological Diversity (UNEP, 1997b).

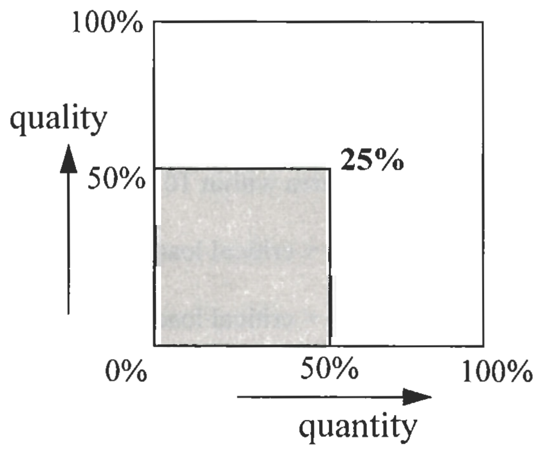


Figure 21 If the remaining ecosystem (ecosystem quantity) is 50% and its quality is 50% than 25% of the ecosystem is left (Natural Capital Index is 25%).

2 Natural area is defined as:

All not human-dominated land, irrespective of whether it is pristine or degraded, such as: virgin land, nature reserves; all forests except wood plantations with exotic species; areas with shifting cultivation; all fresh water areas; and extensive grasslands (marginal land used for grazing by nomadic livestock).

Man-made area is defined as:

All human-dominated, cultivated, land such as: arable land; permanent cropland; wood plantations with exotic species; pasture for permanent livestock; urban areas; infrastructure; and industrial areas. Most of the man-made area is in fact agricultural land.

The adapted NCI Framework: Pressure Index and remaining natural area

Because, no detailed geographic explicit data on ecosystem quality for the whole of Europe is available, pressures to ecosystems are applied as substitute for ecosystem state (quality) variables. Moreover, pressure variables are easy to link with socio-economic factors. As in the Global Environment Outlook (UNEP, 1997a) the assumption is made that the lower the pressure, the higher the chance on high ecosystem quality and vice versa. European geographical explicit data are available on seven biological relevant pressures (Table 10)for the year 1990 as well as for the year 2010 under the Baseline Scenario[3]. Each pressure is preliminary graded on a linear scale from pressure class 0 (no pressure) to pressure class 1000 (very high pressure). Class 1000 indicates a high chance of extremely poor biodiversity compared with the baseline state. Figure 22 expresses that, when pressure increases, the chance of having a high quality ecosystem, decreases.

To give an indication of the chance on high ecosystem quality or total threat to biodiversity, for each grid cell (of 1 km by 1 km) the pressure classes of all seven pressure indicators are added which results in one single Pressure Index per grid cell. In this stage, the Pressure Index is only calculated for natural areas.

Table 10 Pressures to biodiversity and scaling values.

Pressures	High chance on high ecosystem quality Pressure class = 0[4]	Low chance on high ecosystem quality Pressure class = 1000
1. Rate of climate (temperature) change	< 0.2°C change in 20 years	> 2.0°C change in 20 years
2. Human population density	< 10 persons/km^2	> 150 persons/km^2
3. Consumption and production (GDP)	US$ 0 per km^2	> US$ 6,000,000 per km^2
4. Isolation/fragmentation	% natural area within 10 km > 64%	% natural area within 10 km < 1%
5. Acidification	Deposition < critical load	Deposition > 5 x critical load
6. Eutrofication	Deposition < critical load	Deposition > 5 x critical load
7. Exposure to high ozone conc.	AOT40 < critical level	AOT40 > 5 x critical level

This Pressure Index per gridcell ranges from 0 to 7000. It is assumed that there is a low chance on high ecosystem quality in those natural areas where the Pressure Index is larger than 2500. This is an arbitrary level based on the following: a pressure

3 The "baseline scenario" should not be confused with the "postulated baseline" set in pre-industrial times used to assess the quality of ecosystems.

4 Within the limitations of this study it was not possible to make the scaling more biotope specific. The scaling is assumed to be valid for all habitat types.

class of 1000 of one single pressure has already severe detrimental effects on ecosystems with a low chance on high biodiversity as stated above. Additional pressures can only make this a little worse. For the purpose of this report it is therefore assumed that a combined pressure index affects an ecosystem seriously from a level of 2500. Higher Pressure Index values (between 2500 – 7000) make no much difference anymore. Consequently, the ecosystem quality in areas with a Pressure Index higher than 2500 is assumed to be 0%. The highest chance on high ecosystem quality is in those natural areas where the Pressure Index is 0. Ecosystem quality is then assumed to be 100%. This is only aiming at a first, indicative approximation of the quality and especially quality change in ecosystems based on the above 7 pressures.

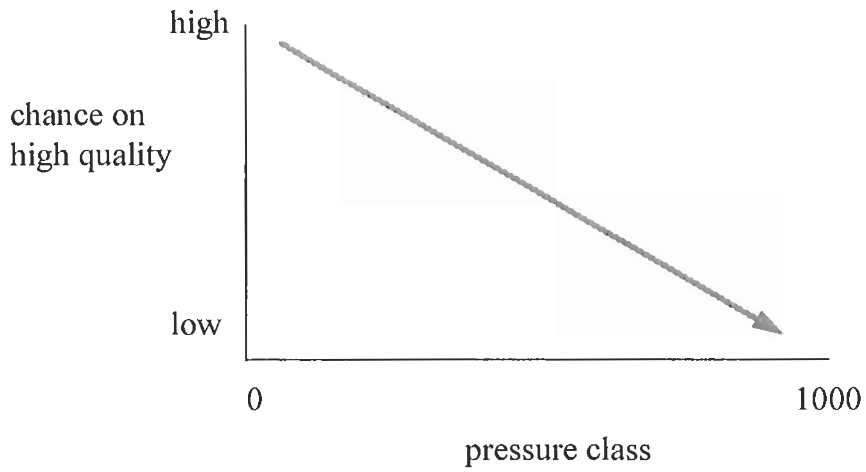


Figure 22 A Pressure Index is used as substitute for ecosystem quality. Assumption: the higher the pressure, the lower the chance on high ecosystem quality.

7.2.2 Future NCI assessment based on socio-economic scenarios

By comparing the Pressure Index and the remaining natural area under different socio-economic scenarios it will be possible to assess the effect of different policy options on potential ecosystem quantity and quality or threat to biodiversity. For this the Baseline scenario has been calculated for 2010. The baseline scenario should not be confused with the "postulated baseline" set in pre-industrial times used to assess the quality of ecosystems. All indicator pressures mentioned in Table 10 are available for 1990 and Baseline 2010.

Land Use change simulation

The main changes in land use are caused by changes in the total agricultural area. Although the amount of land use changes is reasonably well known, it is not known where exactly the changes (e.g., conversion of agricultural areas to natural areas) will take place. This information is needed to calculate the future NCI for natural areas. Therefore, a Land Use Change Simulator was developed to simulate and allocate possible land use changes in space and time. The modelling is based on clear assumptions, which determine the allocation of different land use classes. Reallocation of the current pattern of land use is conducted by a stepwise GIS procedure, realised by multiple ArcInfo AMLs. Current land use, according to the PELCOM database, is first regrouped to three distinct classes of interest: natural land, arable land and urban area. Arable land that will be taken out of production (according to the scenario) is from now on referred to as transitional arable land and natural land that will get cultivated is referred to as transitional natural land. Next the database is resampled to a resolution of 1 km.

A first reallocation step concerns the process of urbanisation. On an arbitrary basis it was decided to reserve 20% of the total amount of transitional arable land for urbanisation. Only arable land adjacent to current urban centers are supposed to get urbanised. A randomised chance is used to select those gridcells adjacent to urban centres that will actually get urbanised.

Next all remaining transitional arable and natural land will be reallocated according to its attractivity. Therefore the attractivity of all natural land and all remaining arable land is calculated per gridcell. From a production point of view the attractivity is first of all supposed to be determined by the soil capacity. The soil reduction capacity is used as an appropriate determinant. Additionally the distance to urban centers is taken into account. The smaller the distance to urban areas, the higher the attractivity for agricultural activities. From a nature conservation point of view the attractivity is first of all determined by the total pressure to biodiversity (the higher the pressure, the lower the attractivity). Moreover the connectivity between current natural land is taken into account. The higher the connectivity, the higher the attractivity for nature conservation. Finally the distance to urban areas is a determinant for nature conservation as well, although inverse. The larger the distance to urban areas, the higher the attractivity for nature conservation.

The total attractivity is calculated by subtracting the conservation attractivity from the production attractivity. Arable land with lowest total attractivity is supposed to be taken out of production. On the contrary, natural land with highest total attractivities is most likely to change into arable land. The thresholds for transition of total attractivity values are determined on EU country level by the baseline scenario. Cumulative thresholding is realised by a loop (cursor) function. Due to the finite number of classes, thresholds are mostly in between existing values of total attractivity. As the AML selects for the lowest class, a certain amount of transitional land remains untouched. A correction AML was developed to correct for this missing part.

Calculation of the total attractivity as described is flexible in its parameter settings. First the relative attention being paid by nature conservation to the decrease of total pressure can be switched linearly from 0 to 5. Consequently the alternative relative attention being paid to the importance of ecological connectivity switches linearly from 5 to 0. In the same way the relative attention being paid by policy makers to the agriculture and nature can be set by weighting both attractivities before calculating the total attractivity.

7.2.3 Sensitivity analysis of NCI assessment for PELCOM

The importance of land cover data within the NCI framework is threefold:

1. The quantity component of the (adapted) NCI approach is determined by the absolute amount of individual land cover types.
2. The quality component of the (adapted) NCI approach is determined by the spatial arrangement of natural LC types.
3. The ecological differentiation of the (adapted) NCI assessment can be realised by the spatial distinction of different land cover types.

Although land cover data are of crucial importance for NCI assessment, absolute NCI values should be independent on the source of land cover data being used. Therefore PELCOM derived NCI values will be tested against the NCI values as derived from a reference database. In this respect the CORINE land cover database is believed to be the most accurate and reliable reference available at this moment (Veldkamp et al. 1998). PELCOM derived NCI values should not differ significantly from CORINE derived NCI values. For EU policy purposes this criteria should at least hold true on EU country level. Additionally the NCI enables to monitor the state of nature. The accuracy of the PELCOM land cover database to do so depends on proposed methodology for change detection.

The NCI approach has been performed with both the PELCOM database and the CORINE database (after resampling to a 1x1 kilometre resolution). Paired t-tests have been used to test for significant differences between PELCOM derived NCI values and CORINE derived NCI values. Since EU-policy requires accurate insight at political division NCI has been calculated on EU country level. No judgement on pixel level was done. The proportion of natural land and the mean degree of isolation of natural land have been treated in the same way. In case of significant (paired) differences both values might still be correlated significantly. In that case PELCOM derived values can be adjusted mathematically. Therefore regression analysis have been performed in addition with PELCOM derived NCI as dependent variable and CORINE derived NCI as independent variable.

7.3 Results

7.3.1 Implementation of PELCOM within the NCI framework

Current biodiversity assessment gives a clear overview of the high pressure on biodiversity in the remaining natural areas in Europe. As explained above this chance is based on underlying maps of the seven pressure factors on which geographic information was available for the whole of Europe. Based on these pressures, the dark green areas can be considered to be under low threat. Those areas have a relative high chance on high biodiversity. The threat to biodiversity is high -or in other words the chance on high biodiversity is very low- in the natural areas coloured red and brown. The white areas represent the man-made areas and the grey areas are those areas where for one of the pressures no data was available for that specific area. Summary statistics are presented in Table 11. Humans dominate obviously large parts of Europe. In many countries (e.g. South of the UK, the Netherlands, north-western part of France, Denmark) only few natural areas still exist. Figure 23 show that many of the remaining natural areas have a low chance on high biodiversity (pressure index > 2500). In the following countries almost all remaining natural areas are confronted by pressures above this very high pressure: Belgium, Czech Republic, Denmark, Germany, Luxembourg, the Netherlands and Poland as also large parts of Austria, France, Slovakia, large parts of Italy and the middle and south of the United Kingdom.

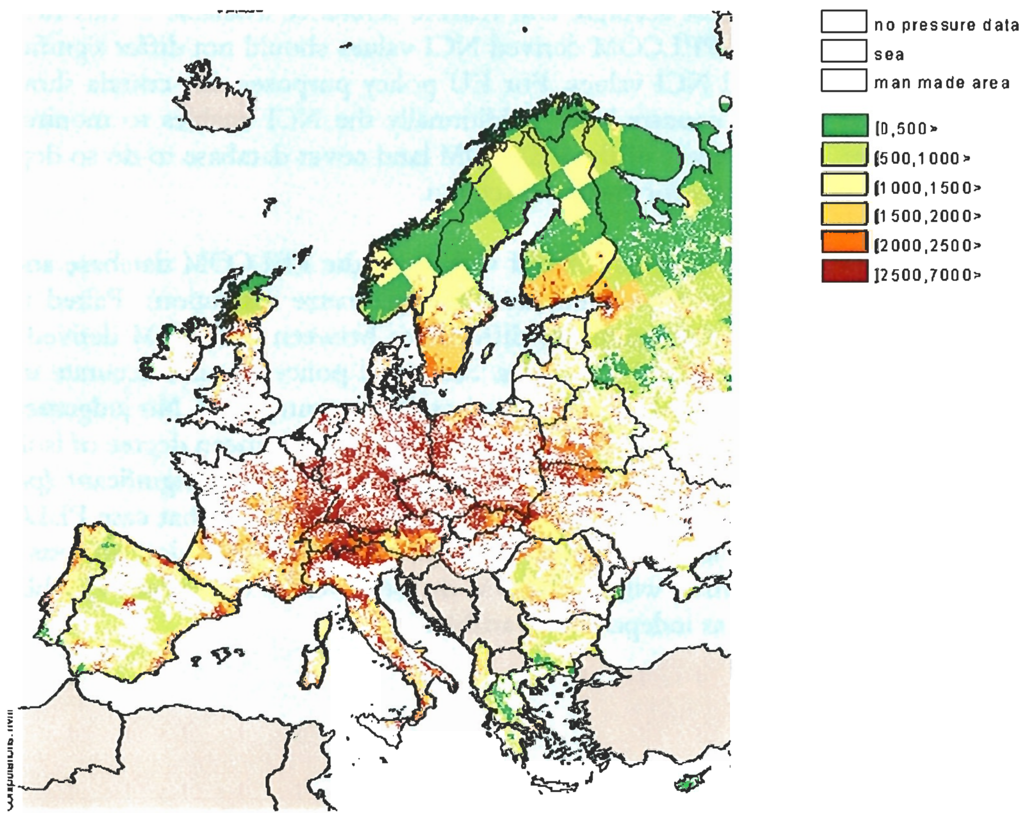


Figure 23 Pressure Index to biodiversity in remaining natural land in 1990 (based on ozone, acidification, eutrofication, temperature change, isolation, population and GDP). Concerned pressures are linearly scaled according to respectively maximum and minimum thresholds of impact.

Natural areas that have a very high chance on high biodiversity can be found in Finland, Norway and Sweden (except for areas in the south of these two countries) and mainly in mountainous areas: Bulgaria (Balkan mountains, Rila mountains, Pirin Planina mountains and Rhodopi Planina mountains), Ireland (Connemara, Kerry Mountains), France (South East: Languedoc, parts of the Jura, Dauphiné, South West (small part), the south: Pyrenees and a part of Corsica), Greece (e.g., Pindus mountains), Italy (middle Appenine; part of Abruzzi), Portugal (middle part: Sierra Da Estrêla), Romania (north: East Karpathians; middle: Bihor mountains, Transylvanic Alps), Spain (north: Pyrenees, Cantabric mountains, middle: Sierra de Guadarrama + Sierra de) , Serrania de Cuenca, south: Sierra de Segura, Sierra de Alcaraz), United Kingdom (north: Scottisch highlands).

Table 11 Summary of Mean Pressure, Mean Pressure Index5 and pressure-based NCI statistics for natural land in 1990 on European countries . Quality is calculated on pixel basis and is based on total pressure to biodiversity with a maximum pressure threshold of 2500.

Country	ozone	isolation	population	temperature	gdp	acidification	eutrofication	total pressure	quality	area(%)	NCI
Norway	4	1	40	162	0	305	26	538	78	97	**76**
Finland	0	1	52	233	40	442	105	871	65	97	**63**
Andorra	733	0	0	154	0	0	129	1016	59	99	**58**
Sweden	34	12	45	190	34	528	64	906	64	88	**56**
RussianFed	19	46	74	211	19	103	175	646	74	66	**49**
Greece	381	111	220	35	40	0	15	794	68	48	**32**
Albania	398	92	482	23	27	0	194	1215	51	58	**30**
Spain	559	84	244	119	91	9	55	1157	54	54	**29**
Portugal	528	90	382	77	79	0	67	1224	51	57	**29**
Estonia	4	160	132	204	35	111	424	1089	56	49	**28**
Bulgaria	385	94	298	36	35	0	158	1005	59	46	**27**
Latvia	85	231	200	191	54	4	337	1102	55	41	**23**
Romania	442	111	460	53	40	60	243	1409	43	42	**18**
UK	92	133	258	94	147	579	28	1384	50	33	**17**
Ireland	84	238	131	51	47	95	51	698	72	22	**16**
Belarus	175	190	221	143	37	450	471	1687	34	43	**15**
Lithuania	138	299	357	172	50	213	288	1518	39	27	**10**
Austria	731	48	334	135	155	546	495	2443	14	68	**9**
Italy	884	96	514	98	279	153	387	2412	16	42	**7**
France	952	161	301	175	162	164	410	2327	18	35	**6**
Ukraine	390	259	374	84	59	277	548	1992	24	18	**4**
Switzerland	703	48	440	174	3	608	731	2706	5	71	**4**
Liechtenstein	603	11	0	166	0	577	1000	2357	6	61	**3**
CzechRep	765	68	539	110	106	652	590	2829	5	52	**3**
Denmark	445	644	451	194	268	207	224	2398	16	13	**2**
MoldovaRep	400	665	685	48	102	98	0	1998	22	8	**2**
Poland	552	257	513	161	75	702	695	2955	5	32	**2**
Hungary	845	409	541	90	95	696	496	3172	2	14	**0**
Germany	902	239	610	187	382	898	880	4098	0	33	**0**
Slovekia	858	264	550	153	144	931	667	3568	0	33	**0**
Netherlands	702	400	582	203	435	992	986	4301	0	12	**0**
Belgium-Lux.	986	174	443	202	202	996	900	3903	0	21	**0**

Scenario based modelling of future biodiversity

The future pattern and statistics concerning the pressures to biodiversity are visualised in Figure 24 and summarised in Table 12 (baseline scenario 2010) Levels of isolation are calculated from a future land cover database, which has been simulated as described before with autonomous rules of allocation.

According to the Baseline scenario today's total agricultural domain of most EU countries will be decreased considerably in the year 2010. Proportions up to 20 % on country-level (Greece) are likely to be taken out of production during the coming decennia. Obviously this offers good opportunities for expansion of the total amount of natural land. In this respect Ireland, Italy and Spain are the only exceptions with increasing amounts of agricultural land and therefore decreasing amounts of natural land.

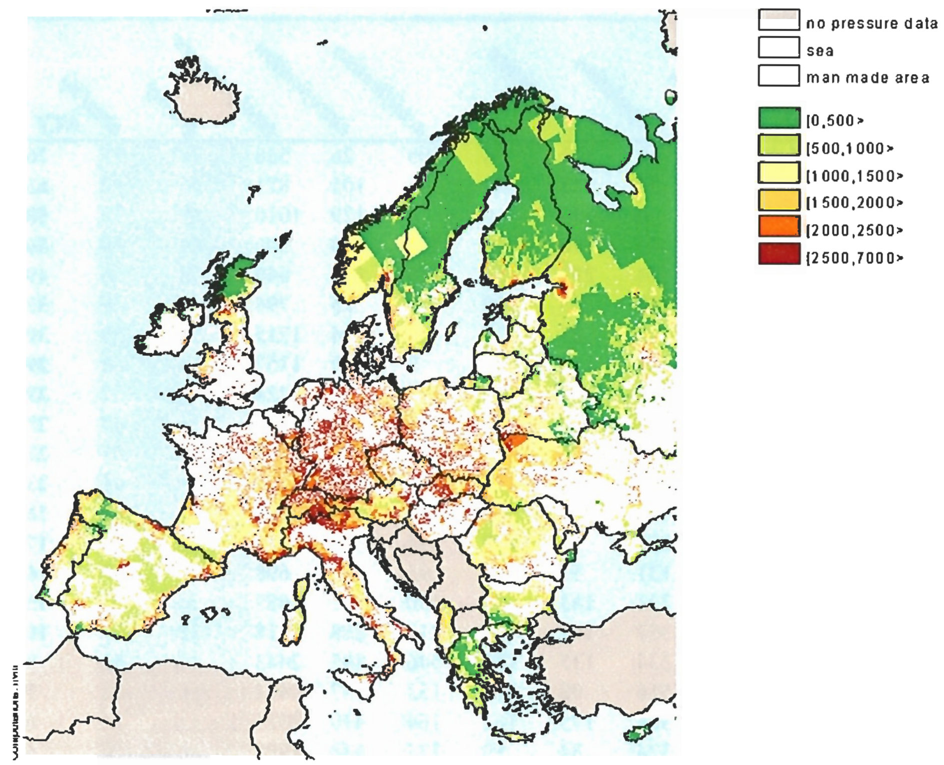


Figure 24: Pressure Index to biodiversity in natural land in 2010 (based on ozone, acidification, eutrofication, temperature change, isolation, population and GDP). Concerned pressures are linearly scaled according to respective maximum and minimum thresholds of impact.

The chance on ecosystem quality will increase in (Baseline) 2010 due to an overall decrease of the Pressure Index. The pattern of the pressures will remain the same as in 1990, though on a considerably lower level. Areas in the south of Finland, Norway and Sweden are likely to switch from (very) high to (very) low levels of pressures. This is mainly due to decreased levels of nitrogen deposition. The same switch can be expected for the alpine and central European region (Germany, Poland, Czech republic, Austria). In general expansion of natural land will tend to decrease the degree of isolation in pan Europe.

As a consequence of both trends towards expansion of natural land and decrease of pressures to biodiversity, the NCI is most likely to increase in the coming decennia. Decreased amounts of natural land in Portugal, Spain, Italy and Ireland are all compensated for by increased chance on high biodiversity in remaining natural land.

Table 12 Summary of Mean Pressure, Mean Pressure Index5 and pressure-based NCI statistics6 for natural land in 2010 on European -country level.

Country	*ozone*	*isolation*	*population*	*temperature*	*gdp*	*acidification*	*eutrofication*	*total pressure*	*quality(%)*	*area(%)*	*NCI*
Finland	0	1	57	378	56	11	29	531	**78**	**98**	**77**
Norway	1	1	43	278	58	279	3	664	**73**	**97**	**71**
Andorra	414	0	0	270	0	0	63	748	**70**	**99**	**69**
Sweden	8	12	49	317	50	141	18	593	**76**	**91**	**69**
RussianFed	3	46	73	347	18	8	60	517	**79**	**87**	**69**
Greece	271	111	226	104	58	0	9	714	**71**	**65**	**46**
Estonia	0	160	124	339	40	2	217	868	**65**	**55**	**35**
Albania	275	92	545	85	36	0	151	1166	**53**	**61**	**33**
Bulgaria	306	94	277	102	44	0	95	909	**63**	**49**	**31**
Spain	366	84	247	225	137	0	29	1069	**57**	**52**	**30**
Latvia	9	231	202	320	50	0	165	932	**62**	**47**	**29**
Portugal	386	90	383	165	135	0	49	1195	**52**	**54**	**28**
Belarus	35	190	219	250	42	82	311	1089	**56**	**49**	**28**
Austria	421	48	408	240	273	58	307	1749	**34**	**71**	**24**
Romania	312	111	447	124	51	24	182	1240	**50**	**46**	**23**
UK	53	133	263	181	198	273	3	1131	**60**	**36**	**21**
Liechtenstein	336	11	0	288	0	48	1000	1683	**33**	**61**	**20**
Lithuania	20	299	362	295	45	20	162	1147	**54**	**36**	**19**
Ireland	30	238	143	121	111	0	28	639	**74**	**21**	**16**
Ukraine	211	259	368	167	48	54	413	1421	**43**	**31**	**13**
France	622	161	319	299	220	36	245	1879	**30**	**40**	**12**
CzechRep	479	68	574	203	141	341	354	2145	**19**	**56**	**11**
Italy	647	96	514	192	374	55	290	2131	**23**	**39**	**9**
Switzerland	416	48	472	295	474	282	588	2577	**12**	**71**	**9**
Poland	309	257	532	275	135	71	447	2006	**24**	**34**	**8**
MoldovaRep	211	665	686	115	60	33	0	1650	**34**	**21**	**7**
Denmark	201	644	447	324	362	101	90	2079	**24**	**20**	**5**
Slovekia	498	264	560	265	199	187	361	2310	**13**	**35**	**5**
Netherlands	485	400	586	339	527	405	617	3327	**20**	**16**	**3**
Germany	542	239	617	313	429	412	444	2974	**7**	**36**	**2**
Belgium-Lux.	849	174	459	334	282	428	641	3141	**6**	**23**	**1**
Hungary	541	409	518	177	133	534	361	2646	**7**	**17**	**1**

7.3.2 Sensitivity of the NCI framework for PELCOM

Sensitivity of Quantity component

The proportions of natural land given in Table 11 are calculated from the PELCOM land cover database and vary from 8 % (Moldavia rep.) up to 97 % (Norway). In order to test for the sensitivity of the NCI quantity component these PELCOM derived proportions are tested against CORINE derived proportions. Regression results are graphically displayed in Figure 25.

Apparently the PELCOM derived proportions are closely related to the proportions derived from the CORINE land cover database. More than 93 % of the variation in the PELCOM derived proportions can be explained by the variation in the CORINE derived proportions. Moreover paired t-test does not indicate significant different sample means (P = 0.36). Hence, in this respect the CORINE derived proportions can be substituted by the PELCOM derived proportions. Although the CORINE derived proportions are significantly related to the 10-minutes database as well ($R^2 = 0.70$; $P < 0.05$), country means of both data sets are significantly different ($P < 0.05$).

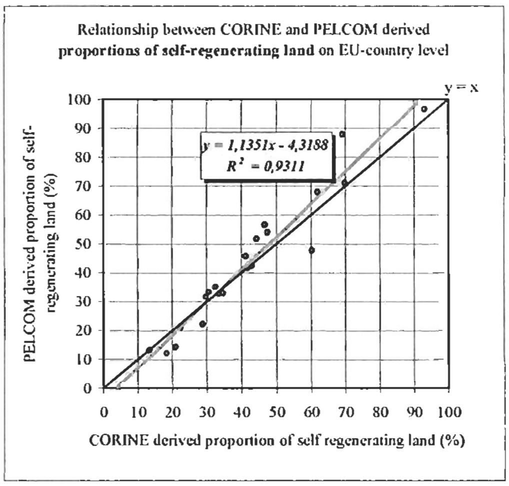


Figure 25 Graphical representation of regression analyses between PELCOM and CORINE derived proportions of natural land ($R^2 = 0.93$; $F < 0.05$). The hypothetical y=x isocline is highlighted.

Sensitivity of Quality component

The mean isolation index given in is calculated from the PELCOM land cover database and vary from 1 (Norway) up to 665 (Moldova rep.). Obviously this average on EU-country level is rather sensitive to classification accuracy and reliability of the land cover database. Therefor the applicability of the PELCOM derived isolation index was tested against the CORINE derived degree of isolation. Regression results are graphically displayed in Figure 26. Obviously the mean isolation indices as derived from the PELCOM database are significantly related to the CORINE isolation index ($R^2 = 0.89$; $P < 0.05$). However paired t-test turns out that the sample means of the PELCOM database differ significantly from the CORINE derived means ($P < 0.05$). Hence the CORINE derived isolation index cannot simply be substituted by the PELCOM derived isolation index. Additionally, the mean isolation index was derived from the 10-minutes database for similar regression analyses with

CORINE derived isolation index. Results for the regression analysis ($R^2 = 0.53$; $P < 0.05$) and paired t-test ($P < 0.05$) are less satisfactory.

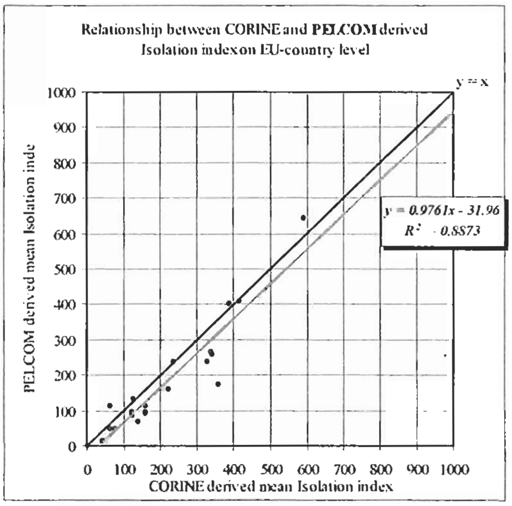


Figure 26 Graphical representation of regression analyses between PELCOM and CORINE derived Isolation Index of natural land (R^2 = 0.89; P < 0.05). The hypothetical y=x isocline is highlighted.

Sensitivity of Natural Capital Index (NCI)

As a criteria for PELCOM land cover data to be applicable within the NCI framework, absolute NCI values should be independent on the source of land cover data being used. Therefore PELCOM derived NCI values were tested against the CORINE derived NCI values. Regression analysis () turns out high significant relationship between both (R^2 = 0,94; F < 0,05). Paired t-tests turns out no significant difference between PELCOM and CORINE derived NCI values on EU-country level (P = 0,40). Hence in this respect the CORINE derived NCI can be substituted by the PELCOM derived NCI. Additionally the mean NCI was derived from the 10-minutes database for similar regression analyses with CORINE derived NCI ($R^2 = 0.80$; $P < 0.05$) and paired t-test ($P = 0.13$).

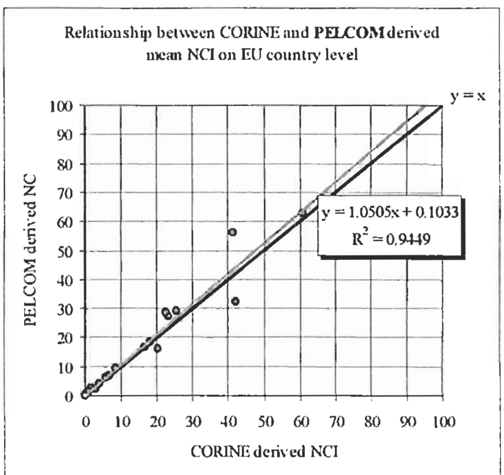


Figure 27 Graphical representation of regression analyses between PELCOM and CORINE derived NCI values (R^2= 0.94; P < 0.05). The hypothetical y=x isocline is highlighted.

7.3.3 PELCOM in relation to long term FAO statistics

Nowadays most judgements on the state of the environment are updated regularly on a 4-years time interval. Therefore land cover databases need to be updated frequently. Obviously the required time interval has implications for desired change detection accuracy. The smaller the time interval the higher the desired accuracy. The required accuracy of change detection for monitoring the Natural Capital Index can be judged on behalf on long term land use statistics. For instance, given a 4-years time interval, agricultural land cover changes of 0.5 – 14.1 (%) need to be detected accurately (Figure 28).

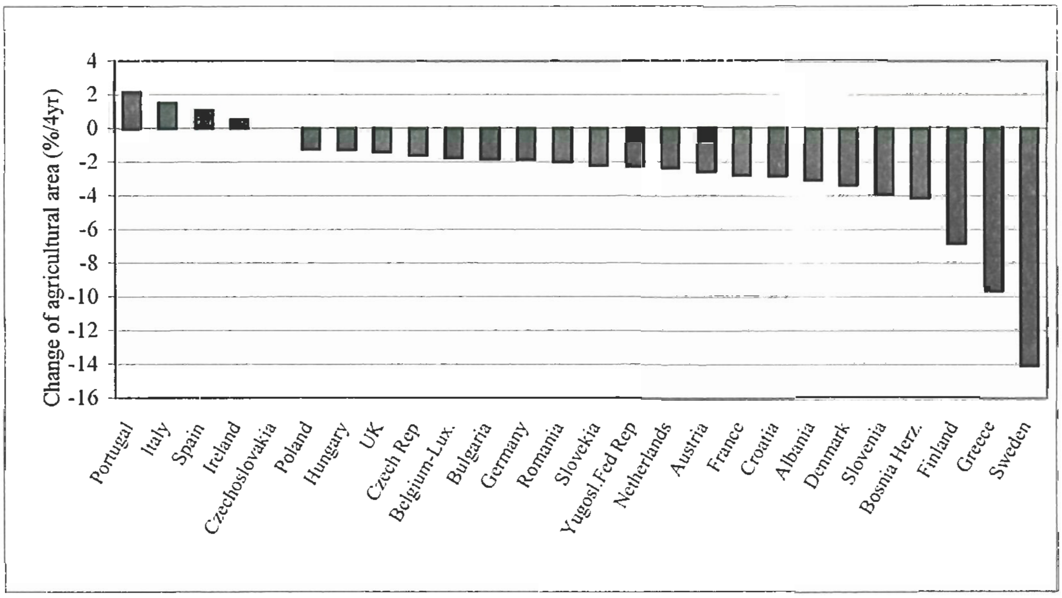


Figure 28 Expected relative change of agricultural land (%) on a 4-years time interval until 2010 (source: FAO statistics).

7.3.4 Suitability of the PELCOM based NCI approach for EU policy development

A CORINE based NCI approach has been implemented and its preliminary results have been communicated to the European Environment Agency (EEA) in 1998 and 1999. RIVM suggested to use the results as input for the 1998 State of the Environment Report for Europe (EU98). EEA is interested in the NCI-approach because it is developed under the CBD and the intention to be feasible and policy oriented. It appeared difficult to assess the state of biodiversity and how European biodiversity might be influenced by changing driving forces, pressures and the abiotic environment based solely on the MIRABEL model. The MIRABEL model is a qualitative nature impact assessment model and is developed by the Topic Centre of Nature Conservation under the EEA (ITE, 1998).

Consequently, EEA has organised a workshop with: the EEA, the Topic Centre on Nature Conservation of the Agency in Paris (ETC-Nature), three CONNECT institutes under contract of the ETC-Nature developing the MIRABEL model: Institute of Terrestrial Ecology in Cambridge (ITE), Institute for Forestry and Nature Research in Wageningen (IBN/DLO) and Norwegian Institute for Nature Research in Oslo (NINA), the Museo Nacional de Ciencias Naturales in Madrid and the National Institute for Public Health and the Environment in Bilthoven (RIVM). It was held at ITE, Monks Wood, UK, 3-4 February 1999.

The EEA has specified the following requirements for modelling that are important in the European context (Moss, 1999):
EEA has a mission to inform policy makers and the public about current and emerging environmental issues. Improved methods will be needed in time for the next 5-yearly report, and possibly for the annual indicator reports beginning in 1999. Indicators must be: clear and simple; easy to understand; comprehensive but few as possible; related to DPSIR; at appropriate scale but possible to aggregate to European level; cover historical trends, the current situation and future scenarios. It is not enough simply to measure change. It is needed to understand how change impacts on the quality of ecosystems. Guiding principles are needed to identify high and low quality, and it is needed to be aware when value judgements are used. Above all, it should be recognised that environmental policy is set in a social framework. Therefore, biodiversity must be considered in relation to its perceived value and its effects on society.

In the workshop it was concluded that (Moss, 1999):
"Quality indicators, such as NCI, are helpful as policy tools, but we should be aware that they may over-simplify reality. Modelling objectives should address policy issues, such as those listed above. MIRABEL and the NCI are complementary responses to these requirements. MIRABEL focuses on the provision and assessment of environmental information, while NCI sets these assessments in the framework of a set of policy values and goals. Both systems must be refined and developed if they are fully to meet the requirements of policy-makers".

In planning this development, a number of challenges on data has been addressed (Moss, 1999):

- Feedback loops between models and data have to be established. Data are needed to initialise and validate the models and to constrain model outputs within realistic bounds.
- Modelling must be anchored in reliable data. Data flows need to be mobilised, especially existing data.
- The capability for survey and monitoring of European ecology and landscapes is of great significance in this respect.
- Be aware of scale, and the requirement to aggregate and disaggregate.
- Improve data inputs: fill gaps in data coverage, regional variations in data supply; address data quality problems.

- Exploit opportunities with big data sets, e.g. update of CORINE Land Cover. How can be moved from land cover to habitats? How far can data sets be stretched in interpretation? Can the CLC classification be revisited before the update (to create a better characterisation of habitat)? What effect would this have on assessment of land cover change? DTMs could provide another large dataset.
- Ways must be find to measure dynamics in agricultural systems that are missed by land cover and land use statistics, e.g. changes in pastoral practice (transhumance); seasonality in cereal crops, etc.
- RIVM's baselines approach has both appeal and challenges: the current state (data) has to be related to something.

From the above it is clear that NCI is in interesting approach and that remote sensing could be a crucial factor in meeting the challenges on data and modelling for EEA reporting. Although most promising for the near future, EEA considered the preliminary results of the CORINE or PELCOM based NCI approach not yet sound enough to be implemented in the 1998 State of the Environment Report for Europe. It should be further developed and reviewed first. A common project has been developed and submitted to the 5th European Framework Programme. Recently the NCI approach is applied using detailed ecological information from the Dutch national survey and from ecological modelling in stead of ecosystem quality information derived from pressure indicators.

Next to the above, RIVM has implemented a (CORINE) based NCI approach in the study "Economic Assessment of Priorities for a European Environmental Policy Plan", commissioned by DGXI, to be able to assess the effect of European policy options on biodiversity. The results are used as a first approximation of the efficiency of various abatement measures on the European scale and will be reported in the study (RIVM, 1999) The pressure scaling values as shown in

Table 13 and the Land Use Change Simulator (see Section 7.2.2) have been applied. For the year 2010, pressures for entire Europe has been calculated for two socio-economic scenarios: Baseline Scenario and New Targets Policy Scenario No Trade (NTPS), next to the current state 1990. Pressure Index maps, Mean Pressures per pressure and Mean Pressure Indices has been calculated, as well as calculations of the remaining natural area, pressure based ecosystem quality and an overall pressure-based NCI per country and EU15 (see Table 13; RIVM, 1999). The pressure-based NCI framework appeared to be the only feasible, quantitative method to assess the effects of various policy options in an integrated manner on the European scale.

Table 13 EU15 overview of Mean Pressure and Mean Pressure Index for 1990, Baseline 2010 scenario and NTPS 2010 scenario (RIVM, 1999).

Mean Pressure	**1990**	Baseline	**NTPS**
Temperature	161	278	278
Population	225	231	231
Ozone	407	266	191
Eutrofication	216	120	92
GDP	119	156	156
Isolation	111	100	100
Acidification	352	95	53
Mean Pressure Index	1596	1249	1107

In the European Priority Study it was concluded that in both scenarios the natural area in 2010 will hardly extend (2%). As for the pressure, in Europe the Baseline Scenario leads to a 22% lower pressure and the NTPS Scenario to a 31% lower pressure, grace to significant decrease in Mean Pressures of acidification (- 299), ozone concentrations (-216), eutrofication (-124) and to a lesser extent de-fragmentation (-11). The pressure-based NCI of EU15 increases with 6 and 8 for respectively Baseline and NTPS Scenario. Although this improvement, threat to biodiversity remains high in both scenarios. Because of the time lag between the past and current pressures and ecosystem effects it is still possible that the decrease of biodiversity -which is currently observed in all European countries- might continue.

However, it is clear that detailed European data on land cover for various habitat types, monitored on regular and comparable bases, would be of great political importance to assess the state of biodiversity and track changes over time in the near future. While CORINE provides a single snap shot of the state in a specific period, PELCOM might provide information on a regular and standardised bases. Given the interest of policy makers and their demand for information the PELCOM based NCI framework offers great opportunities in the future. A prerequisite for this is an improved accuracy of the PELCOM database and further developments of the NCI methodology (see recommendations)

7.4 Conclusions

7.4.1 PELCOM land cover data for current and future biodiversity assessment

With respect to alternative geographic explicit land cover databases the PELCOM database offers useful information on current amounts of natural land for biodiversity assessment purposes. Complex habitat descriptions, like co-occurrence of various land cover types (forest and grassland, wetlands and forest, etc.) can be derived from the original LC database by applying neighbourhood filters, in combination with ancillary data (topography, climate, etc.). Its consistent classification approach for pan-Europe is certainly one of PELCOM's most important added values when compared with the alternative CORINE land cover database and certainly replies to RIVM's data requirements.

Additionally, the PELCOM database offers a good opportunity for quantification of one of today's major threats to biodiversity; isolation. The degree of isolation as suggested here can be calculated with relative ease from the PELCOM database. However, its absolute value seems slightly underestimated and differs significantly from the alternative CORINE database. Additional insight into the process of fragmentation can be obtained from the PELCOM database by taking into account the number and size of patches. Unfortunately both the number and size of patches appear rather sensitive to the resolution and origin of land cover data.

Unfortunately, discrepancies between remotely sensed land cover data and more conventional, statistical, land cover databases remain high, especially on more detailed ecosystem levels of forest, grassland, wetland, etc.. Discrepancies of nomenclature and its interpretation are certainly a main cause of error when land cover data are being used within environmental models. This is probably the main limitation for implementation of land cover data in general within the NCI framework.

7.4.2 PELCOM land cover data for monitoring biodiversity

Given its level of accuracy and reliability, the PELCOM database is not useful for monitoring purposes within the NCI framework. Land use change as given by the baseline scenario is not likely tot be accurately detected on a 4-years interval. Land use change takes place on subpixel level, which makes detection even more complicated. The results obtained so far on land use change detection are neither satisfactory for monitoring purposes within the NCI framework.

7.4.3 The (adapted) NCI concept for EU policy development

The adapted Nature Capital Index is a simple and in this respect effective means of obtaining an indication of the state of biodiversity for large scale studies (continental). It is not very data demanding and can easily be applied for EU policy making. More or other pressure indicators can easily be implemented. For impact assessments of different policy scenarios it offers most useful opportunities. For state of the art biodiversity assessments the adapted NCI needs thorough validation. Though, it should be emphasised that the NCI approach as presented here is an adapted methodology. The general NCI approach, which relates quality to detailed ecological data, could be applied for pan Europe in the future as well when appropriate data become available. This will certainly increase its applicability for policy makers.

7.5 Recommendations

7.5.1 Suggestions for improved land cover classification

Detailed European data on land cover for various habitat types, monitored on regular and comparable bases, would be of great political importance to assess the state of biodiversity and track changes over time in the near future. In this respect the highest priority for improved land cover classification concerns the establishment of an accurate methodology for change detection. Additionally it is of utmost importance to improve current accuracies of individual natural land cover classes in general and those of wetlands and natural grasslands in particular. Probably today's best opportunities to do so lies within direct reach of the PELCOM project. The Land Use Integrator as proposed by GEODAN might foresee in required post classification improvements.

7.5.2 Suggestions for improved NCI modelling

To make it possible to use the Pressure Index properly it should be clearly emphasised and realised that there are limitations to the method presented here. They are: 1) The availability of geographical explicit data; 2) The uncertainty of the modelling / projections for the future; 3. The number of pressures included; 4) Linear grading; 5) The threshold 2500; 6) Use of the Land Use Change Simulator; 7) The local situation; 8) The Management aspect. All these limitations should be taken into account with the interpretation of the results. The results give a rough picture of the order of magnitude and distribution of some relevant pressures and their changes in different policy scenarios. In the future many of these limitations should/can be reduced by improving the data sets, modelling techniques, adding more pressures and increasing knowledge of how the pressures interact/affect biodiversity in different habitat types. However, at the end, it is better to use state indicators in stead of pressure indicators. In addition, the quality should also be determined for agricultural areas.

8 Case study B - CNRM: Application in meteorological models

8.1 Introduction

Numerical weather prediction methods generate a need for surface boundary conditions. (Xue et al., 1996) .For the land surface, topography, land cover and soil properties have to be prescribed. Topography and land cover have to be known in order to compute the friction of the air mass over the earth surface. Vegetation and soil strongly modulate the energy and water balance at the surface, leading to modifications in air mass properties and circulation patterns. Also, the description of moisture conditions at the surface is important if the aim is to forecast clouds, fogs or rain. Recognising this, the approach has been first to develop Soil -Vegetation-Atmosphere Transfer (SVATS) schemes which take into account the essential land surface processes which are simple enough to be coupled to atmospheric models and not too demanding in term of surface information. In a second step, adequate data bases of surface parameters have to be gathered.

Information on soil properties is retrieved from soil maps based on extensive ground surveys, which usually exist on a national basis. At the global scale, the FAO-UNESCO map (FAO, 1988) at 1 :5,000,000 scale is particularly useful because it contains information on soil texture (see also section 3.2.10). Several interpretations of this map, suitable for climate and NWP models have been derived .

For vegetation the situation was originally the same: data sets based on ground surveys have been compiled at the global scale (Matthews, 1993), Wilson and Henderson-Sellers (1995). They have been used in climatology and latter in meteorology. These data sets, however, suffer from several shortcomings. First, the information comes from different sources and is difficult to harmonise (Townshend et al., 1991), second the maps cannot be updated frequently and last the resolution of global conventional maps tend to be too coarse for the most advanced meteorological models. For meteorological applications in fact, a large range of resolutions is needed, the trend is towards higher spatial resolution models and in some cases nested models or stretched co-ordinates are used which are more demanding in term of spatial resolution. These considerations plead for the use of alternative vegetation mapping techniques using observations from space which, in principle, have the potential to fulfil the requirements in term of homogeneity, time and space resolution listed above. This approach was implemented at Météo-France and is described in Champeaux et al., 1999.

8.2 Soil-Vegetation-Atmosphere Transfer Schemes (SVATS) and associated set of surface parameters

8.2.1 Data requirements

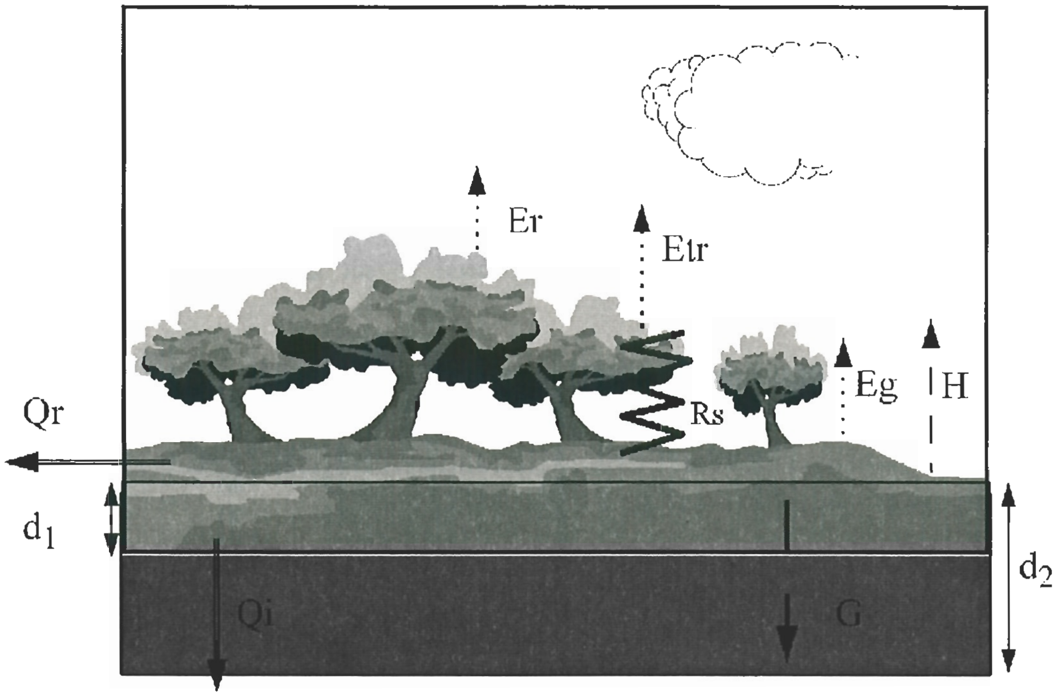
There is now a large variety of soil-vegetation-atmosphere transfer schemes but some consensus has emerged as to which processes should absolutely be represented. A distinction between transpiration by plants and evaporation from the soil has to be made and accordingly a description of the vegetation cover has to be introduced. This can be done in many different ways (Chen, 1997) and for the sake of simplicity the discussion will be limited to the model which is used at Météo-France.

The ISBA (Interaction sol biosphere Atmosphere) model which simulates the interactions between the soil, the biosphere and the atmosphere is now used at Météo-France for research and operational applications in Numerical Weather applications as well as for climate studies (Noilhan and Planton, 1989). ISBA is a simple but physically based model which computes the soil water balance and a single energy budget for bare soil and vegetation (Figure 29). It uses the force restore method (Deardorff, 1978) to compute the heat and water transfers in two soil reservoirs. Three reservoirs are used in this approach to take into account the various evapotranspiration processes. The surface reservoir is the source for soil evaporation, water is extracted from the deep reservoir by the roots, an additional reservoir controls the interception of rain by the canopy. The model has 5 prognostic variables: the water content of the 3 reservoirs and 2 temperatures. 3 extra variables have been added latter to take the snow into account (Douville et al., 1995).

The determination of surface parameters follows two different lines as explained above. Soil parameters are inferred from the soil texture information provided by the soil maps and consequently based on ground surveys only. Vegetation parameters on the contrary are primarily derived from remote sensing observations and ground data is mostly used for calibrations and validation.

In ISBA, the vegetation parameters are the fractional vegetation cover (*veg*), the leaf area index (LAI) and the minimum surface resistance of the canopy to evapotranspiration (Rs_{min}). The roughness lengths for momentum and for heat are also related to the vegetation cover. The rooting depth (d_2) can also, to some extend, be inferred from the knowledge of the vegetation type. These parameters are changing in time and cannot be determined from a vegetation map only.

The PELCOM nomenclature (see Table 7) takes into account the data requirements for meteorology. Classes have been allocated for permanently non-vegetated surfaces and for water bodies for which the energy balance is very different from the energy balance of vegetated surfaces. Thereafter the necessary distinctions have been made for the roughness: forests, tall vegetation (excluding the forests), short vegetation and water bodies.



The ISBA surface scheme. The main features are the existence of 2 reservoirs; d1 is the depth of the surface reservoir and d2 the total depth. The model computes run-off (Qr), infiltration (Qi) and the contribution to the evaporation of vegetation (Etr is transpiration and Er interception) and of the soil (Eg). The soil is regulated by the surface reservoir and the transpiration by the surface resistance Rs. A single energy balance is computed for vegetation and soil.

Figure 29 ISBA Soil Vegetation Atmosphere Transfer Scheme

8.2.2 Derivation of parameters

1. Derivation of the Leaf Area Index (LAI) : The leaf area index varies along the year at a given location, monthly averages or better, ten days averages are considered acceptable for meteorology. The cover type is used to set a lower and an upper bound for LAI. Then, for each class monthly values of NDVI are used to impose a seasonality on LAI.

2. Derivation of the vegetation cover : The vegetation fractional cover is further derived from LAI with the relationship $veg=1-\exp(-\alpha LAI)$ proposed by Kanemasu (1977) in which α is set to 0.5 for forests and to 0.6 for crops. α is in fact the product of 2 terms, one is strictly geometrical, the other is a factor that describes how efficiently the foliage covers the surface.

3. The roughness length for momentum is considered as time-invariant for forests, but varies in time for other species between a lower bound set to 0.01m for bare surfaces to the upper bound listed in Table 14.

4. The canopy resistance to transpiration is inferred from the vegetation type using bibliographic information.

5. The rooting depth is also inferred from the vegetation classification in spite of the fact that it is also related to the soil. Model results are sensitive to this parameter.

Table 14 is an example of look-up table used to set the values of vegetation parameters.

Table 14 Examples of input values for model parameters.

Land cover	$LAI_{min.}$ M^2/m^2	$LAI_{max.}$ m^2/m^2	*veg* min.	*veg* max.	Z_0 m	$R_{s\ min.}$ s/m	d_2 m
Vineyard	0.1	1.5	0.1	0.4	0.2	80	2
Meadow	1.0	3.0	0.5	0.9	0.1	40	1.5
Deciduous forest	0.5	3.5	0.2	0.9	1.0	100	3
Coniferous forest	2.0	4.0	0.5	0.9	1.0	100	3
Orchards	0.1	1.5	0.1	0.7	0.5	80	1.5
Winter crops (1)	0.0	3.0	0.0	0.83	0.15	40	2
Winter crops (2)	0.0	4.0	0.0	0.9	0.15	40	2
Summer crops	0.0	4.0	0.0	0.9	0.20	40	2

8.2.3 Accuracy issues

The influence of various surface parameters on the evapotranspiration flux computed by ISBA is summarised in Figure 30, borrowed from Jacquemin and Noilhan (1990) for a typical mid-latitude situation. This example is for a growing field of maize in south-western France. For the reference situation, the maize covers only 50% of the surface, the leaf area index is 1.0, soil moisture is plentiful. Surface resistance is set to 40s/m. 50 different simulations have been performed to estimate the relative variation of the cumulated daily evaporation when one of the 5 parameters listed on the graph is modified for a range from -90% to 90%.

The most sensitive parameter is surface moisture, then comes veg, Rs_{min}, LAI, and Z_0. All these 4 last parameters are, to some extend, related to satellite observations. For LAI, overestimation would not lead to a very large error in this case because the increase of evapotranspiration with LAI tend to saturate. If LAI is underestimated, an error of 20% would translate in a 10% error in fluxes. This order of magnitude for an error of AVHRR estimated LAI is realistic if one takes into account the 3 main sources of error which are the error on $(LAI)_{max}$, a possible error on NDVI estimations and the rapid increase of LAI which is difficult to monitor from space. In the present scheme, veg is related to LAI and a 20% underestimation for LAI would translate in an underestimation in veg (from 0.5 to 0.43). This would add a 5% error for the evapotranspiration flux. The total error on the evapotranspiration could well be in a range of 15%.

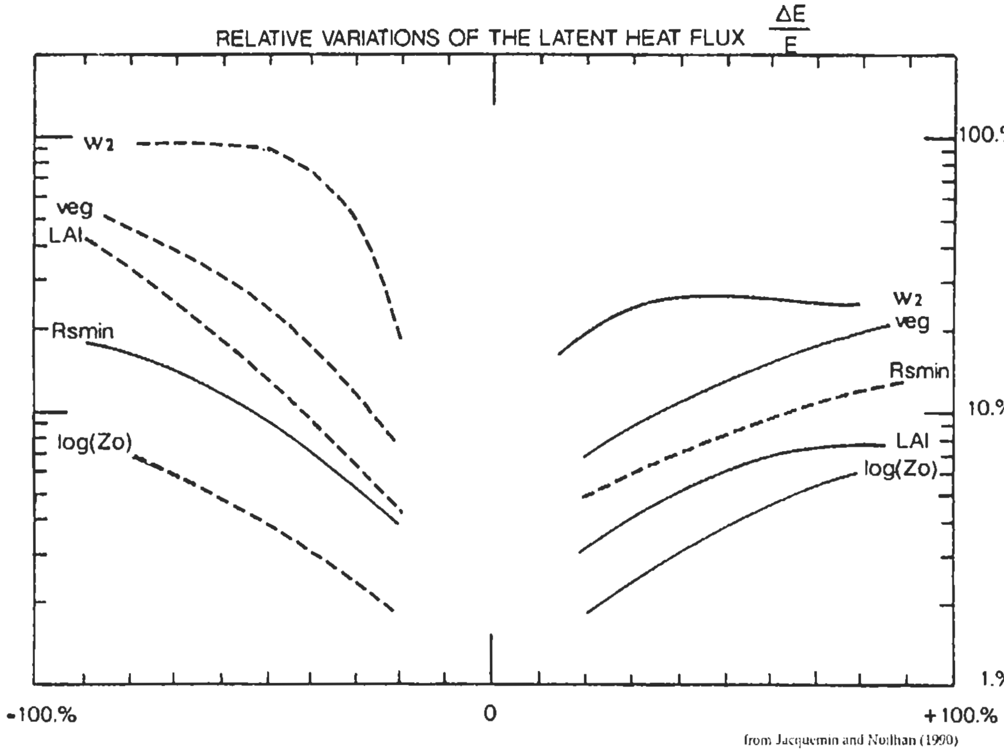


Figure 30 Sensitivity of ISBA to key surface parameters

Errors due to crop resistance to evaporation can be estimated from Table 14 and will only be large if the distinction between short vegetation, permanent tall vegetation and forests is not made, a circumstance which is quite common. If forests are misclassified the error on the evaporation flux will exceed 20%. The error due to the roughness length will in any case remain small, not exceeding 5% for the evapotranspiration flux. Firm conclusions cannot be drawn from a single case study but it points to the weaknesses of the approach which are that the way in which veg is computed, and the impact of forest misclassifications.

8.2.4 Scale issues

The problem of mixed pixels has the same consequences for meteorology as for other applications. The main problem is that mixed pixels can be misclassified and that the class specific relations such as linking *veg* to LAI don't apply any more. It is difficult to select parameters for extremely heterogeneous land covers such as those found in Mediterranean areas: the roughness may be dominated by a low proportion of bushes, whereas the evaporation flux may originate from a few natural or artificial wet spots. These subpixel heterogeneity problems have been studied during the EFEDA field experiment (Bolle et al., 1993). Setting apart these cases, however, one should stress that information already averaged at kilometre scale is an advantage since the atmosphere itself is averaging out the detailed surface feature. For Numerical Weather Forecasting, as will be shown in section 8.3, AVHRR-based maps are too detailed, and have to be averaged. The subgrid scale information however is not completely lost since so-called 'effective parameters' are computed.

8.2.5 Consistency issues

The main maps which are used in atmospheric modelling are topographic, soil and vegetation maps. They have to be consistent and gross incoherence has to be avoided such as a forest on very thin soils or crops at high elevation in the alpine region. For the PELCOM map elevation and vegetation are made consistent, to some extend through the postclassification. The consistency between vegetation and soil has not been directly investigated in PELCOM.

8.3 Use of maps in numerical weather forecasting at Météo-France

A slightly modified version of ISBA land surface scheme (Noilhan-Mahfouf, 1996) has been recently introduced in the global NWP model ARPEGE and the associated Limited Area Model ALADIN which is nested in ARPEGE (WMO bulletin 46-4, 1997). A new analysis scheme for soil temperature and soil water content, based on optimal interpolation from observations of 2m temperature and relative humidity, has been developed simultaneously. The optimal interpolation coefficients used for soil moisture assimilation depend on vegetation characteristics, namely *veg* and LAI/Rs_{min} ratio, and on soil texture. It enhances significantly the sensitivity of the quality of weather forecasts to the description of land surface (Giard and Bazile, 1997).

Since ARPEGE is a global variable resolution model, vegetation characteristics are to be defined for grid-sizes ranging from 20-30km over Europe to 300km at the antipodes (Figure 31). As a consequence, the input databases need to be globally uniform and initialisation is performed in two steps. The global Wilson and Henderson-Sellers (Wilson et al., 1985) land cover database, with a resolution of 1°, is first been used, with an aggregation of classes and look-up tables described in Mahfouf et al. (1995). Vegetation characteristics are modified afterwards over Europe, using the Météo-France AVHRR land cover map (Champeaux,1995), with a resolution of 2km.

The definition of the required parameters for the description of vegetation at each model grid point at that stage is performed in two steps. First, maps at a resolution of 2 km are completed using the land cover map and look-up tables, for the following fields : land-use index (1: sea, 2: ice-cap, 3: low or no vegetation, 4: forest), $1/Rs_{min}$, d_2, veg and LAI (monthly maps in these last two cases). These maps are interpolated to an intermediate regular latitude and longitude grid, with a resolution of 0.1°. This lost in resolution enables a strong reduction in the size of files and is consistent with the current resolutions of the operational versions of ARPEGE and ALADIN over Europe, roughly from 10 to 30km.

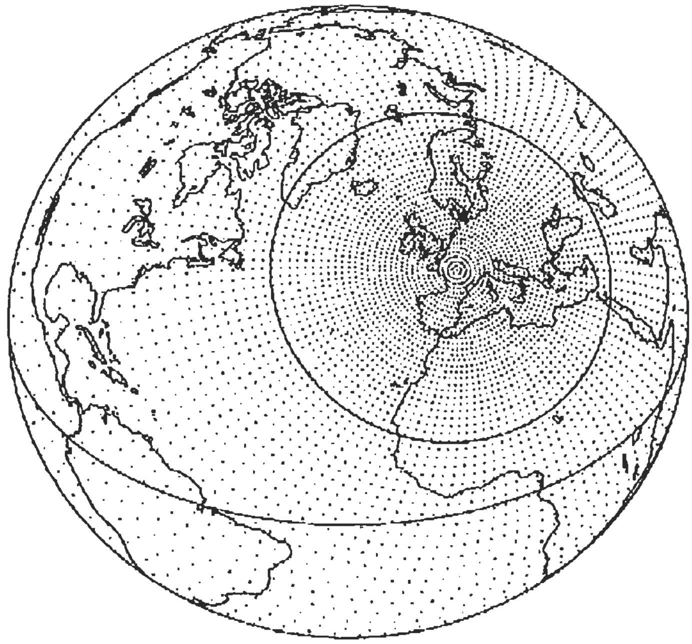


Figure 31 Stretched co-ordinate system for the french ARPEGE variable resolution NWP model.

The contribution of vegetation to albedo and roughness length (Z_0) is defined on this regular grid, as a function of land-use type, and consistently with the look-up tables used for the Wilson and Henderson-Sellers data. The last step is the interpolation from the 0.1° regular grid on to the irregular model grid. In agreement with Noilhan and Lacarrère (1995), the logarithm of the roughness length and the ratio LAI/Rs_{min} are interpolated rather than Z_0 and Rs_{min} directly.

In order to appraise the impact of the new data set before further developments, two ten-day long assimilation experiments have been run, with and without the new high resolution vegetation characteristics. A summer situation (2-12 July 1995) has been chosen, and a preliminary version of the ISBA code and the corresponding analysis, as well as a lower model resolution (T119, i.e. about 35km over Europe) have been used. Upper air, surface and soil variables are analysed every 6h.

According to Figure 32 and Figure 33, the largest improvement in the description of vegetation is over Spain in July. Differences for *veg* and LAI between the 2 maps are very large, with mean values decreasing from 0.83 to 0.53 and from 2.9 to 1.5 respectively. Figure 34 and Figure 36 show the mean and root-mean-square distances to observations of 2m temperature (T_{2m}) and relative humidity (H_{2m}) over Spain along the assimilation cycles. Errors, especially in the description of the diurnal cycle, are reduced with the new data set, by up to 1K for T_{2m} and 0.15 for H_{2m}. Significant precipitation occurred at the end of the experiment, from the 7th day, which likely reduced the impact of vegetation and soil moisture on the 2m fields. The evolution of soil moisture also looks more realistic.

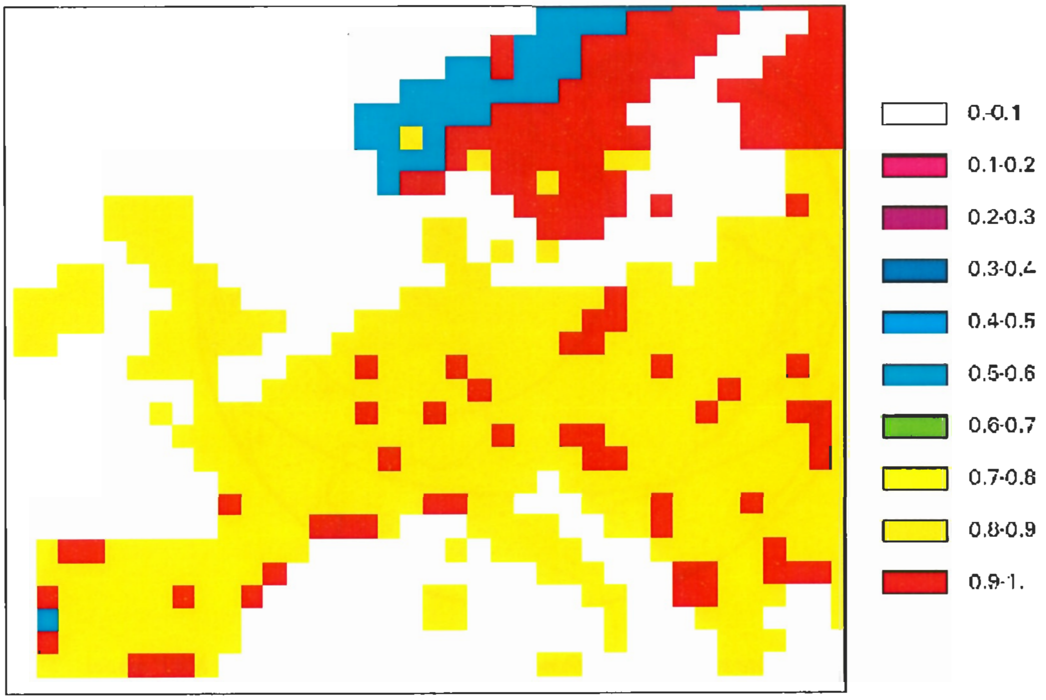


Figure 32 Map of the parameter 'veg' for July from the Henderson-Sellers land cover map at 1° resolution.

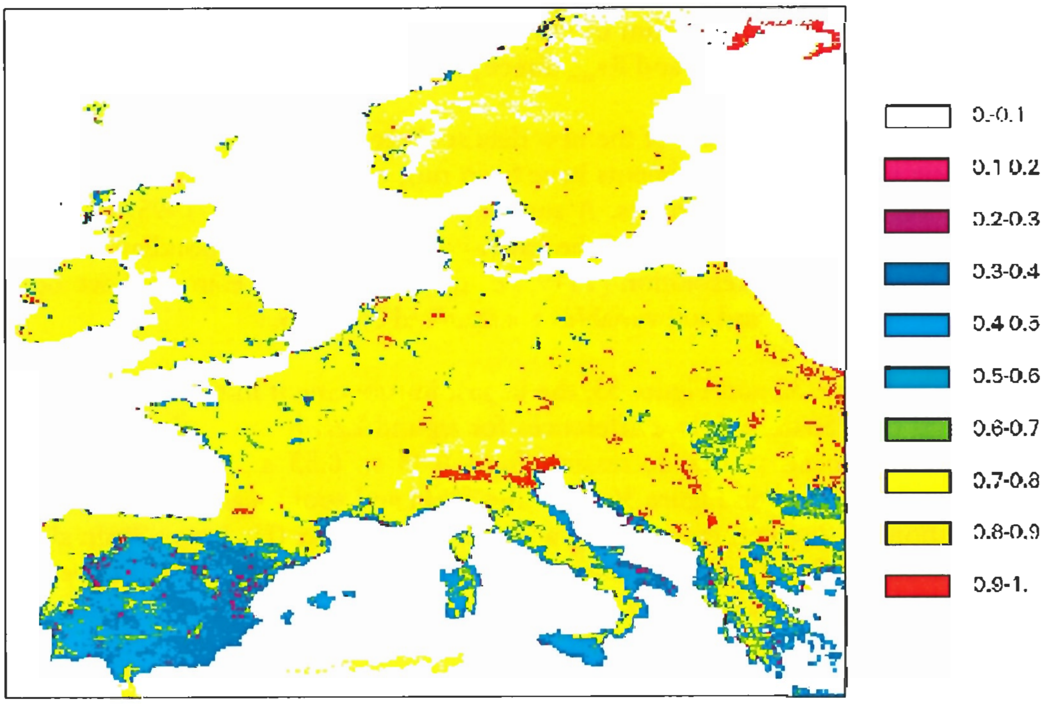


Figure 33 Map of the parameter 'veg' for July from the Météo-France land cover map at 0.1° resolution.

After 5 days of assimilation, the mean value of the soil wetness index is around -0.8 instead of -0.4, which is in better agreement with the dry conditions usually seen in Spain in summer. The impact of the change in vegetation characteristics on 2m fields is less marked on other domains, where differences are smaller and forecast errors are obviously driven by other constraints. Figure 36 show the mean difference in evaporation over Europe between the two experiments and the mean value of the Bowen ratio over Spain for each case. Fields have been averaged over the full length of the experiments, which attenuates discrepancies. Once again, differences are largest over Spain, with a reduction in evaporation of about 0.4mm/day with the high resolution vegetation data (Figure 34). This is in better agreement with climatology, even if evaporation is still too high. The Bowen ratio (Figure 34) increases simultaneously towards more realistic values. The overall impact of this new data is positive, whenever forecasts are really dependent on the description of vegetation. This land cover database is now used in the operational ARPEGE and ALADIN suites.

In the next cycle of the ARPEGE-ALADIN system the PELCOM land cover map will be used for Europe. For a reason of homogeneity and continuity at the boundaries of Europe it is highly desirable to use a land cover map similar to the PELCOM map (i.e. AVHRR-based) for the other continents. The plans are to use the 17 classes map elaborated by the USGS/EROS Data Center in the framework of the IGBP/DIS program. The AVHRR archive used is a monthly composite of NDVI for the March 1992 - April 1993 period. An other land cover map was published by the University of Maryland based on the same archive, the number of cover types is 14. Both maps are, from the point of view of the nomenclature, reasonably compatible with the PELCOM map and similar algorithms can be applied to retrieve the geophysical parameters stand alone tests are being run with ISBA for various points of the globe to select the final data set which will be used outside Europe and to prepare the next cycle of ARPEGE-ALADIN.

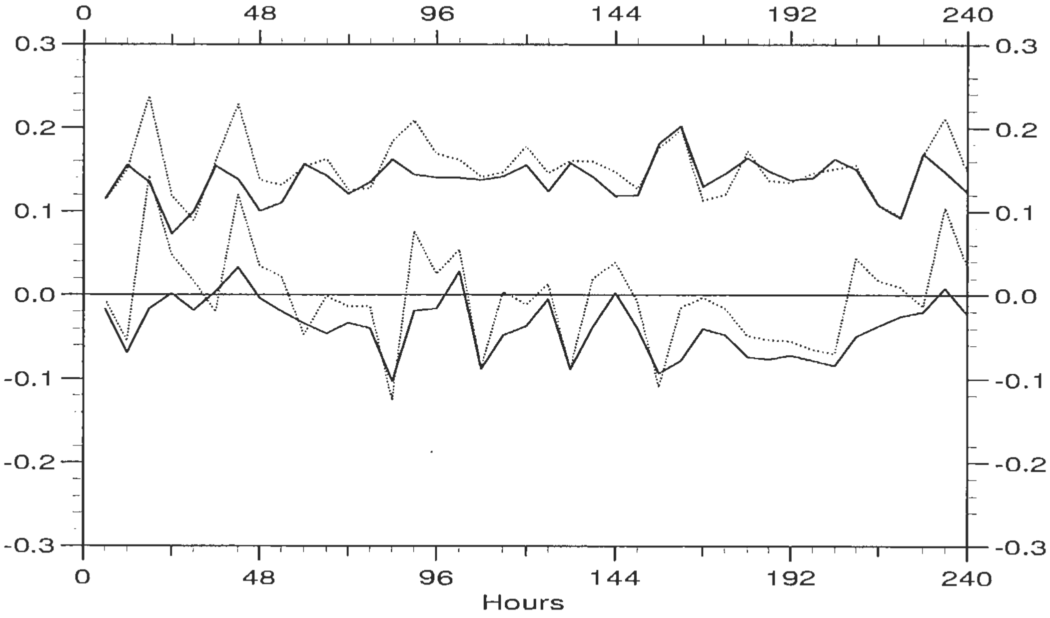


Figure 34 Comparison of modelled with observed humidity at 2m (Hu_{2m}) (mean value, rms) for a 10 days assimilation experiment over Spain (2-12 July 1995) using the ISBA code with the Météo-France land cover mapping at 2km resolution (solid line) and with the Henderson-Sellers land cover map at 1° resolution (dotted line).

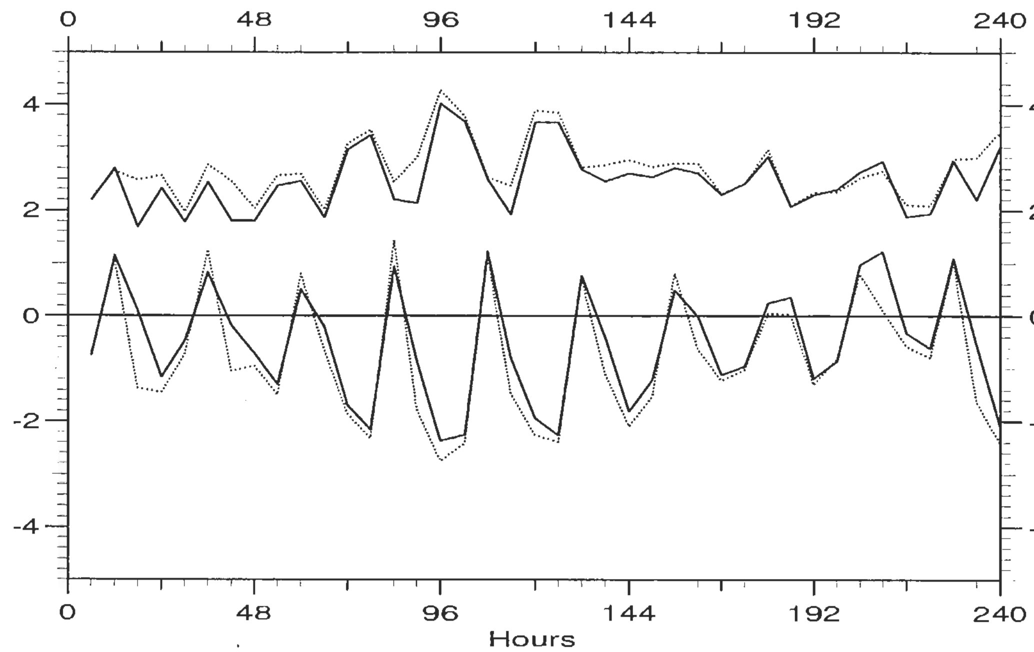


Figure 35 Idem Figure 76 for the observed temperature at 2 m (T_{2m}).

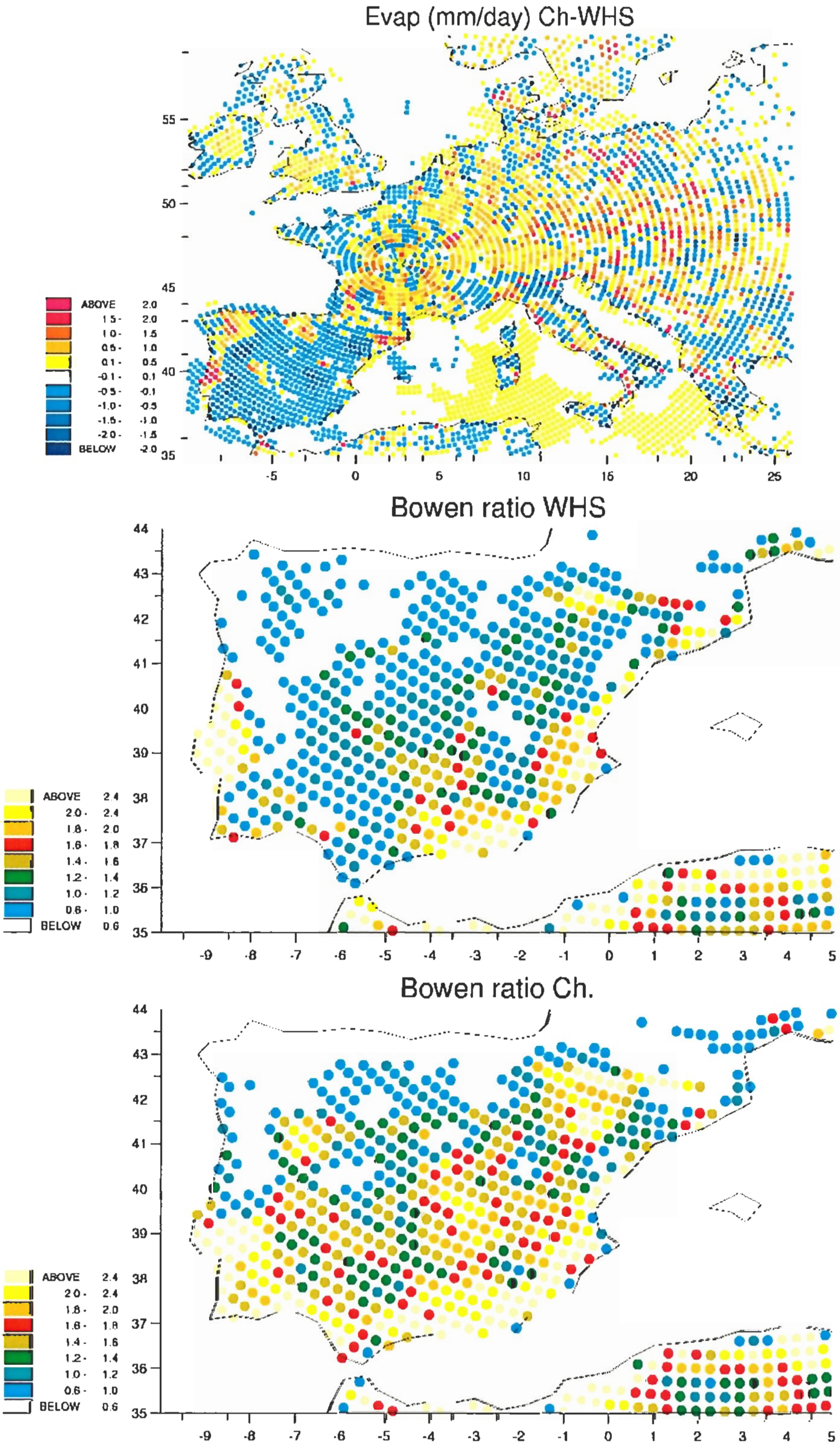


Figure 36 From top to bottom: 78a : Difference in the mean evaporation (mm/day) over Europe between the two experiments. 78b : Mean Bowen ratio (Wilson and Henderson-Sellers) over Spain. 78c : Mean Bowen ratio (pre-PELCOM) over Spain.

8.4 Use of land cover maps in limited area models

Limited area models are used in meteorology for detailed forecasts over a region of interest and are in this case nested into a global NWP model. They are also used in research mode to study atmospheric processes of interest such as sea breezes, convective systems.

8.4.1 Hydrological application of the land cover map.

The ISBA code has been used for a hydrological application over south-western France (Habets, 1998). The model was run over a 100km x 100km domain which was the location for the HAPEX-Mobilhy programme. About half of the domain belongs to the catchment of the Adour river. The interest is focused on the long term water balance for the area, to say one or more year. In this case, the simulation is not interactive with the atmosphere. Rainfall, incoming long and short-wave radiation, air temperature, humidity and wind are prescribed from real observations. The surface domain is gridded in 5km by 5km elements and in some areas the resolution is increased to 2.5km and even 1.25km to follow the boundaries of the catchments. The surface scheme operates on a time step of 5 minutes and computes the components of the water balance: the evaporation related to water intercepted by the vegetation, the transpiration of the vegetation, the evaporation for bare soil and run off. The water is routed to the rivers and the scheme is validated for the hydrograms of the Adour river and tributaries.

The basic land use map is derived from the CORINE land cover database degraded to a resolution of 500m and from the AVHRR classification at 2km resolution (pre-PELCOM map). Both sources of information are merged: CORINE information is used in priority for classes well defined such as vineyard, orchards, meadows, deciduous forests and coniferous forests are directly used. The remaining classes, including arable land and complex cultivation patterns in the CORINE nomenclature, are removed and replaced by winter crops, which form two classes, and summer crop classes inferred from the AVHRR classification. The final result is shown in Figure 37. Vegetation parameters are then prescribed according to observations made in the area for LAI_{max}, LAI_{min}, α, Rs_{min} and Z_{0min} following the method described in section 8.2.2. The roughness length for momentum is considered as time-invariant for forests, but varies in time for other species between a lower bound set to 0.01m for bare surfaces to the upper bound listed in Table 14. A distinction has been made between the short cereals (winter crops) and the taller maize stems (dominant summer crop). The rooting depth (d_2) is extremely important in the context of this hydrological application and is also inferred from the vegetation classification (see Table 14), in spite of the fact that it is also related to the soil. Model results are sensitive to this parameter. In fact, the rooting depth over the Landes forest has been adjusted in order to reproduce correctly the transpiration of the forest in summer and the storage capacity of the soil at the onset of the rainy season in autumn.

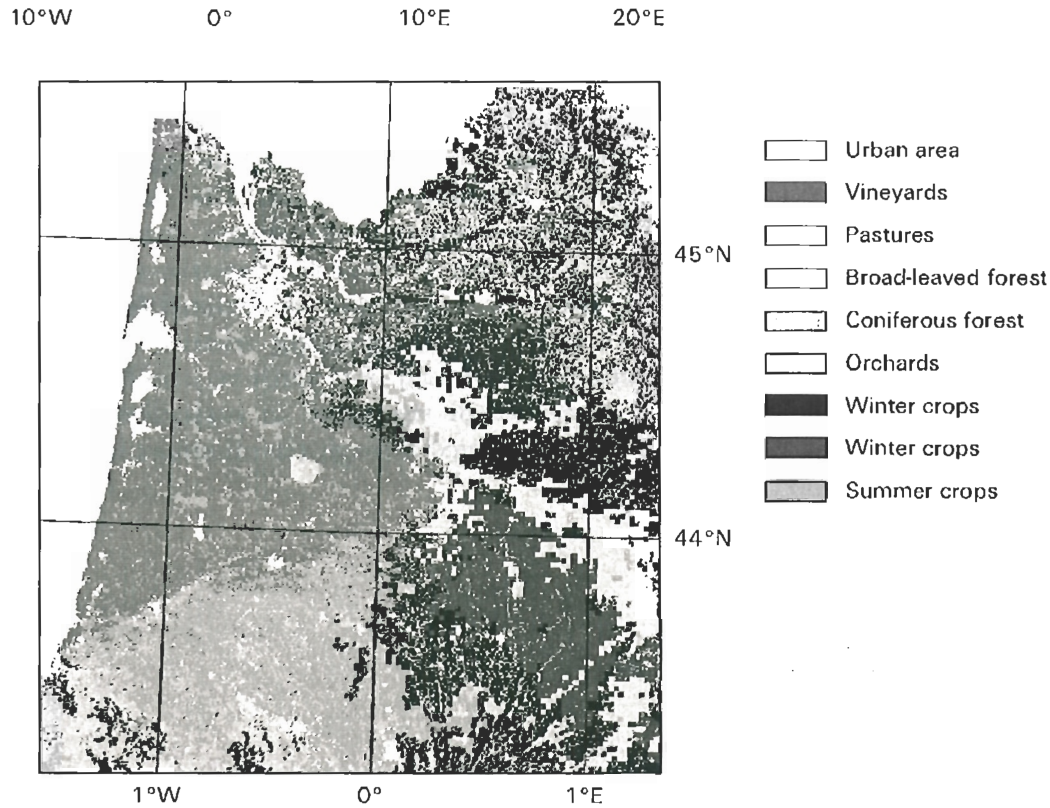


Figure 37 Land cover map over Southwest of France derived from CORINE land cover and NOAA-AVHRR data

For the winter months, the contrast between the forested area in the north and the predominantly bare agricultural surface is very apparent. The vegetation cover over the pine forest falls in a range 0.5 to 0.6 and is modulated by the density of the clearings. Beginning in March, it expands essentially as the brackens composing the undergrowth develop. Later in April, winter crops, predominantly wheat and oats, develop in the south-eastern part whereas maize fields, grown in the moister western part are still bare.

The ISBA model has been run for the year 1986 of the HAPEX-Mobilhy experiment and validated from streamgages records. A climatology of the components of the energy balance has been obtained for this year. Although total annual evaporation varies only from 530mm to 610mm, other component fluxes are highly variable from one vegetation cover to another. Interception is for instance twice as large over the forest as over agriculture land.

8.5 Conclusions

In this chapter, the use of the PELCOM land cover map in Météorology has been reviewed. This map will be used operationally in the next version of the forecasting system ARPEGE-ALADIN. Pending some consistency check, this map will be a good source of information for surface boundary conditions. The way in which parameters will be obtained will however progressively change from what is described above. One source of error is the way in which the vegetation fraction is computed from the leaf area index. Directional signatures, as obtained for instance from POLDER are a powerful tool to improve independent retrieval of veg and LAI. This can be a large improvement in meteorology over partly vegetated canopies. However, such parameters as the resistance of vegetation to evaporation or the aerodynamic roughness will probably be estimated through classifications for a long time.

9 Case study C – ARCS: VOC emissions from forests

9.1 Introduction

Plants are a major source of non-methane volatile organic compounds, which in turn are precursors for tropospheric ozone formation. The emissions of organic compounds, believed to be a plant's physiological response to environmental stress factors such as high temperatures, are especially important in the case of forests, due to the trees' high per-area amount of actively emitting substrate, the leaf biomass.

In order to assess biogenic emissions, certain input information is needed. First of all this concerns temperature and radiation, which are directly effecting the emission behaviour. These parameters can be combined through Environmental Correction Factors (ECF). Next, detailed information about the distribution and the density of plants, including specific species, is required. In this paper we combine the detailed PELCOM land cover information (forest coverage) with additional, spatially much less dissolved data on species distribution. Two scales have been investigated, one is Europe as a whole, the other is Austria, for which a much more detailed set of forest species information was available.

The current procedure of integrating forest emissions into a tropospheric ozone model (photochemical oxidant model) applies temperature and radiation from the meteorology module of the respective model to calculate emissions within the grid cells, which are usually squares of several km side length (depending on the scale of the model as a whole). Most models use relatively simple computational algorithms, discriminating only between coniferous and deciduous forests. Recent research however proves that distinctive differences between species need to be considered beyond a simple coniferous/deciduous differentiation.

The state-of-the-art has been described in detail by Simpson et al. (1999), who also compiles and applies the work of the "Nature Expert Panel" of the UN-ECE Task Force on Emission Inventories (Simpson and Winiwarter, 1998). We therefore do not compare the results of this work to the currently implemented algorithms of photochemical oxidant models, run at the ARCS (Baumann et al., 1996) or elsewhere. Instead, we apply the latest algorithms and derive the differences and potential improvements in relation to Simpson et al. (1999).

9.2 Method

An algorithm for assessing emissions of isoprene and monoterpene from leaves has been described by Guenther et al. (1993). This algorithm is based on considerations of the biological activity, the formation and the emission of the compounds. Formation is a process increasing with light and temperature, with the enzymatic activities however declining again above a certain temperature (approx. 35°C). In the case of isoprene, formation leads to direct emissions. Monoterpene, in contrast, can be stored in the plant. Emissions then are just a function of temperature. In addition, there are emissions of oxygenated compounds (OVOC's), which are believed to occur at a similar mechanism as monoterpene emissions.

The emission rates of trees have been determined at a variety of temperatures and light conditions, and consequently emission potentials at standard temperature and light (30°C, photosynthetically active radiation 1000 $\mu mol\ m^{-2}\ s^{-1}$) have been derived. These emission potentials vary considerably, sometimes even between different species of the same botanical genus (esp. oaks). Most recently, also a component of direct emissions (light sensitive) of monoterpenes has been discovered (Steinbrecher et al., 1997). This emission flux is to be determined in analogy to isoprene.

Standard emission potentials for a number of tree species for all four types of emissions (isoprene and monoterpene, light and temperature sensitive, as well as monoterpene and OVOC's, just temperature sensitive) have been tabulated by Simpson et al. (1999). The authors performed a quite extensive review not only in order to obtain information on many different tree species, but also to compile the data sources which are most useful. As emission potentials are given per dry leaf mass, a conversion factor to forest area has to be applied, the foliar biomass density, in order to obtain per area emissions. Note that this is basically equivalent to a leaf area index (LAI) which is used when emission potentials are given per leaf area (e.g. Lamb et al. 1993). Foliar biomass density has also been tabulated by Simpson et al. (1999).

A next important input requirement is meteorological data which is needed to account for the Environmental Correction Factor (ECF). As indicated above, photochemical models compute these parameters directly from their meteorological modules and consequently derive emissions at a specific situation. For a direct comparison to anthropogenic emissions, annual totals are generally more useful. Therefore Simpson et al. (1998) provide ECF's integrated over a whole year, specific for each European country. This data is compiled from a meteorological model running as a five year mean of actual European conditions on a grid basis (150 x 150 km^2 grid squares).

All these input factors as well as the ECF's used here are basically identical to those used by Simpson et al. (1999. All inputs are documented in the annex. While here we calculate specifically for each PELCOM pixel (however using ECF's on a country basis), Simpson et al. (1999) apply all data on their grid and calculate emissions for

150 x 150 km^2 grid squares. The main difference in approach considers the land use data, the forest areas and the tree species composition of forests.

Simpson et al (1999) used for their assessment a land use map of the Stockholm Environment Institute (SEI), covering most of Western and Central Europe. The map included information on tree speciation, derived from secondary information. In the Eastern Europe, information was limited to a ten-minute land use map of RIVM established by Van de Velde (1994). Land use maps were mainly used to distribute national data on forest coverage and forest speciation within the country. This statistical type of information was compiled from a multitude of sources, including the European Environment Agency (EEA) and the European Forest Institute (EFI). For the comparison here, only the emissions of high forests were included, not grassland, shrubland or tundra vegetation types.

In this report, the total PELCOM forest coverage was taken, as the discrimination between deciduous/mixed/coniferous forest types was not considered sufficiently detailed for emission calculation (see above). The forest species distribution was taken from an assessment by TNO (Nijenhuis, 1999), specifically performed for this project. A forest atlas was used to derive species percentages on a 1° x 2° grid over Europe. The work by Nijenhuis is a refinement of the work published by Veldt (1989).

9.3 Calculation forest areas in Europe

European forest area was available per country from different sources: FAO statistical data (FAO, 1997) on one hand, and the PELCOM database on the other. As PELCOM uses a single-class labeling to each 1100 meter pixel (dominant class), a correction of the areages was performed according to the statistics. Table 15 shows the complete detail of the respective areas, and the correction factor used for each respective country. Simpson et al. (1999) did not apply FAO statistics (even if they report this statistics), instead they rely on a large number of different national or international sources. Thus part of the discrepancy in emissions may be attributed to different total forest area used for calculation (see discussion).

Table 15 Forest area from different sources

	forest area (km2) FAO statistics (FAO, 1997)	PELCOM land use	National statistics, EFI, etc. used by Simpson et al. (1999)	correction factor (FAO/PELCOM)
Albania	10460	10420	14420	1,00
Austria	32270	52484	31697	0,61
Belgium	6170	6313	6960	0,98
Bosnia and Herzegovina	23724	30948	18268	0,77
Belarus	73834	86174	*39000	0,86
Bulgaria	38710	44584	24230	0,87
Denmark	4930	4795	4115	1,03
Ireland	3450	4583	3940	0,75
Estonia	18692	17391	*2016	1,07
Czech Republic	26421	25353	26420	1,04
Finland	232220	184010	197171	1,26
France	148500	171884	133383	0,86
Germany	104030	115842	98560	0,90
Greece	26200	29556	19480	0,89
Croatia	20776	23966	9666	0,87
Hungary	17010	10896	18000	1,56
Italy	67520	101022	61997	0,67
Latvia	28032	21781	*27781	1,29
Lithuania	19677	13763	*19	1,43
Slovakia	19400	24852	19186	0,78
Luxembourg	886	765	863	1,16
Moldova	3570	2397	*	1,49
Macedonia	10790	12129	8312	0,89
Netherlands	3000	2077	2125	1,44
Norway	83300	61864	86761	1,35
Poland	87810	94914	79425	0,93
Portugal	29680	25562	35265	1,16
Romania	66900	77893	49960	0,86
Russia	1446420	956847	*1108676	**1,00
Slovenia	10140	14172	4799	0,72
Spain	158580	140761	132185	1,13
Serbia / Montenegro	41196	43572	31721	0,95
Sweden	280200	240262	279462	1,17
Switzerland	10520	19937	10845	0,53
Turkey		71255		
United Kingdom	24100	24173	19219	1,00
Ukraine	91200	91724	*92391	0,99

* *for these countries, SEI database was not available and thus a cross-check of statistics difficult within the work of Simpson et al., 1999*

** *correction not possible, as forest areas given are based on different total land areas (PELCOM does not cover Russia completely)*

Note that two countries are not fully comprised by the area coverage of PELCOM. A comparison between the total PELCOM land area and the total land area given by EUROSTAT (1995) for the European part of Russia, and by WRI (1994) for Turkey shows that the PELCOM coverage of Russia is approximately 60% of the total area (only the European part is considered), and Turkey is covered by more than 80%. As the major missing part of Russia is in the southern region (Volga lowlands) which is presumably less densely forested, the forest fraction included is larger than that of the total area. Strictly comparing FAO and PELCOM forest areas leads to a fraction of 66%, which is probably the best estimate one may obtain. While Turkey is used for country intercomparisons, it is not included for the calculation of total European emissions, as strictly geographically speaking most of Turkey is *asia minor*. The small European part of Turkey is neglected in these calculations.

When comparing the forest coverage applied by Simpson et al. (1999) to the PELCOM database, it is evident that large deviations occur especially in the East of Europe. For Russia alone, which according to FAO statistics contains 44 % of European forests, the balance of forest emissions may be affected significantly. Data quality also depends on the quality of RIVM ten-minute land use database (see also section 3.2.2), which was the source taken by Simpson et al. (1999) to assess total forest coverage for Russia – for all other countries statistical information on forest coverage was available and applied.

Striking differences are observed in Belarus and the Baltic Republics. Most of these differences may be easily attributed to discrepancies in the total forest area, which are between a factor two to ten different between individual statistical databases. Here the PELCOM land cover, which in itself does not provide an accurate measure, provides an order-of-magnitude check, proving that FAO statistics are more likely to be correct than the different national databases used by Simpson et al. (1999).

9.4 Emissions for Europe

In the emission calculation routine ECF's for individual countries are used (see appendix F) These ECF's, however, are basically very similar for the two approaches taken here, with the exception that they are available at different spatial resolution. Differences between the approaches are in detail as follows:
Simpson et al. (1999) use forest areas and speciation from many different sources, including the European Forest Institute and Eurostat, with land use information from SEI and RIVM. This forest information has been compiled nationally and transferred onto a 150 x 150 km² grid which is used in the EMEP meteorological model. ECF's were calculated for these 150x150 km² grids, emissions calculated and transformed back to countries.

In the current report we use the PELCOM land cover database, forest areas per country from FAO and speciation according to Nijenhuis (1999). ECF's are taken from a table which gives country-specific values (Simpson et al., 1998), which is derived from the 150 x 150 km grid as described above.

While in (1) the number of tree species considered depends on underlying statistics, the approach taken in (2) differentiates nine different species /species classes for all of the area of Europe. The grouping of these classes is less than optimum for the purpose of emissions calculation. In relation to area coverage, larch trees which are distinct among conifers due to their low biomass density, cause about an order of magnitude lower emissions than firs - still those trees form one class. Also, birches and poplars are in one class - with poplars being a major isoprene emitter (see emission potentials given in the annex). The fact that poplar is a dominant species in certain parts of Russia could only be taken into account in this assessment by defining the class to consist of birches west of 30° longitude, and of poplars in the east of this meridian. Figure 38 shows a cluster of high prevalence of this forest species just east of this meridian in a section of PELCOM forest cover with Nijenhuis (1999) data, indicating that this choice is justified. Still information available is sparse. According to the statement of a Russian forestry expert (Gytarsky, 1999), Russian poplars have been planted as wind shields and do not form full-fledged forests. This could imply that areas are in reality not fully covered by poplars, thus significantly reducing the potential emissions. Certainly here is much room for further improvements.

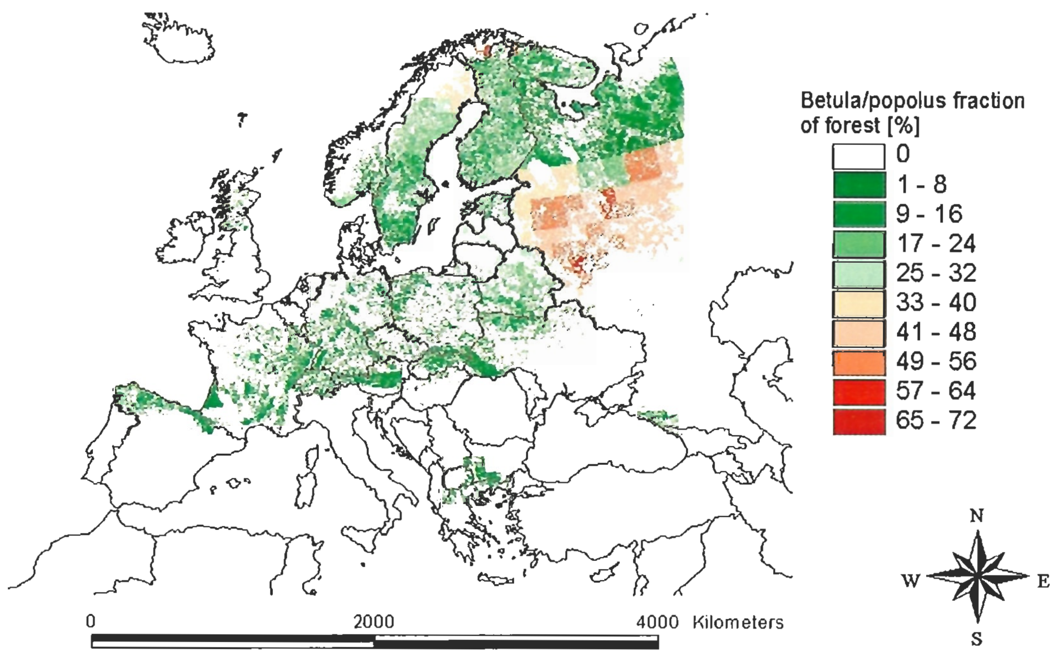


Figure 38 Distribution of the species class birch/poplar in European forests

Emissions from these nine species classes by country are presented in Table 16. As a comparison, the country totals are also shown as given by Simpson et al. (1999), as well as the totals for each species (intermediate results can not be compared directly).

The comparison easily shows the importance of the assessment of Russia. This is not surprising, as Russia comprises nearly half of European forests. Therefore also an emission share in the same magnitude is a priori expected to derive from this country. It should be noted, however, that even though the emissions estimated for Russia within this work are considerably higher than the ones estimated by Simpson et al. (1999), we assume that about a third of the forests contained within Europe are not even covered, as outside the PELCOM forest coverage.

Table 16 Emissions from tree species classes by European country (in Gg/yr)

	Pine	Spruce	Fir, larch	other con.	Quercus ssp.	Quercus ilex	Beech	Birch, poplar	other dec.	Totals	Simpson et al., 1999
Albania	1	2	1		28	14	1		2	51	54
Austria	8	95	9		14	2	2		1	132	125
Belgium	2	10	1		23		1			38	34
Bosnia and Herzegovina	2	20	5	1	28	4	5		4	68	72
Byelarus	117	57			45			35	5	260	150
Bulgaria	25	12	2		173	12	5		4	234	104
Denmark	1	10		1	3		0			15	15
Ireland	2	7			1					11	13
Estonia	19	22			4				2	47	4
Czech Republic	18	83	5	1	18		1		1	127	108
Finland	149	146						12	2	309	341
France	119	71	49	8	593	66	11	2	17	935	1050
Germany	84	236	25	1	88	1	9	1	3	448	377
Greece	24	13	9	1	136	61	2		2	248	153
Croatia	3	13	2	1	42	9	6		4	80	47
Hungary	6	18	2		74		2		4	107	101
Italy	25	57	19	1	210	70	10		13	405	114
Latvia	32	22			5			3	2	64	59
Lithuania	22	21			5			2	1	52	
Slovakia	7	40	6	1	24		3		2	83	86
Luxembourg		1			3					5	3
Moldova		1			24				1	27	--
Macedonia	3	1			25	11	1		1	43	30
Netherlands	4	2	1		5					12	7
Norway	30	60			2			3	1	95	160
Poland	164	61	11		42	1	3	2	5	288	232
Portugal	62			2	138	45			3	251	140
Romania	1	118	17		167		12		9	323	197
Russia	732	1452	6	5	282		2	3033	23	5534	5125
Slovenia	3	17	2		12	4	2		1	41	19
Spain	337		11	9	406	302	5	1	12	1083	511
Serbia / Montenegro	6	16	4	1	105	9	9		7	158	112
Sweden	120	285			17		1	14	4	441	581
Switzerland	1	16	6	1	3	1	1			29	31
Turkey	115	19	25	11	248	11	4		9	443	--
United Kingdom	15	36	7	1	6		1	1	1	67	77
Ukraine	98	90	12		243		5	24	11	484	474
Sum	2358	3133	240	45	3243	624	103	3133	159	13037	10706
Sum without Turkey	2243	3113	215	35	2995	612	98	3133	150	12595	
Sum Simpson (without Turkey)	2036	4356	137	159	2408	360	56	994	211	10716	

On the other hand, the ECF's being used for Russia in this work may be too high in total. Taking one single value for such a vast area means assessing an average, which is probably more shifted to the south than the average forest coverage is, which is more concentrated in the northern part of the country.

Also fairly easy to explain are discrepancies in some East European countries (Lithuania, Estonia, Belarus), which are based on differences in the total forest cover used for assessment. In a similar way, the differences in the countries of former Yugoslavia may be attributed towards differences in forest area between the statistical databases used (see Tabel 15). Especially in Mediterranean shrubland it is very difficult to distinguish, which part to be considered forest and which shrubs.

The example of poplar vs. birch in the case of the current approach, shows in which area it is most difficult to assess the exact reasons for differences. Simpson et al. (1999) performed a split by species, so it is quite straightforward to them to attribute the more suitable emission factors. However, in most countries the speciation in national data is very limited, leaving a broad room for combining species at "other broadleaf" or "other conifers". Especially for Italy, with more than 50% of forests accounted as "unspecified broadleaf", there is wide range of interpretation. In the present report we present a uniform approach for all of Europe. The shortcomings are problems with inappropriateness of speciation for emission calculations. But here errors are uniformly distributed over all countries, even if their results may be different between countries (depending on actual forest composition).

Most of the differences in the totals between countries, when forest area is not applicable, should be attributed to such incomplete speciation information, even if discrepancies may be considerable for some countries (e.g. Italy). A full explanation would again have to access detailed national information, which goes beyond the limits of this work. Instead, detailed evaluation is performed for one test country only (see below).

Forest emissions using the PELCOM dataset are shown in their full detail in Figure 39. Note that the homogeneity across boundaries is clearly visible as emissions stay constant along mountain ranges and other natural features. Steps that indicate an uneven database do exist however: Along the 30° E meridian, which is the line separating poplars from birches, and along 60°N, where biomass density for spruce and pine changes significantly. In northern Russia, also the 1°x2° grid derived from the forest species database becomes evident.

For countries in Eastern Europe – again the predominant example is Russia –the current calculations allow a much better spatial resolution than Simpson et al. (1999) have available. While this does not effect calculation results (as has been stated before, ECF's are only available on the national scale), it allows to understand some of the features. As poplars are dominant in the central part of Russia (actually at the southern rim of the forest belt) according to this data, we may assume that average Russian ECF's are indeed correct for this species – as long as information on high poplar prevalence is accurate – but probably not for the conifers which are dominant further north. For Simpson et al., such a discrimination was not possible from the RIVM database.

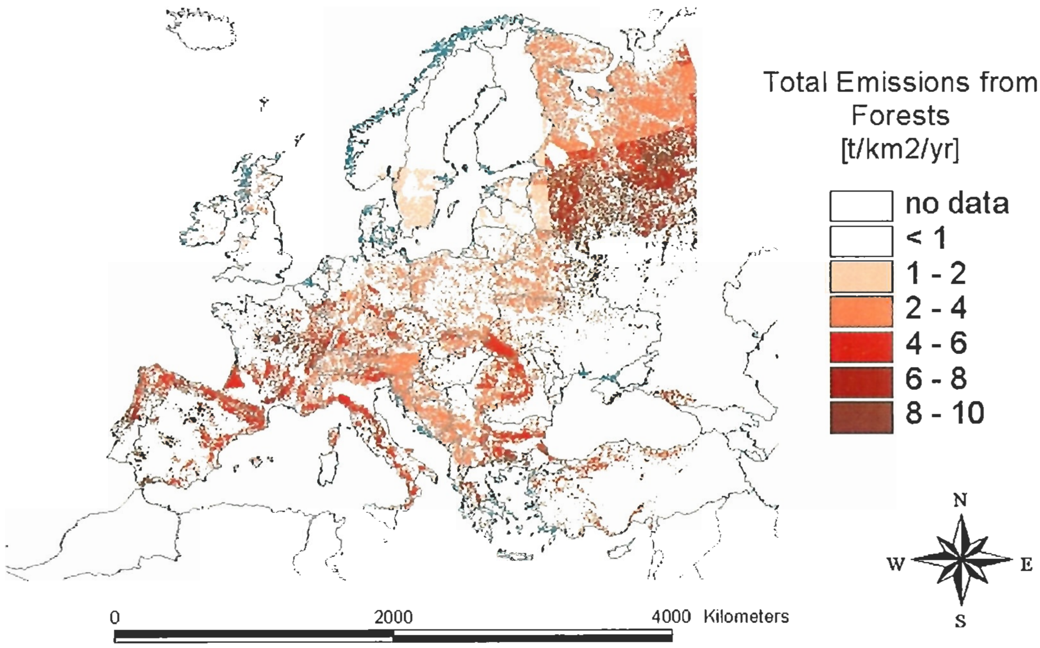


Figure 39 Emissions of European forests calculated for the PELCOM grid

Therefore, using their model of ECF's at a 150 x 150 km grid, they possibly underestimate emission from poplars, as their model assumes a uniform distribution of poplars also further to the north. Since this tree species is characterised by very high emissions especially of isoprene, this underestimation is not compensated by the overestimation of emissions from conifers.

Figure 40 compares the available data on forest emissions derived here with those from Simpson et al. (1999). In order to make data sets comparable, results were transferred to country level. Note that in the case of the literature data, the resolution of the calculations was actually that of EMEP grids (150 x 150 km^2, as shown in the bottom part of Figure 39). Data on that level were however not available for presentation here. Parts of European Russia are not included in the PELCOM map, as the PELCOM coverage does not extend over the total area.

As an overall result, Figure 40 (as well as Tab. 2) agrees for most Western, Northern and Central European countries. Differences are to be seen for Russia, as well as the Mediterranean area. In total, emissions derived from this work are about 20 % higher than those given by Simpson et al. This is well within the error margins, considered to be about a factor of three. However, only one part of the total procedure has been evaluated, and the emission factors themselves as well as their applicability are identical in both approaches. Among tree species, largest differences occur for poplars, part of the reason being the different ECF's used for Russia. The increased emissions for Russian poplar are to some extent compensated by decreased emissions from conifers (partly due to different coverage of the Russian land area).

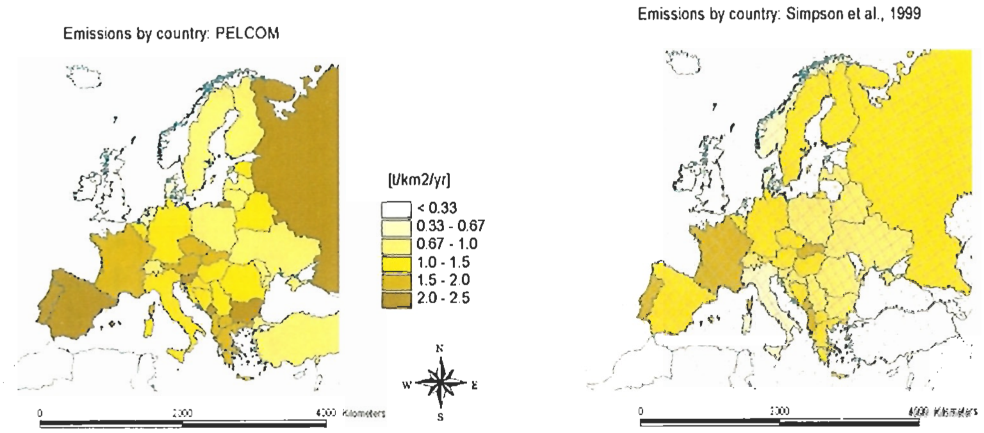


Figure 40 Comparison of forest emissions derived in this work (left map) to literature results (right map). Note that both are compiled from originally finer resolution – calculation by Simpson et al. (1999) has been performed on the EMEP grid as shown, scales differ, as in the upper part emissions are presented per pixel forest, while in the lower part the total land area is base. Also shown is the EMEP grid which determines the area resolution of Simpson et al. (1999).

Increased emissions are distinct for Spain, but also prevalent in other Mediterranean countries, and are characterised by high emissions from oak, but also from pine. To some extent this may also be due to application of the average Spanish ECF's to the cooler northern part, where most of the forest is situated. It should be emphasised again that problems with the ECF would not affect application within atmospheric models, which compute ECF's internally from their meteorological module. We therefore conclude that the overall difference in total emissions between the two approaches is negligible. Interesting is the fact that Italy, amongst the Mediterranean countries, shows the lowest per-area emissions in both approaches.

9.5 Detailed study: Austria

In order to derive the most detailed information possible, one country was selected as test area. For this country, Austria, not only national detailed statistics were applied (in this case: forest coverage and speciation from the national forest institute, FBVA), but also aspects for which differences should be expected between national and continental data are covered.

For Austria, an assessment on – among others – biogenic NMVOC emissions has been published recently (Winiwarter and Fister, 1999). Again, the method by Simpson et al. (1999) has been applied, while in some instances assumptions on the dominant species of an "other" class had to be taken. As a difference to the approach of previous publications, here we also calculate the results of the individual Austrian provinces. This detail in spatial resolution allows to consider climatic zones within Austria. In accordance to Winiwarter et al. (1993) three climate zones were used, one for the very warm and continental Pannonian climate (for the easternmost province Burgenland and for the province of Vienna, which also experiences higher temperatures due to urban heat island effects), one for the mountainous western and central part of the country, which is dominated by forest in higher elevations, and one in the north as well as south of the main alpine ridge. While for the Eastern part ECF's from Hungary were taken according to Simpson et al. (1998) data, the west was assumed to rather agree with the ECF's from Switzerland. These correction factors differ by about a factor of two, making clear how important these factors may get. Speciation and forest coverage for Austria (FBVA, 1998) is available at an even finer spatial resolution, the so-called forest districts, these districts however are not compatible with any of the other Austrian spatial or administrative sub-units and thus were not taken advantage of.

Comparison with the PELCOM data does not affect the calculation of emission by province, as these again had to be scaled according to statistical information. Instead, a more detailed assessment of the discrepancy to statistical area which already has been observed in the Europe-wide calculations is made possible. In addition, the PELCOM forest coverage provides the input needed for small-scale atmospheric modelling, when knowledge on the exact location of the emission sources is required.

The results of the calculation, at the same time compared with data by Winiwarter and Fister, 1999, and Simpson et al., 1999, are shown in Table 17.

As expected, there is very close agreement between the recent emission assessments for Austria (Winiwarter and Fister, 1999) and this work. The main differences in the summation presented here are caused by the differing ECF's used. Basically emissions from all conifers are lower here than in previous work, which is just due to the colder climate assumed for the mountainous part of Austria. An increase compared to previous work can be seen for oaks. This species is prominent in the Eastern provinces, which are now considered to be associated with higher ECF's. The largest difference however occurs for "other hardwood". As is very typical for "other" type of input, it is not quite clear which is the appropriate emission potentials to use. While previously emission potentials of maple were taken, a reassessment of the available data indicates that within this group a large population of willow and also poplar is present. Both are high isoprene emitters, therefore in this assessment the emission potentials of willow were applied. This alone leads to an increase of the emission estimate for the respective source by a factor of three, compensating for the emission reductions in the forest dominated areas in the west of Austria, which are now considered to be in a cooler domain and subject to decreased emissions.

Still larger is the difference to the Austrian emissions as assessed on the European scale (taken from Table 16). Note that the 2°x1° grid used to assess species distribution in part also covers neighbouring countries. This results in calculated emissions of *quercusu ilex* for Austria, a species which is not native to Austria. However there are holm oaks at the southern rim of the Alps, within a grid cell that also covers a part of Austria. Part of this forest is then calculated automatically as holm oaks, which leads to holm oak emissions calculated for Austria. In a similar way, this may also be the case for the species class *quercus ssp.*

Table 17 Forest emissions from Austria by species, by province.

Province	Spruce	Fir	Larch	Scots pine	Black pine	Stone pine	Dwarf pine	other conifers	beech	oak	alder	other hard-wood	softwood	Total
Burgenland	1.8	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.1	2.8	0.0	2.1	0.1	7.7
Carinthia	19.5	0.5	0.2	0.3	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.8	0.1	21.7
Lower Aus.	16.7	0.6	0.1	1.1	0.5	0.0	0.0	0.0	0.4	2.5	0.0	4.7	0.1	26.7
Upper Aus.	14.8	0.4	0.1	0.1	0.0	0.0	0.1	0.0	0.3	0.4	0.0	2.1	0.1	18.5
Salzburg	8.7	0.4	0.1	0.0	0.0	0.1	0.2	0.0	0.1	0.0	0.1	0.7	0.0	10.3
Styria	26.1	0.7	0.3	0.4	0.0	0.2	0.4	0.0	0.2	0.7	0.0	1.5	0.1	30.4
Tyrol	11.4	0.5	0.2	0.3	0.0	0.3	0.6	0.0	0.1	0.0	0.1	0.4	0.0	13.8
Vorarlberg	1.7	0.3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.3	0.0	2.6
Vienna	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.0	0.6
Sum	100.6	3.4	1.0	3.1	0.5	0.6	1.5	0.0	1.3	6.7	0.2	12.8	0.4	132.1
Austria (Winiwarter, Fister 1999)	112.3	3.9	1.1	3.1	0.5		1.8	1.0	1.4	6.1		3.5		134.7
	Spruce	Fir. larch		Pine				other conif.	Beech	Qu. ssp.	Qu. ilex	other dec.	Birch / poplar	
Austria (from table 37)	95.0	9.4		7.9				0.5	1.8	14.3	1.9	1.5	0.1	132.3
													Simpson et al., 1999	125

High prevalence in neighboring countries leads to overestimation of the presence in Austria and thus too an overestimation of the emissions. Certainly the national assessment has to be regarded more realistic and more recent. The resulting emission figures are presented in Figure 41 (numbers are per pixel, one pixel is 1.21 square kilometres) before correction by forest area.

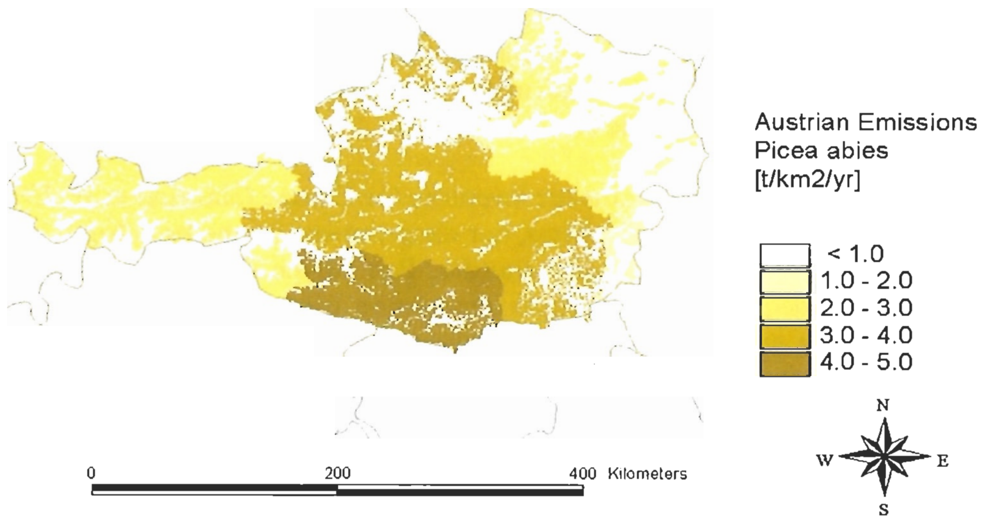


Figure 41 Emissions of NMVOC from Norway spruce in Austria. Data have not been adapted to the statistical forest area (multiplication with province-specific correction factor).

9.6 Conclusions

Assessment of NMVOC emissions from biogenic sources, especially from forests, depends on the availability of reliable, homogeneous data for the whole area under consideration. Previous compilations have put large effort into collecting such data source. As is the case for PELCOM as a whole, also the assessment done here benefits strongly from those previous efforts. Data on total forest cover by countries in Europe have been made available from statistical sources, most prominently from FAO. Climatological information, a basic input for estimating annual emissions from forests, are derived from related activities. And the PELCOM land use database, which is used for the first time for this purpose, is itself a further development from sources which have been used in this field previously (RIVM 10'x10' database, SEI database).

Therefore the outcome of the activities presented here, comparison of PELCOM derived forest emissions to the state-of the art in this field, cannot be assumed to yield totally independent results. Nevertheless, the comparison provides a number of interesting details which describe the applicability, usability and advantages of the methodology applied here, and they allow to identify areas for further study.

First of all, it proves to be a great advantage to be able to rely on just one data source for land use. Any combination of data sources inevitably leads to inhomogeneities in data quality. This has been seen in the comparison, but also in terms of the underlying statistical data. One clear disadvantage of the PELCOM data is that it is not possible to obtain sub-pixel information on the fraction of forest within each pixel and to retrieve consequently actual forest areas. Especially in mountainous, but heavily forested terrain (Switzerland, Austria), total forest area is massively overestimated. But appropriate statistics to be used for correction are available, and PELCOM allows at least an order-of-magnitude check whether a database should be considered reliable or not. This allowed us to make a choice out of two completely different statistical sets in the Baltic and Belarus area.

The comparison with the state-of-the-art inventory for Europe (Simpson et al., 1999) showed good agreement in many respects, but disagreement for the large forest areas of Russia and for the Mediterranean countries. Part of the disagreement may be blamed on the inadequate meteorological information used here, but also a better assessment of highly emitting tree species (poplars; oaks) seems warranted.

For an assessment of the national (or provincial) scale, the statistical data required on forest area is usually available in a homogeneous manner anyway. As is the case for Austria, PELCOM results therefore do not provide much additional information. The differences in results of the approaches shown are caused by other input parameters, especially the climatic input. While also better spatial attribution of climatic parameters is possible using GIS tools, this is actually not needed at this point. Biogenic VOC are especially important as contributors for ozone formation. Those computer models which simulate ozone formation allow to assess temperature and radiation, the base parameter for emission calculation, directly from within their meteorological modules. The grid size of the land-use database then needs to match the grid size of the model. Typical grid sizes of large scale models (see EURADM, LOTOS) are clearly above the PELCOM land-use grid, at 20 to 60 km. On the local scale, used by Urban Airshed Models or by nesting within larger scale models for assessing and tracing ozone plumes, grid sizes of 4x4 or 2x2 km are used. Here the fine grid available from PELCOM clearly becomes essential, and the resolution of the PELCOM land use database still exceeds the requirements.

PELCOM forest subclasses were not used. As differentiation between coniferous and deciduous forest alone is not sufficient anyway, additional information had to be acquired. However, the need to assess forest speciation from numerous individual sources, or from a relatively old compilation (as performed here) limits the quality of the result. A reliable and up-to-date accounting of forest types and tree species on a uniform basis would be extremely beneficial to the application of land use data for assessing biogenic emissions.

10 Conclusions

10.1 Introductory chapters

- Especially since the last century land cover has been changing at an increasing rate in time and space causing increased pressures on the land and implies large impacts on our environment.
- In current environmental policy plans there is an increasing need for up-to-date and reliable information on land use and land cover that covers the whole of Europe.
- Despite the uniqueness of the CORINE land cover database its use is still limited for pan-Europe because a complete coverage of Europe is still not accomplished.
- PELCOM 1-km land cover database fills a gap in environmental & climate applications for Europe.

10.2 Major AVHRR data sources

- Major problems were encountered with respect to radiometric and geometric quality of AVHRR data from the MARS archive. The geometric registration was often poor (misfit up to 50 km can occur) due to the automatic procedure (chip matching) in which only ground control points (GCP's) are used along the coast. Due to occurrence of clouds on the coast line there are often not enough GCP's. This has especially effect on the MVC's which were blurred due to daily shifts in the images, and were therefore not useful. The daily multi-spectral mosaics have, next to the geometric, also radiometric problems. The effect of the scan angle on the reflectances is clearly visible between the stitched orbits, mainly caused by bi-directional effects. In spite of these problems, it seems that the MARS archive is still the best source for daily multi-spectral images. However, additional geometric corrections are necessary and for the classification process training samples have to be identified for each separate orbit.
- From all AVHRR data sources it has been concluded that for NDVI maximum value composites (1997) the DLR archive was the best source. For the use of daily multi-spectral AVHRR mosaics the MARS archive of SAI-JRC was the best source.

10.3 Major ancillary data sources

- Ancillary data sources covering whole of Europe with a high accuracy and reliability are rare. In other words, the use of ancillary data for entire Europe is severely hampered due to large variation in thematic and spatial accuracy of the data sets.

- Integration of satellite images with geographic ancillary data improves any classification.
- Integration of many ancillary data sources is often necessary because most ancillary data sources have a general low accuracy/reliability or do not cover pan-Europe.
- CORINE land cover is perfectly suited for training AVHRR classifications. However, high variety in acquisition dates of satellite images used in the CORINE project demands careful use.

10.4 Classification methodology

- An improved stratified and integrated classification methodology to map major land cover types for pan-Europe using NOAA-AVHRR satellite and additional geographic data has been developed, in the framework of the European Union funded PELCOM project.
- Establishment of a general framework for a consistent and harmonised classification methodology did cost a lot of effort. This is amongst others due to the different experiences by the various remote sensing experts, their tradition in land cover classification and most important a specific classification procedure gives in one region satisfactory results while in another region this does not have to be the case.
- Both multi-temporal NDVI composites and multi-spectral AVHRR scenes are used as input in the classification procedure exploiting the advantages of both data types.
- Multi-temporal NDVI images are easier applicable than daily AVHRR multi-spectral images for large areas due to very high frequency of clouds.
- Forest derived from minimum reflectance of visible reflectance (AVHRR channel 1) with area specific thresholds gives better results for Europe than by classification of NDVI maximum value composites.
- By integrating the PELCOM components, the first-best and second best classification, the PELCOM classification can be improved. However, a clear link with the (spectral) distance ratio has not been found.

10.5 Classification results and validation

- The PELCOM classification methodology resulted in a homogeneous and up-to-date pan-European 1km land cover database with 16 major classes.
- Validation of the regional classification experiments should follow various validation procedures.
- Prelimanary validation results indicated that only major land cover classes such as forest and arable land, which are already responsible for more than 70% of the European surface, can be classified with an acceptable reliability and accuracy. Fragmented land cover classes are much more difficult to identify using NOAA-

AVHRR satellite data. Land cover classifications with AVHRR data has proven to be difficult in heterogeneous areas such as the Mediterranean region.

- Classification results of individual classes depend strongly on homogeneity of the pixels/region and the spectral seperability of classes.
- Quality of the reference data influences classification results highly.
- By omitting the masks for specific regions (e.g. Alpine region) the classification accuracies and reliabilities increased considerably due to low reliability of the masks for the specific region.
- Overall classification accuracy varies strongly per region, depending on the complexity of the region
- Geometric distortions due to various processing techniques and external factors have a large influence on the classification results, especially for fragmented classes.
- The more homogeneous the CORINE pixels for training the classification, the better the classification results.
- Influence of shift of 1 or 2 pixels of reference data (validation set) has a large influence on classification accuracies, especially for small and fragmented classes.
- On basis of interpretations of 40 high resolution images (confidence sites) the PELCOM land cover has been validated independendly. The overall classification accuracy was 69.2% which can be classified as a good result.
- Subclasses of grassland, rainfed arable land and barren land have to be merged due to low accuracies and reliabilities of individual subclasses.

10.6 Monitoring

- Comparing two AVHRR derived land cover maps of different dates for change detection will result in erroneous change maps.
- Thematic fraction images obtained by linear unmixing are a good basis for change detection.
- AVHRR images are moderately suited for change detection at the European scale.
- Development of a change detection method only based on AVHRR images is not feasable.
- Identification of land cover changes with only AVHRR data at the European scale is far from operational. Main problem is that land cover changes take place at a more detailed level.

10.7 Case studies

10.7.1 Case study RIVM: Applications in biodiversity research

- The Nature Capital Index is a simple and in this respect effective means of obtaining an indication of the state of biodiversity for large scale studies (continental). Although the overall NCI seems rather unaffected by the source of LC data, maximum LC accuracy and reliability are needed for regional or ecosystem level NCI computations. Since different ecosystem types have different sensitivity to the various pressures correct classification and differentiation of the main terrestrial ecosystem types is urgently needed. Given the proposed PELCOM nomenclature, NOAA-AVHRR derived LC data offers good opportunities for improvement of environmental models.

- Quality indicators, such as NCI, are helpful as policy tools, but one should be aware that they may over-simplify reality.
- PELCOM's consistent classification approach for pan-Europe is certainly one of PELCOM's most important added values when compared with the alternative CORINE land cover database and certainly replies to RIVM's data requirements
- the PELCOM database offers a good opportunity for quantification of one of today's major threats to biodiversity; isolation. The degree of isolation as suggested here can be calculated with relative ease from the PELCOM database. However, its absolute value seems slightly underestimated and differs significantly from the alternative CORINE database. Additional insight into the process of fragmentation can be obtained from the PELCOM database by taking into account the number and size of patches. Unfortunately both the number and size of patches appear rather sensitive to the resolution and origin of land cover data.
- Discrepancies between remotely sensed land cover data and more conventional, statistical, land cover databases remain high, especially on more detailed ecosystem levels of forest, grassland, wetland, etc.. Discrepancies of nomenclature and its interpretation are certainly a main cause of error when land cover data are being used within environmental models. This is probably the main limitation for implementation of land cover data in general within the NCI framework.
- Given its level of accuracy and reliability, the PELCOM database is not useful for *monitoring* purposes within the NCI framework. Land use change as given by the baseline scenario is not likely tot be accurately detected on a 4-years interval. Land use change takes place on subpixel level, which makes detection even more complicated. The results obtained so far on land use change detection are neither satisfactory for monitoring purposes within the NCI framework.

10.7.2 Case study CNRM: Applications in meteorological models

- The PELCOM 10km land cover database will be used operationally in the next version of the forecasting system ARPEGE-ALADIN. Pending some consistency check, this map will be a good source of information for surface boundary conditions.
- The way in which parameters will be obtained will however progressively change from what is described above. One source of error is the way in which the vegetation fraction is computed from the leaf area index. Directional signatures, as obtained for instance from POLDER are a powerful tool to improve

independent retrieval of veg and LAI. This can be a large improvement in meteorology over partly vegetated canopies. However, such parameters as the resistance of vegetation to evaporation or the aerodynamic roughness will probably be estimated through classifications for a long time.

10.7.3 Case study ARCS: VOC Emissions from forests using PELCOM

- Assessment of NMVOC emissions from biogenic sources, especially from forests, depends on the availability of reliable, homogeneous data for the whole area under consideration.
- It proves to be a great advantage to be able to rely on just one data source for land use. Any combination of data sources inevitably leads to inhomogeneities in data quality.
- One clear disadvantage of the PELCOM data is that it is not possible to obtain sub-pixel information on the fraction of forest within each pixel and to retrieve consequently actual forest areas. Especially in mountainous total forest area is overestimated.
- Comparison with the state-of-the-art inventory for Europe (Simpson et al., 1999) showed good agreement in many respects, but disagreement for the large forest areas of Russia and for the Mediterranean countries. Part of the disagreement may be blamed on the inadequate meteorological information used here, but also a better assessment of highly emitting tree species (poplars; oaks) seems warranted.
- For an assessment on the national (or provincial) scale, the statistical data required on forest area is usually available in a homogeneous manner anyway. As is the case for Austria, PELCOM results therefore do not provide much additional information.
- Typical grid sizes of large scale models (see EURADM, LOTOS) are clearly above the PELCOM land-use grid, at 20 to 60 km. On the local scale, used by Urban Airshed Models or by nesting within larger scale models for assessing and tracing ozone plumes, grid sizes of 4x4 or 2x2 km are used. Here the fine grid available from PELCOM clearly becomes essential, and the resolution of the PELCOM land use database still exceeds the requirements.

10.8 Future Outlooks

Medium resolution satellites (e.g. MODIS, MERIS) in combination with statistical and geographic ancillary data sources have a high potential for land cover change detection at the European scale.
Mult-scale and integrative approach is preferable for a European change detection system.

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Appendix A Acronyms

AML	Arc-Info Macro Language
ARCS	Austrian Research Institute Seibersdorf, Austria
AVHRR	Advanced Very High Resolution Radiometer
BCRS	Netherlands Remote Sensing Board (the Netherlands)
CBD	Convention on Biological Diversity
CCE	Coordination Centre for Effects
CEC	Commission of the European Communities
CEN	Comité Européen de Normalisation
CLC2000	Corine Land Cover 2000 update
CNRM	Centre National de Recherches Météorologiques
CORINE	Coordination of Information on the Environment
DCW	Digital Chart of the World
DEM	Digital Elevation Model
DFM	ESA Digital Forest Map
DLR	Deutches Zentrum fur Lüft und Raumfahrt, Germany
DMA	Defense Mapping Agency (United States)
DN	Digital Number
DPSIR	Driving force-Pressure-State-Impact-Response framework
DTM	Digital Terain Model
ECF	Environmental Correction Factor
ECNC	European Centre for Nature Conservation, Tilburg, the Netherlands
EEA	European Environmental Agency
EEO	European Environmental Outlook
EFEDA	ECHIVAL Field Experiment in Desertification Threatened Areas
ESA	European Space Agency, Paris (France)
ETC	European Topic Centre
ETC-LC	European Topic Centre – Land Cover
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FIRS	Forest Inventory by Remote Sensing
GAC	Global Area Coverage
GCP	Ground Control Point
GDP	Gross Domestic Product
GEO	Global Environment Outlook
GEO	Global Environmental Outlook
GIS	Geographical Information System
GLCC	Global Land Cover Characterization
GTOS	Global Terrestrial Observing System
HAPEX	Hydrologic Atmospheric Pilot Experiment in the Sahel
HRTP	High Resolution Picture Transmission
IFOV	Instantaneous Field of View
IGBP	International Geosphere and Biosphere Programme

ISBA	Interaction Soil-Biosphere-Atmosphere
ITE	Institute of Terrestrial Ecology
IUAV	Instituto Universitario di Architettura, Venice, Italy
IUCN	The world conservation union
JRC	Joint Research Centre of the European Commission, Ispra.
LAC	Local Area Coverage
LAI	Leaf Area Index
LC	Land Cover
LGN	Land Use Database of the Netherlands
LU	Land Use
LUCC	IGBP's Land Use and Land Cover Change project
LuGrid	RIVM 10 Minutes pan-European Land Use Database
LUI	Land Use Integrator
LuStat	RIVM pan-European statistical database
LuVec	RIVM pan-European land use vector database
MARS	Monitoring Agriculture with Remote Sensing
MERIS	Medium Resolution Imaging Spectrometer on board ENVISAT
MIRABEL	Models for Integrated REview and Assessment of Biodiversity in European Landscapes
MODIS	Moderate Resolution Imaging Spectroradiometer
MVC	Maximum Value Composite
NCI framework	A universal and quantitative framework including assessment principles, baselines, indicators and aggregation protocols to describe and assess ecosystems
NCI	Nature Capital Index
NDVI	Normalized Difference Vegetation Index
NMVOC	Non-Methane Volotile Organic Components
NOAA	National Oceanic and Atmospheric Administration
NUTS	Nomenclature d'Unités Territoriales Statistiques
NWP	Numerical Weather Prediction
OECD	Organisation for Economic Co-operation and Development
ONC	Operational Navigation Chart
OVOC	Oxygenated Volotile Organic Components
PEEP	European Environmental Policy Plan
PELCOM	Pan European Land Cover Monitoring project
PELINDA	PELCOM-INDAVOR collaboration
RAMSAR	Convention on the protection of Wetlands of International Importance
RIVM	National Institute for Public Health and the Environment (Bilthoven, the Netherlands)
RS	Remote Sensing
SAI	Space Application Institute of the Joint Research Centre
SEI	Stockholm Environmental Institute
SLU	Specific Land Use
SSC	Swedish Space Corporation
SVATS	Soil-Vegetation-Atmosphere Transfer Schemes

UNEP	United Nations Environment Program
USGS	United States Geological Survey
VOC	Volotile Organic Components
VPF	Vector Product Format
WU	Wageningen University
WFW	World Forest Watch

Appendix B Appendix B. NOAA-AVHRR data sources

B.1 MARS archive

The MARS archive has two components: SPACE system that generates daily AVHRR mosaics and the SCAN system that extracts parameters, such as NDVI from daily mosaics. The Archive covers nowadays (from 1995 and onwards) a large part of Europe (see **Fout! Verwijzingsbron niet gevonden.**), approximately from 84 °N to 25 °N (North-South) 37°W, 55°E (West-East).

The daily multi-spectral mosaics are composed of 1 or 2 afternoon orbits of the AVHRR sensor on board of NOAA satellites. To be able to mosaic the AVHRR data on a daily basis for all five channels, the AVHRR data has to go through the following processing steps (Millot and Loopuyt, 1995; SAI-JRC, 1996):
1. Calibration taking into account the detectors sensitivity decay
2. Atmospheric correction
3. Cloud detection
4. Automatic coastal chip matching
5. Geometric modelling on a orbital pass basis
6. Nearest neighbour resampling on the Albers_Conic_Equal_Area projection with an output pixel size of 1.1 km^2

The resulting mosaics are physically stored in 2 separate files: the image file and the header file. There are mask bits for a.o. land/sea, snow and clouds. The separate leader or header file contains information on the image characteristics (number of pixels in a line, number of lines, corner co-ordinates in latitude, longitude and in map co-ordinates, size of pixel, etc.), the projection parameters, the ellipsoid parameters and the list of input images. The final daily mosaics are referenced to the Albers_Conic_Equal_Area projection with the following parameters (now also referred to as PELCOM projection:

Ellipsoid:	WGS 72
1st standard parallel:	32 30 00
2nd standard parallel:	54 30 00
central meridian:	22 39 00
lat. of projection origin:	51 24 00
false easting:	0
false northing:	0

Data quality
As stated before problems were encountered with respect to radiometric and geometric quality. The geometric registration is often bad (misfit up to 50 km can occur) due to the automatic procedure (chip matching) in which only ground control points (GCP's) are used on the coast. Due to occurrence of clouds on the coast line there are often not enough GCP's. This has especially effect on the MVC's which are blurred due to daily shifts in the images, and are therefore not useful. The daily multi-spectral mosaics have next to the geometric also radiometric problems. The effect of

the scan angle on the reflectances is clearly visible between the stitched orbits, mainly caused by bi-directional effects. In spite of these problems, it seems that the MARS archive is still the best source for daily multi-spectral images. The most practical solution is that the finally selected images get an additional geometric correction if necessary and that during the classification process training samples are identified for each separate orbit.

B.2 DLR archive

- *NDVI Monthly maximum value composites*

The monthly AVHRR maximum NDVI-value composites for 1997 were obtained from DLR. The following text is from 'Stefan W. Dech (DLR 1997).

> After a phase of tests between March and June 1994, the operational production chain was launched on July 1, 1994. Since then, daily, weekly and monthly NDVI synthesis maps covering the European continent were available until September 13, 1994, when the AVHRR on board the NOAA-11 spacecraft failed. The production of daily, weekly and monthly NDVI maps was resumed on February 20, 1995, based on NOAA-14 AVHRR data. Special emphasis is given to a precise image registration and a reasonable cloud screening procedure to ensure that only cloud-free pixels are taken for the later process of composition. Due to the importance of these two tasks, the generation of the NDVI products is a mixture of unsupervised pre-processing steps and a supervised parameterisation of the cloud tests and an image navigation control. Thus, before an image was sent to the data archive and becomes available to the user, it was manually controlled regarding the navigation quality and the cloud tests. So, before the images were delivered by the DLR, some important pre-processing took place in order to increase image quality with respect to cloud/snow cover and geometric accuracy. The major processing steps as were applied on the NOAA-AVHRR images are described in more detail below. Some of these steps were applied by the DLR and some by Alterra.

- *Automatic pre-navigation / Interactive supervision*

Firstly, a process of auto-navigation was performed using WDB-II coastline and river data to improve the accuracy of geo-referencing. This processing was done over the entire pass before the remapping procedure was applied. First, appropriate coastline areas with significant features were selected in 1 by 1-degree boxes and tested regarding cloudiness. For the remaining cloud-free boxes a cross correlation algorithm between the "real" coastline in the satellite image and the coastline of the reference data set was performed. Based on the yielding vector array the satellite's yaw, pitch, tilt, and roll angles were corrected. The complete procedure was first done unsupervised, then the results of the navigation process were checked and if necessary corrected manually. Therefore, best possible quality was guaranteed. This pre-processing step was carried out by the DLR.

- *Calibration*

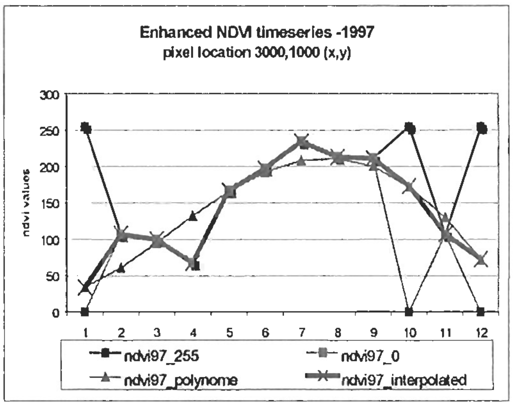
The reflection bands 1 and 2 were calibrated into percentage technical albedo as described by NOAA. The calibration of bands 1 and 2 of NOAA-9 AVHRR was done using time-adjusted pre-launch calibration coefficients. For the NOAA-14 AVHRR, pre-flight values were used between January 19, 1995 and November 21, 1995. The thermal infrared data (bands 3, 4, and 5) were converted from raw counts to radiances and then into brightness temperatures by inverting the Planck function. The reflection bands 1 and 2 were used to calculate the NDVI, the thermal data are used in conjunction with the reflection bands to perform the cloud/water detection algorithm.

- *Cloud/water detection*

To ensure that NDVI values are only derived over cloud-free land surfaces, a couple of cloud/water tests were performed. They were based on the principal spectral characteristics of land, water, and cloud surfaces. The applied thresholds varied from case to case with regard to the specific characteristics of every single pass. The procedure was performed in two steps:
Arid surface test: The first four combined tests were used to calculate valid NDVI values over arid areas, where cloud-free areas were assumed to be warm and bright. Because some arid areas are brighter than clouds, these would be flagged as cloudy using an adequate maximum band 2 brightness threshold for cloud-free vegetated areas. If all conditions were true, the NDVI values were calculated.
The second set of tests determined whether a pixel was cloud/water contaminated or not. If one test was true, the pixel was flagged as cloud or water and excluded from further NDVI processing. For all remaining pixels the NDVI was calculated.
The above described processing procedure was developed by Dr. Stefan Dech at DFD's Value Adding & Visualization group (VAV), 1994 (Copyright DLR 1995). (Source: Stefan W. Dech [DLR], 1997. NOAA AVHRR Data).

- *Clouds and snow cover*

For the NDVI maximum value composites for 1997 about fifty images per month were used. The composites were made by selecting for each pixel the image with the highest NDVI value. This NDVI value was used to construct the final monthly composite. In this way for each month an image was made with almost no traces of clouds. Only for the winter months, mountainous areas and the northern part of Europe (large parts of Scandinavia and Russia), the images were still influenced by clouds and/or snow. Therefore, all cloud/snow contaminated pixels were 'flagged' (set at a value of 255) by the DLR. So, although, the NDVI- images were monthly composites based on about fifty images each, still some areas were covered by snow or clouds during some months of the year.
In order to avoid partly the negative effect of snow/cloud coverage, an algorithm was used which interpolates NDVI values between months in which no snow/cloud coverage was present. Actually, the 'flagged' pixels were replaced by a value obtained from interpolation between periods that these pixels were not covered by snow/clouds. In this way an effort is made to 'look below the snow or cloud coverage'.



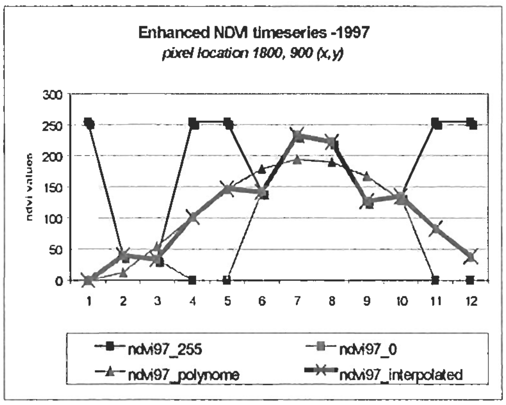


Figure 42 Interpolation between 'un-covered' months in order to estimate the NDVI- value of the land surface below a snow/ could surface.

An example of the interpolation procedure is illustrated in Figure 42. This Figure gives an example of the interpolation at two different pixel locations. The 'flagged' pixels that were initially set at a value of 255 (ndvi97_255) were first transposed to a value of zero (ndvi97_0). Then a fourth order polynome was fitted through the pixel values (ndvi97_polynome). This polynome was initialised at a value of 10 in order to avoid a value of zero at the beginning and end (e.g. January and December). Now, only the snow/cloud-covered pixels were replaced by the interpolated values. The final pixel values are represented by the line ndvi97_interpolated. Figure 3 presents a composition of three maximum NDVI-value composites of May, July and September 1997.

- *Georeferencing*

The monthly NDVI composites were delivered in 8-bit data format and geographic projection. The images were transformed to the same projection as other geographical data available in the PELCOM project. These data use the Albers Conical Equal Area projection with the following projection parameters:

Ellipsoid:	WGS72
1st standard parallel:	32 30 00
2nd parallel:	54 30 00
central meridian:	22 39 00
latitude of projection origin:	51 24 00
false easting:	0
false northing:	0

B.3 Lannion archive

In 1992, Météo-France has decided to implement a regional AVHRR data set for Western Europe. The spatial extent considered herein corresponds to the acquisition disk of the Centre de Météorologie Spatiale (CMS) in Lannion which covers all of western Europe. From April 1992 to August 1996, AVHRR channels 1 and 2 were processed at 2 km resolution , and then at full resolution. The processing line consists in co-registrating the series of images, in updating the instrument calibration, in filtering cloud pixels, and in a last step of removing atmospheric molecular effects. An automatic cloud detection algorithm is applied pixel by pixel. It consists of a succession of threshold tests depending on the location of the satellite sensors measurements and on the time of the day, applied to various combinations of channels (Derrien et al. 1993). A careful navigation has been carried out based upon selected landmarks. The final accuracy is assessed to one pixel which can be perceived as an acceptable result in regard to the resolution achievable with AVHRR (Bordes et al. 1992). Another concern is the quality of the retrieved surface radiometry. The atmospheric correction was performed using the 5S radiative code (Tanré et al 1990) in order to remove the Rayleigh scattering and gas absorption components. However, the signal is not corrected for aerosols due to the lack of concomitant informations on their characteristics. In certain situations, it can yield a significant perturbation on the multi-temporal imagery.

Furthermore, bidirectional effects linked to by variations in sun-view geometries can consistently affect the time series of AVHRR reflectances often increasing the magnitude of the backscattered signal (Roujean et al 1992). Note that at off-nadir viewing zenith angle, the aerosol impact can amplify such trends due to an enhanced atmospheric pathway which leads to stronger perturbations. So, the range of acceptable viewing angles for NDVI computations has been limited with thresholds; for instance, in backscattering conditions, the zenithal solar angle is limited to 70° and the zenithal viewing angle to 60°. For the visible channel, a more severe test has been used. For each 10 day period and each month, the minimum value of the visible AVHRR reflectance and the maximum value NDVI composite (Holben 1986) have been archived.

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B.4 IGBP-DIS archive

The global land 1-km data set project represents an international effort to acquire, archive, process, and distribute 1-km AVHRR data of the entire global land surface in order to meet the needs of the international science community. A network of 29 high resolution picture transmission (HRPT) stations, along with data recorded by the National Oceanic and Atmospheric Administration (NOAA), has been acquiring daily global land coverage since 1 April, 1992. A data set of over 40,000 AVHRR images has been archived and made available for distribution by the United States Geological Survey, EROS Data Center and the European Space Agency. Under the guidance of the International Geosphere Biosphere Programme, processing standards for the AVHRR data have been developed for calibration, atmospheric correction, geometric registration, and the production of global 10-day maximum normalised difference vegetation index (NDVI) composites. The major uses of the composites are related to the study of surface vegetation cover. A prototype 10-day composite was produced for the period of June 21-30, 1992. Production of a 30 month time series of 10-day composites is underway" (J. C. Eidenshink and J. L. Faundeen, 1994) "The 1-km AVHRR global land data set: first stages in implementation").

The data has gone through the following processing steps:
1. radiometric calibration
2. atmospheric correction
3. computation of NDVI
4. geometric registration
5. compositing

The IGBP-DIS Archive contains the following 10-day products from April 1992 till 13 September 1994 and from February 1995 onwards:

Band	Description	Band	Description
1	AVHRR channel	6	NDVI
2	AVHRR channel	7	Satellite zenith
3	AVHRR channel	8	Solar zenith
4	AVHRR channel	9	Relative azimuth
5	AVHRR channel	10	Date Index

Data quality
Because 10-day composites have been made for each channel and the physical meaning behind this is not yet clear, especially for the thermal bands, only the 10-day NDVI composites have been evaluated. The geometric registration of these images seems to be good and consistent over the images due to the use of additional inland GCP's. However, a water mask (both for sea and inland water is used) has been superimposed on the images - which hampers an evaluation. The radiometric quality of the composites was disappointing. Most of the orbits were still visible in the 10-day composites. Only in the monthly NDVI composites this effect is reduced. However, one should be careful when using these monthly composites due to above mentioned reason.

Appendix C CORINE nomencla ture

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

Appendix D Bartholomew thema tic layers

Layer name	Description
Town_Sml	Population under 10,000 with name and whether or not a capital
Town_Med	Population 10,000 - 100,000 with name and whether or not a capital
Town_Lge	Population 100,000 - 2,000,000 with name and whether or not a capital
Town_Xlg	Population over 2,000,000 with name and whether or not a capital
Tourist	Places of interest, information centres, golf courses, waterfalls, etc.
Mountain	Summits, volcanoes and mountain passes, with name & height where known
Airport	International airports and local airports
Junction	Junctions and toll booths on motorways and main roads, border crossings
Intl_Bdy	International boundary lines (repeat, as thin black lines)
MajorBdy	Major internal boundary lines (repeat, as thin black lines)
MinorBdy	Minor internal boundary lines (repeat, as thin black lines)
Ferry	Ferry routes
Motorway	Toll and other motorways (broken lines - under construction)
DualCarr	Dual carriageway major roads (broken lines - under construction)
MainRoad	Single carriageway major roads (broken lines - under construction)
Minor_Rd	Single carriageway minor roads (broken lines - under construction)
Railway	Railway lines, public and private (broken lines - through tunnel)
Graticul	Regular lines at intervals of 10° longitude and 5° latitude
MiscLine	Dams, flood dykes, glacier form lines, linguistic boundaries, pipelines, etc
Coast	Coast line
RiverSml	Small rivers (broken lines - impermanent)
RiverMed	Medium rivers (broken lines - impermanent)
RiverLge	Large rivers (broken lines - impermanent)
Canal	Canals (broken lines - through tunnel)
Intl_Bdy	International boundary lines, as conventional thick coloured lines
MajorBdy	Major internal boundary lines, as conventional thick coloured lines
MinorBdy	Minor internal boundary lines, as conventional thick coloured lines
Gazeteer	Gazetteer of cities and towns, including population where known
*Woodland	Woodland (British Isles only)
*Reserve	Reserves
*For_Park	Forest parks
*Reg_Park	Regional parks
*Nat_Park	National parks
*Lake_Sml	Small lakes
*Lake_Med	Medium lakes
*Lake_Lge	Large lakes
*Adm_Area	Polygons for each admin division (e.g. county/unitary authority in UK)
*Built_Up	Built-up urban areas
*MiscWatr	Lagoons, sea lochs, marshes, dry salt lakes, glaciers and ice caps
*Sand	Sand banks, sandy beaches and desert areas
*Contour	Hypsometric tints, indicating height of land above or below sea level

The file names of the layers, listed in the same order as in the project (Layers marked with * consist of regions, made up of polygons which may or may not be filled):

Appendix E Explanation pressur e factors in biodiversity study

Below, an explanation is given of the seven pressure factors taken into account in the pressure index.

E.1 Rate of climate change

It is expected that climate change can have serious impact on biodiversity (Watson et al., 1996; Markham et al., 1993; Abrahamson, 1989; Pearman, 1988; McNeely et al., 1990; Dawson, 1992). Changes in physiology, competition, phenology, abundance and distribution of species are expected to occur at a much higher speed than most species can deal with. Therefore, not so much the absolute temperature as well as the *rate of climate change* is selected as pressure variable. The pressure is rated on a scale ranging from a change of mean annual temperature of < 0.2°C per 20 years (minimum pressure class = 0) to a mean annual change of 2°C in 20 years (maximum pressure class = 1000) based on PEEP 2 calculations of the IMAGE model (Alcamo et al., 1996). For 1990, the rate of temperature change between 1970 and 1990 is used and for 2010 the rate of temperature change between 1990 and 2010 is used.

The minimum pressure class is a 'threshold of rate of change at which ecosystems might be able to adapt effectively to climate change (Jäger, 1987; 1990). This is based on the still rudimentary understanding of the vulnerability of ecosystems to pre-industrial temperature changes. The maximum pressure class is set at ten times this threshold: 2.0°C in two decades. This increase has been suggested as the "absolute limit beyond which the risks of grave damage to ecosystems, and of non-linear responses, are expected to increase rapidly"(Jäger, 1990).

E.2 Human population density

Many studies have indicated that human population density can function as an indicator of habitat destruction and thus as an indicator for threat to biodiversity. According to Groot and Kamminga (1995) population density is one of the typical examples that can be used to describe the process of deforestation. Lanly (1982) also concluded in this study that population growth was the cause of deforestation globally. According to a study of Verburg and Veldkamp (1997), the area devoted to residential and industrial sites is obviously correlated to the population density. "Population size and rates of growth are key elements in environmental change. At any level of development, increased populations increase energy use, resource consumption and environmental stress." (United Nations Population Fund, Population Issues Briefing Kit, 1993).

The pressure of human population density is rated on a scale ranging from 10 to 150 persons per square kilometre in and near natural areas (if population density < 10, pressure class = 0; if population density >150, pressure class = 1000). The maximum pressure classes for population density are derived from Bryant (1995), Hannah et al.

(1994), Harrison (1992) and Terborch (1989). Data on population density is obtained from Eurostat/RIVM and the UN-Medium scenario.

E.3 Gross Domestic Product (GDP)

GDP is used as an approximation of the production and consumption rate and the related land use of, and pressures on, natural area by factors such as extraction of natural resources, contamination and physical disturbances. The maximum GDP per square kilometer is similar to values found in highly populated and highly industrialised areas such as the lower trajectory of the river Rhine. Consumption and production rate is characterised by GDP on a scale from US$ 0 (pressure class =0) to US$ 6,000,000 (pressure class = 1000) per square kilometre per year (RIVM/UNEP, 1997). It is the product of the number of inhabitants and the average GDP per person.

E.4 Isolation/fragmentation

Isolation reduces the rate of exchange of individuals between sub-populations which affects the genetic variability of species. Furthermore, with decreasing size of the natural areas relatively more of the area will be influenced by edge effects (ACT, 1997; EWGRB, 1997). This may lead to an increasing predation pressure from invading predators and human interventions such as exploitation, pollution and disturbance. Fragmented areas, with consequently smaller populations, are also more susceptible to natural random and extreme events (such as fluctuations in weather, sex ratio, genetic sampling at reproduction), that influence the variance in population growth rate and the chance on extinction (EWGRB, 1997). Isolation can, furthermore, result in changes in types and qualities of food resources, alteration to microclimate (temperature, moisture), changes in availability of cover types and changes in species associations (which can affect rates of competition, predation and parasitism).

Based on PELCOM data, the percentage of natural area is calculated within a radius of 10 km around each grid cell of natural area. This percentage is scaled. The minimum pressure class is assigned per grid cell when the percentage natural area within a radius of 10 km is >64%. This is an area larger than 20,000 ha. Under this conditions enough natural area is present to guarantee sustainable populations of most mammal and bird species (Kalkhoven et al., 1995). If the percentage nature within a radius of 10 km is less than 1% it is assumed that the natural area is highly isolated, therefore, maximum pressure class 1000 is assigned for that grid cell. This is an area smaller than 310 ha. (Kalkhoven et al., 1995).

E.5 Acidification

Acidification due to deposition of SO_2, NH_3, and NOx causes leaching of metal cations and other plant nutrients from the soil into the (ground) water. This leaching results in limited plant nutrients (nitrogen, phosphorus, potassium, magnesium etc.) and a decrease in biomass production. In many cases, a plant's ability to absorb these nutrients depends on the level of acidification in the soil. Furthermore, acid rain kills mycorrhiza and portions of the detritus food chain. Vegetation exposed to acid rain will therefore absorb less of essential nutrients. The result is poorer quality of a plant's proteins, stunted growth and exposure to diseases. As green plants are the foundation of the food chain, a reduction in plant production will have consequences higher up in the food chain. Animals and human beings may experience less valuable nutrition.

The leaching of metal ions has lead in extreme circumstances to damages of forests, lakes, watercourses, and fish. Sources for drink water may become poisoned by high concentrations of copper, lead, and aluminium. Aluminium causes the most severe problems to e.g. the water in southern Norway.

Death of fish, caused by leaching of metal ions, is the best known effect of acidification. There are two reasons for the death of fish. When the acidification reaches a certain level, the fry die. Species of fish have specific tolerance levels to acidic water. The presence of aluminium in the water is common cause of fish death. Aluminium is toxic to fish, because it prevents a fish from absorbing salts and destroys the gills (Bjørke and Parmann, 1997).

A common method to give an indication of threat to ecosystem caused by acidification is the use of critical loads. A critical load of an ecosystem is essentially a 'no-effect' level for a pollutant, that is, the level of a substance (acid deposition, as an example) which does not cause long-term damage to an ecosystem (Grennfelt and Thörnelöf, 1992). Areas, which have a limited natural capacity to absorb or neutralize acid rain, have a low critical load. Ecosystems that are more able to buffer acidity (through e.g., different soil chemistry, biological tolerances, or other factors), have a correspondingly higher critical load[5]. Therefore, the critical level for each grid cell depends on the ecosystems present. When the deposition is below the critical level no threat to biodiversity is assumed (pressure value = 0). If the deposition is higher than five times the critical level, threat to biodiversity is assumed to be at its maximum level (pressure class = 1000). For example, critical loads in the so-called Black Triangle-area in Central Europe are between 5 to 10 times higher. The critical levels as well as the modeled exceedences of these critical loads for the combined N and S deposition are obtained from the Co-ordination Center for Effects (CCE) (Posch et al., 1997).

[5] http://www.iiasa.ac.at/Research/TAP/rains_asia/docs/critload.html

E.6 Eutrofication

One of the major threats to the structure and the functioning of natural and semi-natural ecosystems, and thus to the natural variety of plant and animal species, is the increase in air-borne nitrogen pollution (NH_3 and NOx) in the past decades (Bobbink, et al., 1996). The impacts of increased nitrogen deposition upon biological systems are diverse, but the most important effects are:

- Accumulation of nitrogen compounds, resulting in changes of (competitive) relationships between species;
- Increased susceptibility to secondary stress and disturbance factors such as pathogens, frost and drought damage;
- Soil-mediated effects of acidification;
- Direct toxicity of nitrogen gases and aerosols to individual species

The different ecological effects of nitrogen deposition can lead, alone or in combination, to severe changes in species composition and, finally, to losses of diversity. The severity of the effects depends on the amount and duration of the inputs and on the abiotic conditions in the ecosystem (e.g., buffer capacity, soil nutrient status, and soil factors which influence the nitrification potential and nitrogen immobilisation rate (Bobbink et al, 1998).

Similar to acidification, ecosystem specific critical loads for excess nitrogen deposition are known. The critical loads have been set on the basis of observed and published changes in the structure or function of ecosystems using experimental (field) data, field observations and/or dynamic ecosystem models (Bobbink et al., 1992; Bobbink and Roelofs, 1995). When the deposition of NH_3 and NOx is below the critical level no threat to biodiversity is assumed (pressure class = 0). If the deposition of NH_3 and NOx is higher than five times the critical level, threat to biodiversity is assumed to be at its maximum level (pressure class = 1000). However, in some habitat types large changes in species composition might already occur at two to three times the critical load (e.g., Bobbink et al (in press), Heij and Schneider (1995)). The critical levels as well as the modeled exceedences of these critical loads are obtained from the Co-ordination Center for Effects (CCE) (Posch et al., 1997).

E.7 Exposure to high ozone concentrations

High ozone concentrations have adverse effects on plant and animal species and human health and it can also affect materials such as paint and plastic. Ozone affects leaves from the inside (stomata) which will negatively affect the water balance in plants. It affects cell membranes with leakage and death of the cells as a result. It will also cause oxidative stress within plant cells which disrupts many physiological processes. The plant can defend itself by forming substances that can function as antioxidants (mainly vitamin C for protection of outside of cells and vitamin E for within cell membranes). The plant will try to repair its cells. This is energy consuming and results in limited plant growth and production. Furthermore, when a plant is stressed by ozone it will increase the production of Ethane (plant hormone) which has large physiological consequences. Crops will ripen or die too early and leaves will fall too early. Besides its effects on plants ozone will also affect humans and thus probably also mammal species. High ozone concentrations can cause premature ageing of the lungs, lung tissue damage, eye, nose and throat irritation, and thus causing breathing difficulties, coughs and headaches (California Air Resources Board Status Report, 1994; Stanners and Bourdeau, 1994).

Based on the scientific work on critical levels carried out under the UN/ECE Convention on Long-range Transboundary Air Pollution Working Group on Effects (UNECE, 1997, 1996), a number of guideline values are recommended by WHO (1997). The Accumulated exposure Over a Threshold (AOT) is used as indicator for effects of ozone. The cumulative exposure index using a threshold of 40 ppb (AOT40) has been accepted as the best available exposure index for damage to crops and natural vegetation (Kärenlampi and Skarby, 1996, UBA, 1996) using hourly concentrations during daylight hours over a three-month period (growing season). The critical level for agricultural crops and natural vegetation (excluding forests) (relating to a five percent crop loss) has been set at an AOT40 of three ppm.hours. It has been shown elsewhere that for the currently prevailing European ozone regime the critical level for crops and natural vegetation is stricter than the critical level for forest trees; in other words, while the critical levels for forest trees are usually met when the critical level for crops and vegetation is achieved, the opposite statement does not hold.

In this threat assessment it is assumed that the pressure class for ozone is 0 when the AOT40 is below the critical level for crops and vegetation. Determining the maximum threat level is difficult, as scientific information on this issue is very scarce. Based on expert judgements, which suggest that there is a very marginal difference between toxic and non-toxic ozone levels in the atmosphere we assume that threat to biodiversity is at its maximum when the critical level is exceeded 5 times (pressure class = 1000).

E.8 Definitions9

Assessment frameworks provide a systematic structure for organising indicators so that, collectively, they paint a broad picture of the status of biodiversity. It consists of assessment principles (baselines), indicators (and underlying variables), and methods of aggregation.

Baselines are 'starting points," and can be used, for example, to measure change from a certain date or state. For instance, the extent to which an ecosystem deviates from the natural state or the year the CBD was ratified. The baseline used strongly determines the meaning of the indicator value.

Biodiversity is defined similar to the CBD as the variability among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems .

Biodiversity loss is the anthropogenic caused reduction in biodiversity relative to a particular baseline. In general the process of biodiversity loss results in a decline in the abundance and distribution of many species and the increase of some other species.

Cultural area: see man-made area.

Habitat type is a specific type of vegetation. Major habitat types as distinguished under the CBD are forest, tundra, grassland, (semi) desert, inland waters, marine and agriculture.

Index is usually a ratio between two values of the same variable, resulting in a factor. Two or more indicators with different units are usually aggregated by converting them first into similar ratios, e.g. average distance from baseline, distance to target, or annual change

Inventorising concerns the determination of the present biodiversity at genetic, species and/or ecosystem level in a specific area

Man-made area is defined as all human-dominated, cultivated, land such as: arable land; permanent cropland; wood plantations with exotic species; pasture for permanent livestock; urban areas; infrastructure; and industrial areas. Most of the man-made area is in fact agricultural land. Synonym: cultivated area or domesticated area.

Mean Pressure is the mean of all grid cells (1 by 1 km natural area) for one single pressure per country or Europe

Mean Pressure Index is the mean of the Pressure Indices of all natural grid cells per country or for Europe

Monitoring is a periodic, standardised measurement of a limited and particular set of biodiversity variables in specific sample areas.

Natural area: area is defined as all not human-dominated land, irrespective of whether it is pristine or degraded, such as: virgin land, nature reserves; all forests except wood plantations with exotic species; areas with shifting cultivation; all fresh water areas; and extensive grasslands (marginal land used for grazing by nomadic livestock). Synonyms: natural area or self-regenerating area

Pressure Index is the pressure on biodiversity in one grid cell due to one or more different pressures. In this report it ranges from 0-7000.

Pressure-State-Response assessment framework is an analytical framework which considers various different stages in the causal chain:

> ***Pressures***: socio-economic factors (driving forces which affect biological diversity)
> ***State***: condition or status of biological diversity as such
> ***Responses***: measures taken in order to change the state.

Self-regenerating area: see natural area

Targets often reflect tangible performance objectives, developed through policy-planning processes. For example, a country has established a target of protecting at least 5% of each ecosystem type. One indicator for measuring performance would be the percentage of total ecosystem type protected, relative to the 5% target. Another example is the restoration of specific species populations to a particular level. Targets may include both those that measure pressure, state, and response (whether mechanisms and actions have been put into place) and capacity (whether resources are available to do the job).

Appendix F Forest emissions calculation procedures

Species available in the extended forest PELCOM class (after extension with specified data)

Table 18 A total of 9 species classes is available (S1, …, S9) from the Nijenhuis (1999) dataset. All from Simpson et al., 1998; The Abies/Larix *class is based on additional assumptions: emission factors were taken from fir, the biomass density however adapted according to 2/3 fir, 1/3 larch. Other conifers treated as cedars; other deciduous treated as alder. The geographic differentiation between* Betula *and* Populus *is merely based on information of high poplar prevalence in Russia.*

PELCOM name	Latin name	Type	Foliar biomass density, D (g/m^2)	Iso.	Terpenes		O-VOC	Remarks
				ε-iso	ε-mtl	ε-mts	ε-ovoc	
				ε1	ε2	ε3	ε4	
Pinus (Pine)	*Pinus sp.*	e	700	0.1	0	3	1.5	S of 60° lat
			500	0.1	0	3	1.5	N of 60° lat
Picea (Spruce)	*Picea sp.*	e	1600	1	1.5	1.5	1.5	S of 55° lat
			1400	1	1.5	1.5	1.5	55 - 60° lat
			800	1	1.5	1.5	1.5	N of 60° lat
Abies, Larix (Fir, Larch)	*Abies; Larix*	e; dc	1000	0.1	0	3	1.5	
Other coniferous		e	700	0.1	0	1.5	1.5	
Quercus ssp. (Oak)	*Quercus ssp.*	d	320	60	0	0.2	1.5	
Quercus ilex (holly oak, holm oak)	*Quercus ilex*	e	500	0.1	20	0	1.5	
Fagus (Beech)	*Fagus*	d	320	0.1	0	0.65	1.5	
Betula (Birch)/ Popolus (Poplar)	*Betula*	d	320	0.1	0	0.2	1.5	W of 30 lon
	Populus	d	320	60	0	0	1.5	E of 30 lon
Other deciduous		d	320	0.1	0	1.5	1.5	

Table 19 Countries (C1 - C37) – all environment correction factors Γ have been derived by Simpson et al. (1998)

	Γ-mts = Γ-ovoc		Γ-iso	
	6-month [Γ1]	12-month [Γ2]	6-month [Γ3]	12-month [Γ4]
Albania	745	976	563	719
Austria	588	734	452	540
Belarus	753	895	581	684
Belgium	739	969	580	712
Bosnia Herz.	709	893	561	686
Bulgaria	824	1029	620	755
Croatia	883	1121	667	815
Czech Republic	712	885	533	633
Denmark	518	704	373	485
Estonia	565	669	422	491
Finland	458	523	339	379
France	840	1107	669	829
Germany	698	890	525	632
Greece	1076	1440	816	1057
Hungary	966	1188	730	874
Ireland	467	713	337	478
Italy	904	1208	711	902
Latvia	636	757	486	572
Lithuania	675	813	516	613
Luxembourg	786	1003	620	745
Macedonia,F.Y.R.	631	783	492	597
Moldova, Rep. of	858	1040	649	771
Netherlands	676	901	513	643
Norway	327	397	240	284
Poland	736	912	558	669
Portugal	1015	1388	853	1093
Romania	783	964	587	706
Russia, Fed.	808	917	637	717
Slovakia	797	977	607	724
Slovenia	745	940	562	682
Spain	982	1301	806	1004
Sweden	423	508	315	368
Switzerland	465	580	368	432
Turkey	976	1263	783	983
United_Kingdom	493	720	358	492
Ukraine	856	1023	656	771
Yugoslavia	752	937	557	674

Emissions for evergreen (class "e") species are calculated for each pixel of the PELCOM database, which is considered covered with forest, as:

$$E(S,C) = fraction(S) * D(S) * ((\varepsilon1(S) + \varepsilon2(S)) * \Gamma4(C) + (\varepsilon3(S) + \varepsilon4(S)) * \Gamma2(C)) * corr(C)$$

fraction(S) is the species fraction in forest according to a forest speciation map corr (C) is the correction factor to be derived between total forest coverage of a country and the respective area given by PELCOM. Note that D(S) is in some cases latitude dependent

Emissions from deciduous (class "d", includes larch) trees – most classes of broadleaf species – are calculated as:

$$E(S,C) = fraction(S) * D(S) * ((\varepsilon1(S) + \varepsilon2(S)) * \Gamma3(C) + (\varepsilon3(S) + \varepsilon4(S)) * \Gamma1(C)) * corr(C)$$

When figures are taken as tabulated, emissions will result as $\mu g/m^2$ or g/km^2; all emissions are displayed as such, but are also summed according to their respective countries (NOTE: multiplication with 1.21 is needed, when pixel values are summed up, as each pixel comprises 1.21 km^2).

Table 20 Species table for Austria (emission potentials ε from Simpson et al., 1999)

BFVA name (English translation)	Latin name	Type	Foliar biomass density, D (g/m^2)	Iso.	Terpenes		O-VOC
				ε-iso	ε-mtl	ε-mts	ε-ovoc
				ε1	ε2	ε3	ε4
Fichte (Norway spruce)	*Picea abies*	e	1600	1	1.5	1.5	1.5
Tanne (fir)	*Abies*	e	1400	0.1	0	3	1.5
Lärche (larch)	*Larix*	dc	300	0.1	0	1.5	1.5
Weißkiefer (Scots pine)	*Pinus sylvestris*	e	700	0.1	0	1.5	1.5
Schwarzkiefer (Austrian black pine)	*Pinus nigra*	e	700	0.1	0	3	1.5
Zirbe (cembra pine, stone pine)	*Pinus cembra (as Pinus sp.)*	e	700	0.1	0	3	1.5
Latsche (dwarf pine)	*Pinus sp.*	e	400	0.1	0	3	1.5
sonstige Nadel-bäume (other conifers)	*(Default evergreen)*	e	500	0.1	20	0	1.5
Buche (beech)	*Fagus*	d	320	0.1	0	0.65	1.5
Eiche (oak)	*Quercus petraea; Q. robur*	d	320	60	0	0.2	1.5
Grünerle (alder)	*Alnus*	d	320	0.1	0	1.5	1.5
sonstiges Hartlaub (Other hardwood)	*(as salix / willow)*	d	320	34	0	0.2	1.5
Weichlaub (Soft wood)	*(as cherry)*	d	300	0.1	0	0	1.5

Table 21 Environmental Correction Factors by Austrian Provinces

	Γ-mts = Γ-ovoc		Γ-iso	
	6-month [Γ1]	12-month [Γ2]	6-month [Γ3]	12-month [Γ4]
Burgenland	966	1188	730	874
Kärnten	588	734	452	540
NÖ	588	734	452	540
OÖ	588	734	452	540
Salzburg	465	580	368	432
Steiermark	465	580	368	432
Tirol	465	580	368	432
Vorarlberg	465	580	368	432
Wien	966	1188	730	874

Explanation: ECF's taken from Simpson et al. (1998), assuming that the eastern provinces show more resemblence to Hungary, while the alpine provinces are similar to Swizerland. For an assessment of Austrian climate zones in relation to atmospheric emissions see also Winiwarter et al., 1993.

Table 22 Forest composition in the Austrian provinces (species distribution, in %) according to FBVA, 1997

	Burgen-land	Kärn-ten	Nieder-öster-reich	Ober-öster-reich	Salz-burg	Steier-mark	Tirol	Vor-arlberg	Wien
Fichte	16	68	43	58	59	65	55	47	0
Tanne	0	2	2	2	3	2	3	10	0
Lärche	2	7	3	3	8	7	10	0	0
Weißkiefer	25	4	10	2	0	4	5	2	0
Schwarzkiefer	1	0	3	0	0	0	0	0	0
Zirbe	0	1	0	0	1	1	3	0	0
Latsche	0	1	0	2	6	4	12	15	0
sonstige Nadelbäume	0	0	0	0	0	0	0	0	0
Buche	9	6	15	16	10	6	4	9	14
Eiche	16	0	4	1	0	1	0	0	29
Grünerle	0	1	0	0	5	1	3	7	0
sonstiges Hartlaub	20	3	13	9	5	4	2	8	43
Weichlaub	10	5	6	4	3	4	3	2	14

Appendix G Other End Users of P ELCOM

G.1 Coordination Center for Effects (CCE)

Under the United Nations Economic Commission for Europe (UN/ECE) regular intergovernmental meetings of, *among others*, the governing bodies of the UN/ECE environmental conventions are organised. At these meetings, official representatives from Europe, North America, Central Asia and Israel address environmental issues. One of the important issues here is air pollution for which in 1979 an international Convention on Long-range Transboundary Air Pollution (LRTAP Convention) was signed in the effort to protect our environment. It entered into force in 1983. It was drafted after scientists demonstrated the link between sulphur emissions in continental Europe and the acidification of Scandinavian lakes and later studies confirmed that air pollutants could travel several thousand kilometres before deposition and damage occurred. This implied that Cupertino at international level was necessary to solve problems such as acidification. The Convention was the first internationally legally binding instrument to deal with problems of air pollution on a broad regional basis. Since its entry into force the Convention has been extended by seven protocols.

The Convention also set up a framework associating research and policy. A mapping programme and five co-operative programmes for assessing and monitoring the effects of air pollution are now in operation. The Co-ordination Center for Effects (CCE), located at RIVM, supports the task force of the mapping programme with scientific and technical input on determining and mapping critical levels and loads and their exceedances (assessing potential damage) for e.g. forests, natural vegetation and crops, with particular attention to the direct effects of air concentrations of polluting compounds and the indirect effects of long-term deposition of its derivatives. The CCE integrates such ecosystem-effects related data, available on national scale and contributed by National Focal Centers (NFCs), into pan-European maps and data sets, that are used by the Working Groups of the Convention in development and preparing new protocols. In 1996, negotiations started on a new multi-effect, multi-pollutant protocol on nitrogen oxides and related substances, addressing photochemical pollution, acidification and eutrophication. They were completed in early September 1999 and the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone is ready for adoption by the Executive Body at its session to be held at ministerial level in Gothenburg (Sweden) on 29 Nov. - 3 Dec. 1999.

In order to evaluate the status of implementation of the Convention and its protocols
reviews of the *compliance* by the parties (countries) with their obligations under the protocols will be carried out. The mapping programme will support these activities, but at present there is no uniform land cover/use database available which is used and accepted by all parties involved. Countries concentrate on specific ecosystems for which input data are not taken from one unique source. Promotion of 'the use of

one common land cover/use map plays an important role in answering questions like:

1. Where and at what vegetation type occur exceedances of critical loads and levels? Based on the answers vegetation parameters in the critical loads equations can be verified.
2. What is the damage or what are the damage-risks to ecosystems by harmful effects of Ozone, heavy metals and exceedances of critical loads of acidification and eutrophication. It includes 'sub-questions' like: (a) how manifests the (potential) damage in relation to the compliance with the protocols?, (b) what trends show damage maps in time?, and (c) what is the relation with the real damage reported from within the network?

A uniform land cover/use map appears to be necessary as a basis in the analyses of these questions. A short inventory should lead to the identification of one (or more) existing land cover/use map(s) that will be made operational within the CCE activities and network related to the compliance phase of the Convention. The map will be used as fundament in the communication with the NFCs. Input from within this network will be necessary to keep the map up-to-date.

The first impression of the CCE is that the PELCOM map has a strong chance of being selected as the most suitable land cover/use map, since it seems to meet with most criteria, such as:

- high grid resolution (1 km) that meets with international and most national needs
- lessons learned from previous land cover/use mapping projects
- one standardised and consistent classification methodology for whole of Europe
- one uniform and useful classification scheme all over Europe
- classification based on (best possible) objective criteria, incl. proper descriptions
- sources and techniques are already successfully used for other scientific purposes
- widely used and acknowledged data used as sources (e.g. satellite imagery)
- same data sources available for the whole of Europe
- clear validation
- produced by a project team consisting of experts from all over Europe (is good fundament for creating European consensus also at UNECE activities)
- database recently produces and delivered, thus an up-to-date product representing up-to-date actual land cover/use
- updating map is relative fast and simple
- proper reporting on classification and mapping methodologies and criteria, on restrictions, on input data and on validation
- proper availability of database.
- suitable classification for including potential and actual damage and multi-stress information and its geographical distributions and intensities.

The Co-ordination Center for Effects is eagerly waiting for the final reporting on the products delivered by the PELCOM project.

G.2 Critical loads for heavy metals on European forest soils.

G.J. Reinds, W. de Vries and J.E. Groenenberg

Concern about the deposition of heavy metals (specifically cadmium and lead but also copper and zinc) on terrestrial ecosystems, such as forests, is mainly related to impacts on soil organisms and to bioaccumulation in the organic layer (Bringmark and Bringmark, 1995; Bringmark et al., 1998; Palmborg et al., 1998). With respect to copper and zinc, the possible occurrence of deficiencies in view of forest growth is another relevant aspect. One approach to successful international negotiations on the reduction of atmospheric deposition of pollutants is to determine the maximum atmospheric load that causes no or tolerable damage (the so-called critical load). A major advantage of this method is that it can be used to optimise the protection of the environment for a given international investment in pollution control.

As a basis for the critical load computations, an overlay was made of 5 different maps:

- A map with grid cells of 0.5° × 0.5° that serves as the base map for acid deposition, heavy metal deposition and climate data estimates.
- A map with the soil types of Europe (the EU soil map on scale 1:1,000 000 for the EU countries except for Sweden and Finland and Central Europe (EC, 1985), the FAO soil map at scale 1:5,000 000 for the other countries (FAO,1992))
- A map with the forest types in Europe. This PELCOM map was constructed using detailed NOAA-AVHRR satellite images (with a resolution of approximately 1×1 square km), and distinguishes conifers- broad-leaved- and mixed forest based on differences in their reflection.
- A map with climate zones for Europe derived from EC/UN-ECE (1996).
- A map with 500-m altitude zones, derived from detailed elevation data from USGS (Row et al., 1995).

The maps with climate zones and altitude zones were used in the procedure to estimate forest growth (c.f. section 3.4). The resulting map contains about 80,000 different units for which computations were made with the critical load model STRESS.

G.3 Application of the model SMART to Europe

Gert Jan Reinds, Maximilian Posch (RIVM-CCE), Wim de Vries

To evaluate the combined effects of reductions in acid deposition (through abatement strategies for the emissions of SO_2 , NO_x and NH_3) and climate change, an extended version of the dynamic acidification model SMART was applied to Europe. Originally, SMART was developed to evaluate effects of changing acid deposition on the acidification status of the soil. To evaluate effects of climate change scenarios, effects of changes in temperature on geochemical processes such as aluminium dissolution, $CaCO_3$ dissolution and on bio-chemical and biological processes such as mineralisation of organic matter and forest growth, were included. Furthermore, changes in temperature and precipitation affect the results of the hydrological part of the model through a change in computed precipitation excess. Effects of changes in CO_2 concentration on e.g. growth and nutrient cycling were not included. As with the study describe above the PELCOM forest map was used to create computational units for the modeling with the SMART model on the European scale.

Appendix H PELCOM publicat i on lists

Champeaux J-L, D. Arcos, E. Bazile, D. Giard, J. Noilhan, 1998: Vegetation parameters maps over Europe using NOAA/AVHRR in Meteorological models. In IEEE International Geoscience and Remote Sensing Symposium, Seattle 6-10 July 1998, Vol. III, pages 1726,1728.

Champeaux J-L, D. Arcos, E. Basile, J.P Goutorbe, D. Giard, F. Habets, J. Noilhan, and J.L Roujean, 2000: AVHRR-derived vegetation mapping over western Europe for use in numerical weather prediction models. *Int. J. Remote Sensing (special issue on Global and Regional Land Cover Characterization from Remotely Sensed Data)., in press.*

Kressler F. and Steinnocher K., 1996, Change detection in urban areas using satellite data and spectral mixture analysis. *International Archives of Photogrammetry and Remote Sensing*, 31, B7, 379-383.

Kressler F.P., Steinnocher, K.T, 1998, Applying a linear unmixing method to determine the abundance of different land cover types from NOAA-AVHRR data 27th International Symposium on Remote Sensing of Environment, Tromsø, Norway, 8-12 June 1998, pp. 407-410 1998 Proceedings.

Kressler F.P., Steinnocher, K.T, 1998, Detecting land cover changes form NOAA-AVHRR data using spectral unmixing analysis. EARSeL Symposium on operational remote sensing for sustainable development, , Enschede, The Netherlands, 11-14 May 1998.

Mücher, C.A., Steinnocher, K., Kressler, F and C.Heunks, 1998, Land cover characterization and change detection for environmental monitoring of pan-Europe. *Int. J. Remote Sensing (special issue on Global and Regional Land Cover Characterization from Remotely Sensed Data)., in press.*

Mücher, C.A., K. Steinnocher, J.L. Champeaux, S. Griguolo, K. Wester and P.Loudjani, 1998, Land Cover Characterization for environmental monitoring of pan-Europe. In: Proc. 18th EARSEL Symp. on Operational Remote Sensing for Sustainable Development, ITC, Enschede, 11-13th May 1998, pp 107-113.

Veldkamp J.G., C. Heunks, V.F. van Katwijk, M. Barkhof , C.A. Mücher and B.J.E. ten Brink, 1998. Towards an improved methodology for Pan-European land cover classification. Applicability of NOAA-AVHRR and ancillary data for land cover based environmental monitoring on a European scale. Final Report part 2. BCRS publication 98-06, Delft, the Netherlands, pp.90.

Appendix I PELCOM relevant web sites

PELCOM PARTNERS	
http://www.alterra.wageningen-ur.nl/	Alterra, Green world Research
http://www.arcs.ac.at/	Austrian Research Centre Seibersdorf (ARCS)
http://www.satellus.se/	Satellus
http://www.sai.jrc.it/	Space Applications Institute (SAI-JRC)
http://www.meteo.fr/	Météo France (CNRM)
http://www.rivm.nl/	Dutch National Institute of Public Health and the Environment (RIVM)
http://web.iuav.it/iuav/	Instituto Universitario di Architettura (IUAV)
http://www.geodan.nl/	GEODAN IT.
INSTITUTIONS/ORGANIZATIONS	
http://www.eea.eu.int	European Environment Agency (EEA)
http://etc.satellus.se	European Topic Centre on Land Cover (ETC-LC)
http://www.ecnc.nl	ECNC homepage
http://ceo-www.jrc.it	Centre for Earth Observation (CEO)
http://www.wcmc.org.uk	World Conservation Monitoring Centre (WCMC)
http://www.iiasa.ac.at	International Institute for Applied Systems Analysis (IIASA)
http://edcwww.cr.usgs.gov/landdaac	Earth Resources Observation Systems data center - Distributed Active Archive Center (EROS)
PROGRAMS	
http://www.grida.no/	United Nations Environment Program (UNEP)
http://www.minvenw.nl/rws/mdi/bcrs	Beleidscommissie Remote Sensing (BCRS)
http://www.igbp.kva.se	International Geosphere-Biosphere Program
http://www.cnrm.meteo.fr:8000/igbp/	International Geosphere-Biosphere Program Data Information System (IGBP-DIS)
http://www.icc.es/lucc/	Land Use and Cover Change (LUCC)
http://ceo-www.jrc.it/vgt-docs/vgthmpg.html	VEGETATION Programme!
http://www.ecnc.nl/doc/europe/legislat/strafull.html	pan-European biological and landscape diversity strategy
PROJECTS	
http://www.geodan.nl/ec_lu	Pan European Land Cover Monitoring (PELCOM)
http://edcdaac.usgs.gov/glcc/glcc.html	Global land cover characterization (IGBP-DIS)
http://www.nioo.knaw.nl/cto/clue/clue.htm	Changing Land Usage, Enhancement of biodiversity and ecosystem development (CLUE)
http://www.icc.es/lucc/projects/claude.html	Coordinating Land Use/Land Cover Analysis and Data in Europe (CLAUDE)
http://ceo-www.jrc.it/mobio.html	Monitoring of changes in biotopes (MOBIO)
http://www.egeo.sai.jrc.it/forecast/firs	Forest Inventory by Remote Sensing (FIRS)
http://mpapad.geo.auth.gr/docs/clivara.html	Climate Change, Climatic Variability and Agriculture in Europe
http://geospace.co.at/EON2000/eonhome.htm	Earth Observation for NATURA 2000
NOAA/AVHRR DATA	
http://shark1.esrin.esa.it	Ionia "1 km AVHRR Global Land Data Set"
http://www.sat.dundee.ac.uk	NERC Satellite Station, Dundee University, UK
http://www.ncdc.noaa.gov	NCDC Home Page
http://xtreme.gsfc.nasa.gov	AVHRR Pathfinder Home Page
http://www.ngdc.noaa.gov/dmsp/dmsp.html	NOAA DMSP Program at NGDC Home Page
http://edcwww.cr.usgs.gov/landdaac/1KM/1kmhomepage.html	1-KM Project

http://edcwww.cr.usgs.gov/landdaac/1KM/comp10d.html	AVHRR 10-day composite
ftp://ftp.ncdc.noaa.gov/pub/noaanews	Directory of /pub/noaanews
http://www.noaa.gov	NOAA Home Page
http://xtreme.gsfc.nasa.gov	AVHRR Pathfinder Home Page
ANCILLARY DATA	
http://ilm425.nlh.no/gis/dcw/dcw.html	Digital Chart of the World (DCW)
http://edcwww.cr.usgs.gov/landdaac/gtopo30/gtopo30.html	Global 30 arc second elevation data set GTOPO30
http://www.iucn.org/themes/ramsar/ramsar-site_list.html	Ramsar list of wetlands
http://www.wcmc.org.uk/data/database/un_combo.html	United Nations list of protected areas 1993
http://www.chest.ac.uk/datasets/barts/bartsover.html	Bartholomew databases
http://www.isegi.unl.pt/Labnt/projects/dmeer/index0.htm	Digital Map of European Ecological Regions (DMEER)
http://www.eea.dk/document/Entecrep/Corine/corindoc.htm	CORINE land cover database
http://www.geodan.nl/lu10/general.htm	The 10 Minutes pan-European Land Use Database
http://europa.eu.int/en/comm/eurostat/serven/home.htm	Statistical Office of the European Communities (EUROSTAT)
http://apps.fao.org	FAO statistical database
http://edcwww.cr.usgs.gov/landdaac/glcc/glcc.html	Global Land Cover Characterization (GLCC)
http://aisws6.jrc.it:2001	AISIS home page
MAPS OF EUROPE	
http://www.lib.utexas.edu/Libs/PCL/Map_collection/europe.html	
http://ceo-www.jrc.it/CEO_eudata.html	European relevant data archives
http://www.eea.dk/products/databases/databases.html	EEA: databases
http://www.grid.unep.ch/europe_m.html	European data sets
http://edcwww.cr.usgs.gov/webglis	Global land information system
http://www.cirad.fr/cgi-bin/cig/cig_eng	Carthographic databases
REMOTE SENSING & GIS	
http://neonet.nlr.nl/	NEONET
http://ewse.ceo.org	European Wide Service Exchange (EWSE); an information exchange for earth observation
http://slipper.ip.lu/cesd/rsprg.htm	Remote sensing and statistics
http://www.ccrs.nrcan.gc.ca/common/comndexe.html	Index of RS glossaries and acronyms
ftp://gis.queensu.ca/pub/gis/docs/gissites.html	Internet GIS and RS information sites
http://head-smashed-in.ccm.emr.ca/naismap/naismap.html	NAISMap Home Page
http://www.eurimage.it/einet/einet_home.html	EiNet(sm) Home Page
http://www.vtt.fi/aut/ava/rs/virtual	The World-Wide Web Virtual Library: Remote Sensing
ftp://daac.gsfc.nasa.gov/data/avhrr	Directory of /data/avhrr
http://edcwww.cr.usgs.gov/landdaac/1KM/comp10d	AVHRR 10-day composite
METADATA	
http://www.geoplaza.nl/ravi/owa/splash	Dutch National Clearinghouse Geo-information
http://idefix.geodan.nl/	Dutch National Clearinghouse
http://www.ign.fr/megrin/gddd/gddd.html	European Metadata
http://130.11.52.178/metaover.html	Web-based FGDC Metadata Entry System
http://idefix.geodan.nl:8080/pelcom/metaform.html	ELCM meta data entry form
http://www.geodan.nl/esmi/index.htm	The European Spatial Metadata Infrastructure Clearinghouse
http://fgdc.er.usgs.gov/Clearinghouse/Clearinghouse.html	Federal Geographic Data Committee Clearinghouse

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