Gerard, F.; **Petit, S.**; **Smith, G.**; **Thomson, A.**; **Brown, N.**; Manchester, S.; **Wadsworth, R.**; Bugar, G.; Halada, L.; Bezak, P.; Boltiziar, M.; De badts, E.; Halabuk, A.; Mojse, M.; Petrovic, F.; Gregor, M.; Hazeu, G.; Mucher, C.A.; Wachowicz, M.; Huitu, H.; Tuominen, S.; Kohler, R.; Olschofsky, K.; Ziese, H.; Kolar, J.; Sustera, J.; Luque, S.; Pino, J.; Pons, X.; Roda, F.; Roscher, M.; Feranec, J..
2010 Land cover change in Europe between 1950 and 2000 determined employing aerial photography. *Progress in Physical Geography*, 34 (2). 183-205.
10.1177/0309133309360141

Cover Page:

Manuscript word count: 9123 (including references - 940, figure and table headings - 582)

Corresponding author:

France GERARD, Centre for Ecology and Hydrology Wallingford, Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire, OX10 8BB, UK. tel: +44(0)1491 692383, fax: +44(0)1491 692424, e-mail: ffg@ceh.ac.uk

Contacts points and full addresses for co-authors:

Lubos HALADA, Institute of Landscape Ecology of the Solvak Academy of Sciences (ILESAS), Stefanikova 3, 81499 BRATISLAVA, Slovakia. tel: + 421 2 52493882, fax: +421 2 52494508, e-mail: lubos.halada@savba.sk

M. GREGOR, GIM nv, Interleuvenlaan 5, Researchpark Haasrode, 3001 HEVERLEE, Belgium. tel: +352 26 44 09 55, fax: +352 26 44 09 56, e-mail:mirko.gregor@gim.lu

Sander MUCHER, Alterra B.V. (ALTERRA), Droevendaalsesteeg 3 a, 6700 AA WAGENINGEN, The Netherlands. tel: +31 317 474 320, fax: +31 317 419000, e-mail: sander.mucher@wur.nl

Jan. KOLAR, GISAT s.r.o., Charkovská 7, 10100 Praha 10, Czech Republic. tel: +420 2 7174 1935, fax: +420 2 7174 1936, e-mail:Jan.kolar@gisat.cz

Sandra. LUQUE, Cemagref - Institute for Agricultural and Environmental Engineering Research, 2 rue de la papeterie, BP 76, F-38402 St-Martin-d'Hères, cedex, France, tel: +33 (0) 476762827, fax: 33 (0) 476513803 , e-mail: sandra.luque@cemagref.fr

Konstantin. OLSCHOFSKY, Universitaet Hamburg, Moorweidenstrasse, 18, 20148 Hamburg, Germany. tel: +49 40 73962 107, fax: +49 4042891 2665, e-mail:k.olschofsky@holz.uni-hamburg.de

Joan. PINO, Centre de Recerca Ecologia I Aplicacions Forestals (CREAF), establish in Univ. Autonoma de Barcelona – Edifici C, 08193 BELLATERRA, Spain. tel: +34 93 581 46 65, fax: +34 93 581 41 51, e-mail: Joan.Pino@uab.es

Land cover change in Europe from 1950 to 2000 determined from aerial photography.

F. GERARD*[1], G. BUGAR[2], M. GREGOR[3], L. HALADA[2], G. HAZEU[4], H. HUITU[5], R. KÖHLER[6], J. KOLAR[7], S. LUQUE[8], C.A. MÜCHER[4], K. OLSCHOFSKY[6], S. PETIT[1], J. PINO[9], G. SMITH[1], A. THOMSON[1], M. WACHOWICZ[4], P. BEZÁK[2], N. BROWN[1], M. BOLTIZIAR[2], E. DE BADTS[2], J. FERANEC[10], A. HALABUK[2], S. MANCHESTER[1], M. MOJSE[2], F. PETROVIC[2], X. PONS[9], F. RODA[9], M. ROSCHER[9], J. SUSTERA[7], S. TUOMINEN[5], R. WADSWORTH[1], H. ZIESE[6]

[1] Centre for Ecology and Hydrology Wallingford (CEH), UK.

[2] Institute of Landscape Ecology of the Solvak Academy of Sciences (ILESAS), Slovakia.

[3] GIM nv, Belgium.

[4] Alterra B.V. (ALTERRA), The Netherlands.

[5] The Finnish Forest Research Institute (METLA), Finland.

[6] Universitaet Hamburg, Germany.

[7] GISAT s.r.o., Czech Republic.

[8] Cemagref - Institute for Agricultural and Environmental Engineering Research, France

[9] Centre de Recerca Ecologia I Aplicacions Forestals (CREAF), Spain.

[10] Institute of Geography of the Slovak Academy of Science, Slovakia.

Keywords: Land cover change, historical, Europe, aerial photographs, BIOPRESS, monitoring biodiversity, NATURA 2000

Running Title: Land cover changes in Europe from 1950 to 2000

Abstract

BIOPRESS (‘Linking Pan-European land cover change to pressures on Biodiversity’), a European Commission funded ‘Global Monitoring for Environment and Security’ project produced land cover change information (1950–2000) for Europe from aerial photographs and tested if this information is suitable for monitoring habitats and biodiversity. The methods and results related to the land cover change work are summarised. Changes in land cover were established through 73 window and 59 transect samples distributed across Europe. Although the sample size was too small and biased to represent the spatial variability observed in Europe, the work highlighted the importance of method consistency, the choice of nomenclature and spatial scale. The results suggest different processes are taking place in different parts of Europe: the Boreal and Alpine regions are dominated by forest management; abandonment and intensification are mainly encountered in the Mediterranean; urbanisation and drainage are more characteristic of the Continental and Atlantic regions.

1 Introduction

Our environment is continuously undergoing change caused by a combination of social, economic and natural processes which operate at all scales from the local to the global. The present most prominent changes we are witnessing and which have recently been confirmed by the fourth IPCC summary report (IPCC 2007) are those caused by global climate change. Not least important and related to climate change are the changes in the use of our environment and natural resources. The Convention on Biological Diversity which was agreed in 1992, and more recently, the UN Millennium Ecosystem Assessment, which carried out a first global ‘scientific appraisal of the condition and trends in the world’s ecosystems and services they provide’(Millenium Ecosystem Assessment 2005), demonstrate a growing international awareness in the importance of maintaining ‘healthy’ ecosystems to preserve life as we know it today.

In Europe several national and international legal mechanisms (e.g. Amsterdam Treaty 1997, Habitats Directive, EU Common Agricultural Policy) have been set up to protect the European environment, ensure sustainable use of its natural resources and maintain an acceptable level of biodiversity. Protection requires monitoring and so in Europe these mechanisms have encouraged the establishment of a wide range of, often unconnected national and regional, environmental monitoring activities. Without a common method and/or reference point it has been difficult to consolidate or compare the findings of such activities to build up an overview of the environmental changes occurring across Europe.

GMES (Global Monitoring for the Environment and Security, http://ec.europa.eu/gmes/index_en.htm) and INSPIRE (Infrastructure for Spatial Information in the European Community, http://www.ec-gis.org/inspire/) are initiatives which began shortly after the start of the millennium. GMES is driven jointly by the European Space Agency and the European Commission and aims to establish a European capacity for monitoring the environment by 2008. This involves, amongst others, the consolidation of existing national, regional monitoring networks and the development of benchmark datasets. INSPIRE recently delivered the European INSPIRE directive, which entered into force on 15 May 2007, laying down rules for the establishment of an infrastructure for spatial information in Europe, 'in support of environmental policies and policies or activities which may have a direct or indirect impact on the environment'. With the establishment of a global commitment to the Global Earth Observation System of Systems (GEOSS) in 2005, GMES and INSPIRE became part of Europe's contribution to GEOSS.

This paper gives an overview of a European Commission funded GMES project BIOPRESS ('Linking Pan-European land cover change to pressures on Biodiversity'). The initial focus of BIOPRESS was to produce a standardised historical (1950–2000) land cover change product that would be extendable to the pan-European level and to identify and report to GMES the technical, scientific, all aspects of data accessibility, data quality, organisational, legal and institutional hurdles encountered at each stage of the development and production process. BIOPRESS also tested the hypothesis that remotely sensed derived land cover is suitable for monitoring habitats and biodiversity. The aim of this paper is to summarize the key steps and main results related to the land cover change work. Further publications from the team have presented specific methodological developments and more detailed results (e.g. Thomson et al. 2007).

2 Background

The clearest indication of a change in the environment is when the land cover changes. Information on land cover and land cover change is believed to be one of the benchmark datasets which requires a common approach in recording across countries because of its value as an environmental change indicator (Wickham *et al.* 2000; Weber and Hall 2001; Pereira and Cooper 2006). At global, continental and regional level, land cover type products have and are being produced which are different in terms of their spatial cover and scale and class definition, their characteristics being determined by the purpose for which the were created and the adopted method. The 1 km IGBP land cover map, for example, was the first global land cover map at a 1 km resolution which was produced using satellite imagery (i.e. 1 km Advanced Very High Resolution Radiometer on board the NOAA satellite series) acquired in 1992-93 (Loveland and Belward 1997). Its 17 cover classes are restricted in number and detail by the source data used and its reliability varies with cover class as this map was specifically produced to establish the global distribution of the main forest types (Loveland *et al.* 1999). Subsequent global land cover maps, also derived from satellite imagery, are the 1 km Global Land Cover 2000 database (derived from 1 km SPOT Vegetation sensor data on board the ENVISAT satellite) and the 1 km MOD12Q1 product (derived from the 1 km Moderate Resolution Image Spectroradiometer on board the TERRA and ACQUA satellites) (Friedl *et al.* 2002). Realising the varying needs of different user communities MOD12Q1 represents the globe in five different land cover classifications, one of which is the IGBP classification, another is an 11 class Plant Functional Type classification. The 300 m GlobCover LC v2 product (Arino *et al.* 2005, GlobCover Land Cover v2 2008 database) is currently the most recently developed global product. It is derived from time series of MERIS - ENVISAT imagery acquired from December 2004 to June 2006 and exploits variations in phenology to distinguish thematic cover classes that are compatible with the

FAO Land Cover Classification System, also referred to as the UN Land Cover Classification System (LCCS) (Di Gregorio and Jansen 1998).

The first land cover map produced for Europe is the CORINE land cover map (CLC) which again was derived from satellite imagery acquired in the 1990'ies (i.e. 30 m Thematic Mapper sensor on board the Landsat satellites). But this is where similarities end. The CORINE land cover map (CLC1990) is produced through manual interpretation and has a minimum mapping unit of 25 ha for area features and minimum width of 100 m for linear features (Heymann *et al.* 1993). At its highest thematic level (level 3) it shows 44 classes which describe land cover and use. CORINE land cover has recently been updated using Thematic Mapper imagery acquired in 2000 and a CORINE land cover 2006 is currently under production. Another more recent source of land cover and use data for Europe is provided by the Lucas Survey (Land Use/Cover Area frame statistical Survey) which was first carried out in 2001-03 and repeated in 2005-07. In contrast with the satellite based approaches listed above this survey uses a statistical sampling framework (i.e a two stage sampling design based on an 18 km x 18 km grid and relies on field surveys and aerial photography to determine the class membership of grid points (Gosepath *et al.* 2003). Even though the grid point density is relatively high, LUCAS cannot deliver spatial statistics.

Land cover change can be determined using a wide variety of approaches which can be grouped into three main categories: post classification comparison, updating or backdating from a base line classification and direct detection of change by combining multi-temporal source data (i.e. mostly airborne or satellite imagery). (Coppin *et al.* 2004) provide a comprehensive review, including technical advantages and disadvantages, of the post classification comparison and direct change detection approaches that have been developed to date. Both types of approaches generally are based on automated image processing and classification techniques. Backdating or updating from a baseline classification is very much associated with manual interpretation of aerial or satellite imagery. The main issue with post classification comparison is that the accuracy of the change detection will be at best as good as the combined accuracy of the two independent classifications (Coppin *et al.* 2004), while, backdating and updating are affected by the accuracy of the baseline classification. The direct detection methods are designed to circumvent this problem, but rely more heavily on consistency (with respect to for example timing of acquisition, quality, sensor type) in the source data. Although the general consensus is that reliable change detection requires consistency in the used source data and classification system between time points, one small advantage of post classification comparison is that, if the independent land cover products are based on different classification systems it still is possible to derive change statistics provided that the classification systems are thematically linked (i.e. harmonised, (Wyatt and Gerard 2001). (Comber *et al.* 2004; Fisher *et al.* 2006) advocate a fuzzy, probabilistic approach, whilst (Lepers *et al.* 2005) who were synthesising global land cover change information and were dealing with 49 different data sets, would adopt the definitions of a particular data set which would vary with the type of change that was under scrutiny. The other approaches inherently assume the use of the same classification system at each time point. In this case, the initial choice or design of a classification system (land cover and or use) is crucial as there is no such thing as a standardised land cover classification system that will satisfy all possible national, European or global stakeholders concerned with environmental monitoring. The FAO land cover classification system based on a system of attributes (Di Gregorio and Jansen 1998) is one of the best attempts to date to provide a common but still flexible system.

Both IGBP and CORINE land cover are some of the few global/continental land cover products which can provide change statistics for a ten year period. CLC2000 was produced through the manual updating of CLC1990. In this case the updating was also seen as an opportunity to correct for errors observed in the 1990 layer (Perdigao and Annoni 1997). As a result CORINE updating produced simultaneously a CLC2000 layer, a corrected CLC1990 layer, and change detection statistics observed over a 10 year period. Table 1 below gives the change statistics calculated for CLC thematic level 1, the lowest thematic level. The table shows that ‘Agricultural Areas’ underwent the biggest changes: ~814 thousand ha (i.e. 0.2 % of the 359 million ha with CORINE coverage) was lost to ‘Artificial Surfaces’ and while in some areas of Europe ~ 406 thousand ha was converted to ‘Forest and semi natural areas’, in other areas ~ 368 thousand ha of ‘Agricultural Areas’ were reclaimed from ‘Forest and semi natural areas’.

Insert Table 1

With respect to Europe, there have been three additional instances where change detection was carried out for a period longer then ten years. Two of these activities focused on obtaining change information for certain key areas of Europe: the European coastline (i.e 1970-1990, the LACOAST project, (Perdigao and Christensen 2000)) and the peri-urban zone of 25 large cities (i.e.1950-1990, the MURBANDY/MOLAND project, (Lavalle *et al.* 2001; Lavalle *et al.* 2002) and were both based on the manual backdating of CLC1990 using MSS (Multi-Spectral Scanner on board the early Landsat satellites) and aerial photography respectively. The LACOAST results showed an urban gain along most parts of the European Coastline mainly at the cost of agricultural and forested areas (Figure 1). MURBANDY/MOLAND found a general increase in urban sprawl ranging from 25 % (Ruhrgebiet, Germany) to 270 % (Algarve, Portugal) of the original urban area recorded in the 1950s with an average of 117 % (Table 2). The average loss of natural and agricultural land to urban sprawl was 22.0 % with Iraklion, Greece loosing the most (41.3 %) and Dresden, Germany the least (7.3 %). The third instance carried out manual backdating of CLC1990 with 1970s MSS imagery for four neighbouring Eastern European Countries, namely, Czech Republic, Slovakia, Romania and Hungary (Feranec *et al.* 2000). The work highlighted national variations, where, although deforestation was the most important change for Czech Republic, Slovakia and Hungary, the net amount of forest lost would vary from 52.5 %, to 25.9 % and 10.1 % respectively. Both Romania and Slovakia witnessed substantial losses and gains of intensively cultivated land, respectively 26.2 % and 23.5 % loss and 21.6 % and 34.3 % gain. This also occurred in Hungary and the Czech Republic, but to a lesser extend.

Insert Figure 1

Insert Table 2

BIOPRESS's focus was to determine how past changes in land cover from 1950 to 2000 may have impacted on habitats and their associated biodiversity. Similarly to LACOAST and MURBANDY/MOLAND a manual backdating approach was adopted, but the aim of BIOPRESS was to capture overall patterns of change that had occurred in the main bio-geographical zones of Europe, with a focus on protected areas, and to develop ways of converting this information into measures of impact on biodiversity. Aerial photography was chosen as this was the only type of data that remained consistent from the 1950s to the present.

3 Methodology

The applied method was designed to produce land cover change information collected in an operational and consistent manner from samples which are representative of the main bio-geographical regions of Europe and including areas of importance for European biodiversity (NATURA 2000 sites - European (Commission 2003). Land cover is classified according to the

CORINE Land Cover nomenclature with 44 classes at the highest level 3 (Heymann *et al.* 1993). Change was captured by means of ‘backdating’ where the older dataset is compared against the most recent. There were two approaches with different scale of interpretation:

- For regions (‘windows’) of circa 30 km x 30 km in size, aerial photographs of the 1950s were compared against CLC90. A minimum mapping unit of 25 ha was used which is in line with the standard CORINE Land Cover minimum mapping unit.
- For transects of 2 km x 15 km, aerial photography from 1950, 1990 and 2000 were interpreted at a more spatially detailed minimum mapping unit of 0.5 ha.

The whole process involved 5 key steps:

- the selection of NATURA 2000 sites to position the windows and transects,
- the search, acquisition and pre-processing of aerial photographs,
- the manual interpretation of the photographs
- the assessment of the quality of the interpretation and
- the storage of interpretation results and its associated data and metadata in a central database.

3.1 Sampling of sites

To ensure that the results of the analysis of land cover change could be interpreted in the wider European context, windows and transects that are truly representative of the diversity of European biogeography would have to be selected. However, the diversity in land cover and related local landscape features across Europe is very high and not randomly distributed so that a representative sample would need to be stratified and large in size. Several external factors constrained the sampling strategy. Budgetary constraints required an approach which aimed at ensuring the highest benefit from a limited (i.e. affordable) number of sample sites. Stakeholders were expecting the data not only to describe general patterns of change across the European countryside, but also to provide comparisons between changes inside and outside protected nature reserves (i.e. NATURA 2000 sites). As a result the NATURA 2000 network became the starting point from which the windows and transect sites were selected. The Biogeographical Regions Map of Europe (BRME) (http://www.eea.europa.eu) was used for stratification providing close linkage to the Habitats Directive, Birds Directive, Emerald Network and NATURA 2000.

Direct access to the NATURA 2000 database which contains location and habitat description of all NATURA 2000 sites in Europe proved impossible because of restrictions on access to this source. So, a super-set of 229 NATURA 2000 sites of European importance were identified by an external expert (Pierre Devillers of the Royal Belgian Institute of Natural Sciences) with access to the database. Pierre Devillers used a combination of information within the NATURA 2000 database and his expertise to select representative and important sites across Europe.

Next, a selection from the super-set of 229 sites was made, aimed at (i) generating a BRME area-weighted sample of 100 windows and (ii) representing as many of the 4 EUNIS Annex-I habitats (http://eunis.eea.europa.eu/introduction.jsp) that were identified by the stakeholders, as possible (i.e. ‘Freshwater habitats’, ‘Natural and semi-natural grassland formations’, ‘Raised bogs and mires and fens’ and ‘Forests’). In cases of equal number of habitats present per BRME region, window selection was done randomly. In parallel the partners set out to select between eight and ten transects per partner country (UK, Finland, Belgium, The Netherlands, Germany, Spain, and Slovakia) according to the following rules:

- Each transect is located inside a super-set window site and contains at least part of a NATURA 2000 site.
- Select two representative transects for each of the four pre-defined Annex-I habitat types.
- For additional transects, nationally important NATURA 2000 sites should be considered.
- Transects should represent a gradient of pressures on land cover starting from the edge of a NATURA 2000 site and bearing towards an intensively used area.

3.2 Aerial photography

The search criteria for the aerial photography were:

- Photo cover for the windows must include the NATURA 2000 centre point.
- The location of the windows can be shifted and/or rotated provided that the NATURA 2000 centre point is at least 5 km from the edge of the photo cover. The location of transects can be shifted as long as selection criteria (see above) are not compromised.
- The photographic coverage is at least 75 % of the window. Cloud coverage is less then 10 % and imagery is snow free.
- The timeframe for windows is between 1943 and 1959 and for transects between 1943-1959, 1988-1992 and 1998-2002.
- The scale of the photographs is between 1:25000 and 1:60000 and between 1:10000 and 1:25000 for windows and transects respectively.

It was clear from the beginning that these preset criteria combined with external factors such as data availability, accessibility and cost would affect the final number of windows and transects. Also depending on the source of the photos, pre-processing was expected to involve any number of the following steps: (1) scanning of hard copy, (2) introducing fiducial marks, (3) ortho-rectification, and mosaicking.

3.3 Manual photo interpretation

The problem with most European data sets is that they are inconsistent across regions and/or countries. In this project one of the main steps taken to achieve consistency was the design of two manuals for photo interpretation (Feranec *et al.* 2004; Feranec *et al.* 2004b): one clarifying the CLC level 3 class definition with respect to 1:25 000 a 1:60 000 scale panchromatic aerial photos (minimum mapping unit of 25 ha) and providing rules for backdating CLC90 with photos (windows), another describing the CLC level 3 classes with respect to 1:10 000 a 1:25 000 scale photos (minimum mapping unit of 0.5 ha) and providing rules for change detection from photo–to–photo interpretation (transects). The other steps taken to ensure consistency were training of the interpreters and quality assessment.

The interpretation approach adopted for the windows was to overlay the CLC90 polygons on mosaics of 1950s photos and to focus on identifying change. The original 1990s Landsat scenes from which CLC90 is derived were, where available, used to distinguish real changes from changes due to errors in the CLC90 database. Only the changes believed to be real were recorded. The resulting output was a CLC50 to CLC90 change matrix for each window. The approach adopted for the transects was to interpret the most recent aerial photographs first and then backdate (Figure 2). The first interpretation has polygons labeled with the land cover of 2000 (CLC00). In the second interpretation, using the aerial photos of 1990 (CLC90), only new lines are added. The newly created polygons receive a label with the land cover of 1990 and also 2000. For polygons that did not change, the attributes of CLC00 are copied to CLC90. When the interpretation of 1990 is finished the same procedure can be followed for 1950 (CLC50). This ensures that the interpreter only adds lines and creates polygons if the land cover has changed. The results are polygons with multiple attributes which were used to produce change statistics.

Insert Figure 2

3.4 Quality Assessment

Quality assessment provides a measure of accuracy of the interpretations. The general principle of any quality assessment (QA) procedure consists of comparing the obtained results with independent data. However, especially for the 1950s, no comparable independent dataset exists, so the QA procedures that were developed aimed at establishing a measure of consistency between interpreters. For the windows, an independent expert (controller) would reinterpret sampled areas (5 km x 5 km verification units) that were identified within a selection of windows by placing a square grid 5 km x 5 km over the window area and looking for 5 km x 5 km areas which include the most commonly occurring types of land cover changes of the country the window represented or where strange and unexpected types of changes were observed. The windows selected were those which showed the highest rate of change within one country. In total circa 7 % of the total area interpreted was verified. The consistency R (%) for a given window was calculated as: R= A/N*100 where A is the number of identical changes (i.e. in both size and type) and N is the number of all changes in given window identified by controller and interpreter. A window is rejected and returned to the interpreter for improvement when its consistency rate is below 85 %.

For the transects, a more extensive approach was adopted aimed at evaluating the thematic, geometric and change detection aspects of the interpretation. Here 18 transects were reinterpreted six times using a point grid sample, each time by a different independent controller and five transects were reinterpreted fully by one independent controller. Only the results based on the point reinterpretation that assess the consistency in class identification (i.e. thematic) and change detection are included in this paper. The thematic consistency between controller and interpreter was calculated by means of confusion matrices (Provost and Kohavi 1998). Cover class consistency $\hat{p}_c$ and overall thematic consistency $\hat{p}$ were calculated as follows:

$$\hat{p}_c \quad \frac{\mathrm{a_c}}{n_c * 6}$$

where a_c is the number of grid point observation identified as class C on both occasions (by one of six controllers and interpreter), and n_c is the total number of grid points identified as class C by the interpreter. As one interpretation is controlled independently by six observers, it has to be weighted by the number of observers.

and

$$\hat{p} \quad \frac{\mathrm{a}}{n * 6}$$

where *a* is the number of grid point observations that identified the same class on both occasions (by one of six controllers and interpreter), and *n* is the total number of grid points.

The consistency in detecting change was done by comparing the land cover changes statistics calculated from the interpretation of the local interpreter and the controllers for the periods between 1950-2000, 1950-1990 and 1990-2000.

4 Results

4.1 Window and transect sites

Aerial photos of the 1950s were obtained, processed and interpreted for 73 window sites and 59 transect sites. The 73 windows are distributed across 17 countries, 36 are located in the eight partner countries and 37 outside partner countries (Figure 3 and Table 3). The total interpreted window area is 59297 km^2 and the total interpreted transect area is 1807 km^2. While for the transect sites full area coverage was achieved in most cases (i.e. 30 km^2 per transect) the resulting area interpreted per window site depended on the available photo-coverage and CLC90 coverage (Figure 4). 36 of the 73 windows achieved more then 750 km^2 coverage. The lowest coverages achieved were for windows in Hungary and Romania. The exceptionally large average size of windows in Poland is caused by the merging of two partially overlapping windows into one.

Insert Figure 3, Table 3 and Figure 4

Figure 5 compares the relative area distribution per BRME zone, with the relative area distribution achieved by transect and window sites and the relative number distribution of the original 229 super-set sites. Note that there are no transects within the Pannonian zone, although there are windows. In general, the Alpine and Atlantic zones are over-sampled, whereas the Boreal zone is under sampled. Note also that the expert was biased in his selection towards NATURA 2000 sites located in the Mediterranean and the Pannonian zones.

Insert Figure 5

The variability of the BRME zones and the window and transects sites in terms of CORINE land cover class proportions was investigated in detail to assess the use of the BRME as a spatial framework for extrapolating the land cover and land cover change data measured from the sites. Figure 6 shows that the sample size is too small to differentiate between the biogeographical regions due to the large variability in land cover distributions within the regions and the sites. The use of the NATURA 2000 network as the focus for the sampling has also influenced the results returned by the windows and transects as both are biased toward semi-natural conditions. As a result both the window and transect sites are less representative of the BRME zones as a whole than a random stratified sample would be.

Insert Figure 6

Although the BRME was considered to be the most suitable stratification for BIOPRESS given its wide user support and the small number of zones, the overall conclusion of the analysis was that the nature of the BRME and BIOPRESS sampling scheme were not appropriate for extrapolation of land cover change results across Europe with any reasonable level of confidence. The real issue is the number of samples and their distribution. The window areas probably represent no more than 1.5 % of Europe which is inadequate for a region with such varied landscapes molded by nature and humans. At a workshop (Jongman, personal communication) a team of experts estimated that approximately 5250 sites of 1 km^2 in size distributed in a stratified random manner using the much more detailed 350 class European landscape database for stratification (i.e. LANMAP2 (Jongman *et al.* 2006) would provide a statistically reliable estimate of all European habitats (i.e 15 sites of 1 km^2 per stratum). If the aim is to compare the situation inside and outside protected nature reserves an additional sample set representative of the nature reserves would have to be added.

4.2 Quality of interpretation

A total of 204 verification units were assessed located in 43 of the 73 windows. The average acceptable consistency rate achieved was 94 %. Table 4 gives the overall thematic consistency calculated for the three time points and the three CLC classification levels, using the results from all grid points of all transects. As the resulting number of grid points differed between individual transect, a transect specific weighting was assigned to each point. The weighting factor was defined as the total transect area, divided by the number of validation points. The time point was found to have no influence on thematic consistency. Increasing thematic detail at the other hand has a high impact, causing a reduction in interpreter's consistency from 91 % at level 1 to ~ 54 % at level 3.

Insert Table 4

At individual transect level, the thematic consistency shows the same trends as observed for the overall thematic consistency. However, due to the specific landscape characteristics of some of the sites we found in some cases that interpretations at CLC level 1 and 2 achieved similar levels of consistency which were very different from the consistency achieved at level 3, whilst other transects show similar consistency at level 2 and 3 (e.g. Table 5). Table 6 shows the overall consistency in detecting change at CLC level 3. In 77 % of the cases the local interpreter and the controllers agree on the changes. In 14 % of the cases the controller found changes that were not detected by the local interpreter and 9 % of changes are identified by the local interpreter but not by the controller.

Overall, the interpretation team managed to maintain a high level of interpretation consistency. This means that the team's interpretation of cover classes and their changes were found to be either consistently correct or incorrect. At CLC levels 1 and 2 consistency is very high (~91 % and ~81 % respectively). At CLC level 3 only ~ 54 % of the time the interpreters agree on the cover class. The QA enabled us to identify which classes at what thematic level where prone to confusion. For example, the importance of the conversion between arable field and grassland is expected to be inflated as the quality assessment highlighted a consistent confusion between grassland and arable fields. The main causes for confusion for both, the window and transect interpretations, were ambiguous CLC class definitions, and the similar appearance of CLC classes on panchromatic aerial photography. An error propagation analysis (not shown here) based on the QA results also enabled us to establish that aerial photo quality was another main factor introducing confusion. What we were not able to establish, due to lack of independent reference data, is how often and in which cases interpreters agreed wrongly.

Insert Table 5 & Table 6

4.3 Observed land cover and land cover changes

Although the size and location of the samples did not allow for an extrapolation across Europe to produce a European map of change, the data collected still produced some interesting results. Table 7 shows that the European landscape is mainly a mixture of agricultural land (~ 30 % + ~ 10 % pastures), forests (~ 35 % + ~ 11 % semi-natural areas) with an increasing amount of urban fabric (~ 7 %). Figures from the 'DOBRIS assessment' which were estimated from an aggregated (to a 250 m grid) and generalized CORINE land cover 1990, suggest a higher proportion of land covered by arable land and a smaller proportion covered by urban fabric: forest cover 33 %, arable land 24 %, extensive agriculture and mixed land use 24 %, permanent crops 15 %, permanent grassland 2 % and urban areas 1 % (Stanners and Bordeau 1995). The agricultural areas have seen a decrease in areas of complex cultivation, whilst forested areas show an increase for all forest types (broadleaved, conifer and mixed forests) and a slight decrease in transitional woodland and shrub (Figure 7).

Insert Table 7, Figure 7, Figure 8

The total extent of land cover changes that have occurred within all windows account only to an average of 10 % of the total measured area (the average is taken from the three thematic interpretation levels). In other words, 90 % of the measured window areas have shown no change of land cover at all. Increasing the spatial resolution from 25 ha minimum mapping (windows) unit to 0.5 ha minimum mapping unit (transects) invariably led to an average of 2.8 times more area being identified as having changed. This increase represented on average 7 % or 25 % of the total area when interpreted at level 1 (five cover classes: Artificial areas, Agricultural areas, Forests and semi-natural areas, Wetlands, Water bodies) or level 3 (44 cover classes) respectively. An increase in thematic detail, from 5 cover classes in level 1, to 44 classes in level 3, not only caused an increase in the amount of change detected but also altered the trends observed in the annual rate of change (Figure 8). Where at level 1 the transect data is suggesting a slow down in the most recent ten years, at level 3 changes in the last ten years are more evident in particular for Belgium, Germany and UK. The aggregated level 1 does not provide evidence of changes happening at a finer thematic level as shown from the analysis done at level 2 and 3. This suggests that many of the changes have occurred within the more general landscape level 1 categories of build up, agricultural land and forest/semi-natural land.

The dynamics of the changes can be better understood when analysing the land cover flows for the windows and transects. With a classification system of 15 (level 2) or 44 classes (level 3) theoretically 210 or 1892 different types of land cover change are possible. Figure 9 show the largest cover flows observed in level 2 and level 3 from the windows (≥ 10000 ha or 0.2 % of total interpreted area for 1950-1990) and transects (≥ 1300 ha or 0.7 % of total interpreted area for 1950-1990; ≥ 300 ha or 0.2 % of total interpreted area for 1990-2000) in terms of total area changed. The most important land cover conversions were found to be the following:

- From heterogeneous agricultural areas (24 or 242, 243) to urban fabric (11 or 112), to arable land (21 or 211) and to forest (31 or 311, 312).
- From arable land (21 or 211) and pastures (23 or 231) to urban fabric (11 or 112) or industrial, commercial, and transport units (12).
- From shrub and/or herbaceous vegetation association (32 or 324) to forests (31 or 311,312,313), and its inverse conversion, i.e. from forest to shrub and/or herbaceous vegetation association.

The increased spatial detail of the transects highlighted two additional conversion types:

- From pastures (231) to shrub and/or herbaceous vegetation association (324).
- From arable (211) land to pastures (231) and its inverse conversion.

The importance of the latter conversion highlighted may have been inflated by the consistent difficulty in differentiating grassland from arable field on panchromatic photography, even though rotation between arable crops and grasslands is common practice in many European countries. From the flows it is not clear how many of the inverse conversions observed relate to opposite changes which are occurring in different places or to areas which have been converted back to their 1950s state. Figure 10 shows the proportion of the interpreted transect area that underwent change twice subdivided into the proportion that has reversed back to its original 1950s state (i.e. inverse conversion) and the proportion that changed into a different state twice (i.e. forward conversion). At thematic level 2, Finland and Slovakia showed both, the largest proportion of interpreted area that underwent change twice and the largest proportion of area showing an inverse conversion. Interestingly at thematic level 3 the overall area proportions have increased substantially for all countries except Finland, but more striking, for Finland the area proportion undergoing forward and inverse conversion is reversed. Further investigation and comparison of the Finland and Slovakia cases show different patterns of change which are dependent on the history and economy of the region. For Finland, where forest management is a key part of its economy, the inverse conversions at level 2 and the forward conversions at level 3 represent in most instances the same changes which are associated to a forest type ‘A’ (e.g. 313) – non-forest (324) – forest type ‘B’ (e.g. 312) conversion. Slovakia, at the other hand, shows a large proportion of inverse conversions at both thematic levels 2 and 3. Here, previously collectivized and intensified arable land has, since 1990, slowly been reclaimed, abandoned or restituted to co-operatives (Kuemmerle *et al.* 2006), which could explain the proportions of land (28 % and 4 % of land that underwent change twice – Figure 11) showing an inverse conversion from 242, ‘complex cultivation’ to 211, ‘non-irrigated arable land’ and back and 231, ‘pastures’ to 242 ‘complex cultivation’ and back. Forest management is likely to be the main explanation for the transitions from 231 and 324, ‘transitional woodland shrub’ to 31*, ‘forest’ and back.

Insert Figure 9, Figure 10 and Figure 11

To determine whether characteristic regional patterns of change could be observed at European level, the 1892 different types of possible land cover change (CLC level 3), observed for the period 1950-1990, were translated into six specific environmental processes using a land cover flow to pressures conversion matrix:

1. Agricultural Intensification: includes agricultural conversions as well as cases in which human-altered areas become transformed into a more intensive practice by changing the natural cover.
2. Land Abandonment: includes the cropping cessation and conversion into early successional, herbaceous habitats. The transition to woody, later-successional habitats has been considered as a Mediterranean extension of afforestation.
3. Afforestation: includes the conversion of open (more or less natural) habitats into forests or macchias.

4. Deforestation: we have distinguished deforestation from afforestation instead of considering the first as a relaxation of the second. Both are in fact affecting biodiversity in different ways.
5. Drainage: in a broad sense, includes all changes affecting aquatic habitats that are transformed into more terrestrial ones: disappearance of wetlands, but also changes in rivers and in estuarine areas. We have included land gain from intertidal and sea areas in the Netherlands, as well as the lost of peatlands drained due to agricultural practices or replaced by forests in Finland.
6. Urbanisation: includes the transformation to urban covers but also to related covers (road system, leisure areas, construction sites, etc.)

Variations in terms of these pressures (expressed as % window area) at play in the windows were assessed by means of a detrended correspondence analysis (DCA, CANOCO 4.5). In addition to individual windows, the BRME regions (as the barycentre of sets of windows located within each region) and the six pressures (as barycentre of individual window scores) were projected on the ordination plan. The first ordination plan shown on figure 12 explains 50 % of the variation in the proportion of land cover change accounted for by the six pressures. The first axis separates landscapes mainly affected by afforestation and deforestation, two pressures located close together on the plan; those are mainly found in Boreal and Alpine regions, two areas which are dominated by forest management activities. The second axis singles out changes associated with agricultural activities, mainly abandonment and intensification which are located close together on the plan and are mainly encountered in the Mediterranean region, suggesting that in this region, the two processes occurred simultaneously but not necessarily in the same place. The same pattern was found to have occurred in Romania (Feranec *et al.* 2000) which in BIOPRESS is classified as Continental or Alpine. Finally, urbanisation and drainage are shown to be more characteristic of the Continental and Atlantic regions.

Insert Figure 12, Table 8

5 Discussion

Because of the sampling size and a bias towards areas containing nature reserves, it was not possible to produce statistical reliable estimates of land cover change for the six BRME regions of Europe based on the BIOPRESS sites. BIOPRESS was a demonstration project testing a methodology that could be applied to monitoring habitats and their biodiversity from pan-European land cover change on an operational basis if adequate sampling was provided. In this context, the project produced some interesting results. The degree of thematic detail and level of spatial detail of the land cover measured will determine the type, amount and rate of change detected. It will also to a certain extent determine the reliability of the results, although other factors such as clarity of definition and the quality of the source data will also play a role. The original choice of nomenclature used to define the land cover, the characteristics of the imaging system and the capability of this system to distinguish the classes defined by the nomenclature is important. For long term land cover change detection, consistency in methodology is key, so the solution is either to have a nomenclature designed independent of the imaging system used or to rely on the long term availability of similar and affordable imagery (with respect to spatial and spectral resolution) (Duhamel 1998).

BIOPRESS, LACOAST and MOLAND/MURBANDY agree that Europe has witnessed an increase in urban sprawl, mainly in the form of discontinuous buildup. Interestingly BIOPRESS found that this is mainly at the cost of arable land (211, 231 or 242) whilst LACOAST also highlights losses of forest to urban and MURBANDY losses of natural areas to urban. Bearing in mind that all three findings are based on biased samples – LACOAST having focused on a 10 km coastline buffer coastline, MOLAND/MURBANDY on large urban centers and BIOPRESS on areas near or surrounding nature reserves - the results suggest that urbanisation is widespread across Europe but that the losers to urban sprawl will depend on the local context.

The BIOPRESS results show different types of changes dominating different regions in Europe. These are likely to have been the result of different social, political and economic processes. One particular example was highlighted in this paper, showing hints picked up by BIOPRESS from the observed differences between Finland and Slovakia. Other more localized and detailed studies clearly demonstrate the importance of these processes at national and local level and their impact on the evolution of the local landscape. For example, (Kuemmerle *et al.* 2006) found distinct differences in the economic and political processes and subsequent changes that occurred following the breakdown of the Soviet Union between three neighbouring Eastern European countries. (Mottet *et al.* 2006) who studied the land use history of eight farms in the French Pyrenees confirmed ‘remoteness’ to be an important generic cause of land cover/use change in the European mountain areas but also detected local specific dynamics. A stratification of the European landscape should therefore, where relevant, take into consideration local social, economic and political backgrounds (Jongman *et al.* 2006).

The methods implemented by BIOPRESS (and LACOAST and MOLAND/ MURBANDY) are only able to determine conversions from one cover type into another. Land cover modifications, where ‘more subtle changes affect the character of the land cover without changing the cover itself’, are generally more common than land cover conversions (Copin and Lambin 2004) and often have a significant negative or positive impact on habitat quality and biodiversity. A good example of land cover modification is the case of agricultural intensification. The ‘agricultural intensification’ detected by BIOPRESS does not include, the subtle changes in, for example, ploughing frequency and fertilizer and pesticide use. Since the ultimate aim of BIOPRESS was to assess how changes in the land cover had impacted on the habitats and their biodiversity, the original idea was to capture some of the subtle changes through the integration of social and economic indicators with the land cover change matrices. However we soon found out that (i) there was very little of such data available for the 1950s, (ii) the more recent data found for Europe varied significantly in spatial and temporal coverage, scale and semantics and (iii) many datasets came with a price tag. Another GMES funded project EUROSION which required a wide variety of coastal related data experienced similar stumbling blocks (EUROSION 2003). Still, BIOPRESS, in its second phase, was required to assess the impact of land cover change on habitats and their biodiversity. Land cover type products derived from remote sensing are often listed as a ‘biodiversity’ or ‘environmental’ indicator suitable for determining trends in habitats and landscape level biodiversity. BIOPRESS demonstrated, by incorporating the land cover change data into biodiversity impact tables (methods and results not shown in this paper) that, although data such as the CLC product can provide valuable information with potential for improvement, there are clear limitations associated to this approach.

6 Acknowledgements

The presented work was carried out in the framework of the BIOPRESS project ‘Linking Pan-European Land Cover Change to Pressures on Biodiversity’ which was partially funded by the European Commission DG Research under the ‘Energy, Environment and Sustainable Development’ programme of the Fifth Framework. The production of both interpretation manuals were funded by the European Topic Centre on Terrestrial Environment. The authors would like to thank Pierre Devillers of the Royal Belgian Institute of Natural Sciences for his vital input with respect to the NATURA 2000 site selection, Stefan Kleeschulte from the European Topic Centre on Terrestrial Environment, Dominique Richard, from the European Topic Centre on Biological Diversity, and Chris Steenmans from the European Environmental Agency (EEA) for their support and valuable advice as representatives of our stakeholder (EEA). Our thanks also go to Robin Standring, specialist in searching historical aerial photo archives (CAR Ltd), whose customer's services to the research team exceeded all expectations.

7 References

Arino, O., Trebossen, H., Achard, F., Leroy, M., Brockman, C., Defourny, P., Witt, R., Latham, J., Schmullius, C., Plummer, S., Laurent H., Goryl P., Houghton, N. 2005: *The GLOBCOVER Initiative. In Proceedings of the MERIS (A)ATSR Workshop 2005 26 - 30 September Esrin*, Frascati: European Space Agency.

Comber, A., Fisher, P., Wadsworth, R. 2004: Assessment of a semantic statistical approach to detecting land cover change using inconsistent data sets. *Photogrammetric Engineering and Remote Sensing* 70, 931-938.

European Commission, 2003: *Natura 2000 and forests: 'Challenges and opportunities'. Interpretation Guide*. Luxembourg, Office for Official Publications of the European Communities.

Coppin, P., Jonckheere, I., Nackaerts, K., Muys, B., Lambin, E. 2004: Digital change detection methods in ecosystem monitoring: a review. *International Journal of Remote Sensing* 25, 1565-1596.

Di Gregorio, A., Jansen, L.J.M. 1998: *Land Cover Classification System (LCCS): Classification Concepts and User Manual*. Rome: Environment and Natural Resources Service, Soil

Resources, Management and Conservation Service, Food and Agriculture Organization of the United Nations.

Duhamel, C. 1998: *Interfaces: Nomenclatures. Luxembourg: CESD-Communautaire.*

Eurosion, 2003: Eurosion Datatset Structure Description, Comission Contract nr: B4-3301/2001/329175/MAR/B3. Toulouse: EADS S&DE.

Feranec, J., Cebecauer, T., Ot'ahel', J. 2004: *Manual of computer aided visual interpretation of aerial B&W photographs*. Bratislava: Institute of Geography, Slovak Academy of Sciences.

Feranec, J., Cebecauer, T., Ot'ahel', J. 2004b: *Photo-to-photo interpretation manual*. Bratislava: Institute of Geography, Slovak Academy of Sciences.

Feranec, J., Suri, M., Ot'ahel, J., Cebecauer, T., Kolar, J., Soukup, T., Zdenkova, D., Waszmuth, J., Vajdea,V., Vijdea, A.-M., Nitica, C. 2000: Inventory of major landscape changes in the Czech Republic, Hungary, Romania and Slovak Republic 1970s - 1990s. *International Journal of Applied Earth Observation and Geoinformation* 2, 129-139.

Fisher, P., Arnot, C., Wadsworth, R., Wellens, J. 2006: Detecting change in vague interpretations of landscapes. Ecological Informatics 1, 163-178.

Friedl, M. A., McIver, D.K., Hodges, J.C.F., Zhang, X.Y., Muchoney, D., Strahler, A.H., Woodcock, C.E., Gopal, S., Schneider, A., Cooper, A., Baccini, A., Gao, F., Schaaf, C. 2002: Global land cover mapping from MODIS: algorithms and early results. *Remote Sensing of Environment* 83, 287-302.

GlobCover Land Cover v2 2008 database. 2008: European Space Agency GlobCover Project, led by MEDIAS-France. 2008. http://ionia1.esrin.esa.int/index.asp

Gosepath, A., Saradeth, S., Relin, A., Richter, R. 2003: *LUCAS Lot 6, Role of photo interpretation in the LUCAS survey*. Munich: European Commission Statistical Office of the European Communities, Eurostat, Unit F-2 Statistics on Agriculture, Environment and Energy.

Heymann, Y., Steenmans, C., Croisille, G., Bossard, M. 1993: *CORINE land cover project - Technical guide*. Luxembourg: European Commission, Environment, Nuclear Safety and Civil Protection.

IPCC, 2007: Summary for Policymakers. In Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L., editors, *Climate Change 2007: The Physical Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge and New York: Cambridge University Press, 1- 18.

Jongman, R. H. G., Bunce, R. G. H., Metzger, M.J., Mucher, C.A., Howard, D.C, Mateus, V.L. 2006: Objectives and applications of a statistical environmental stratification of Europe. *Landscape Ecology* 21, 409-419.

Kuemmerle, T., Radeloff, V.C., Perzanowski, K., Hostert, P. 2006: Cross-border comparison of land cover and landscape pattern in Eastern Europe using a hybrid classification technique. *Remote Sensing of Environment* 103, 449-464.

Lavalle, C., Demicheli, L., Kasanko, M., McCormick, N., Barredo, J., Turchini, M., da Graça Saraiva, M., Nunes da Silva, F., Loupa Ramos, I., Pinto Monteiro, F., Caetano, M. 2002: *Towards an urban atlas. Assessment of spatial data on 25 European cities and urban areas*. Copenhagen: European Environment Agency.

Lavalle, C., Demicheli, L., Turchini, M., Casals-Carrasco, P., Niederhuber, M. 2001: Monitoring megacities: the MURBANDY/MOLAND approach. *Development in Practice* 11, 350-357.

Lepers, E., Lambin, E., Janetos, A., DeFries, R., Achard, F., Ramankutty, N., Scholes, R. 2005: A synthesis of information on rapid land-cover change for the period 1981-2000. *Bioscience* 55, 115-124.

Loveland, T.R., Belward, A.S. 1997: The IGBP-DIS global 1km land cover data set, DISCover: first results. *International Journal of Remote Sensing* 18, 3289-3295.

Loveland, T. R., Zhu, Z., Ohlen, D.O., Brown, J.F., Reed, B.C., Yang, L. 1999: An Analysis of the IGBP Global Land-Cover Characterization Process. *Photogrammetric Engineering and Remote Sensing* 65, 1021-1032.

Millenium Ecosystem Assessment. 2005: Ecosystems and human well-being: Synthesis. Washington, DC.: Island Press.

Mottet, A., Ladet, S., Coque, N., Gibon, A. 2006: Agricultural land-use change and its drivers in mountain landscapes: A case study in the Pyrenees. *Agriculture Ecosystems & Environment* 114, 296-310.

Perdigao, V., Annoni, A. 1997: *Technical and methodological guide for updating CORINE Land Cover data base*. Brussels: Joint Research Centre, European Commission.

Perdigao, V., Christensen, S. 2000: *The LaCoast Atlas: Land Cover Changes in the European Coastal Zones*. Ispra, Italy: European Commission, Joint Research Centre, Space Applications Institute.

Pereira, H.M., Cooper, H.D. 2006: Towards the global monitoring of biodiversity change. *Trends in Ecology & Evolution* 21, 123-129.

Provost, F., Kohavi, R. 1998: Guest editors' introduction: On applied research in machine learning. Machine Learning 30, 127-132.

Stanners, D., Bordeau, P. 1995: *Europe's environment; The Dobris assessment*. Copenhagen: European Environment Agency.

Thomson, A.G., Manchester, S.J., Petit, S., Swetnam, R.D., Smith, G.M., Wadsworth, R.A., Gerard F.F. 2007: The use of digital aerial photography and CORINE-derived methodology for monitoring recent and historic changes in land cover. *International Journal for Remote Sensing* 28, 5397-5426.

Weber, J.L.,Hall, M. 2001: *Towards spatial and territorial indicators using land cover data*. Copenhagen: European Environment Agency.

Wickham, J. D., O'Neill, R.V., Jones, K.B. 2000: Forest fragmentation as an economic indicator. Landscape Ecology 15, 171-179.

Wyatt, B., Gerard, F.F. 2001: What’s in a Name? Approaches to the inter-comparison of Land Use and Land Cover Classifications. In Groom G., editor, *Strategic Landscape Monitoring for the Nordic Countries*. Copenhagen: Levison &Johnson & Johnson, 113-121.

Figures and Tables

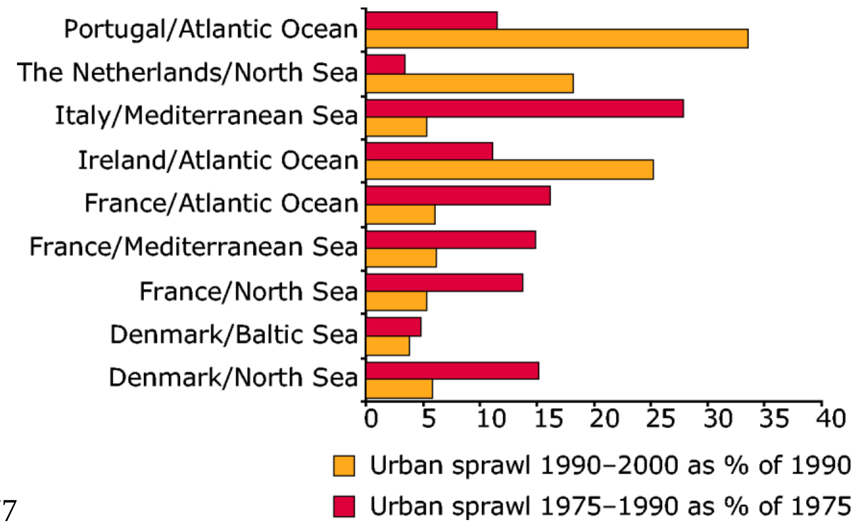


Figure 1. LACOAST: Urban sprawl shown as a % change based on the initial urban area for each coastal sector. Copyright EEA, Copenhagen, 2006 (Source: http://www.eea.europa.eu).

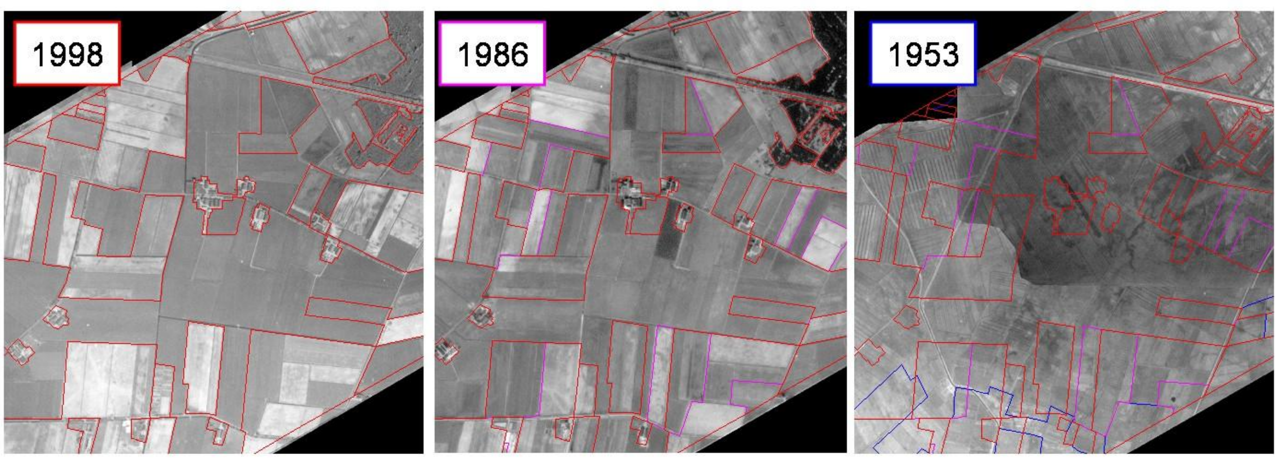


Figure 2. Photo-to-photo interpretation (transects), left, 1998; middle, 1986 photo with 1986 interpretation added to 1998 polygons; right, 1953 photo with 1953 interpretation added to 1986 and 1998 polygons.

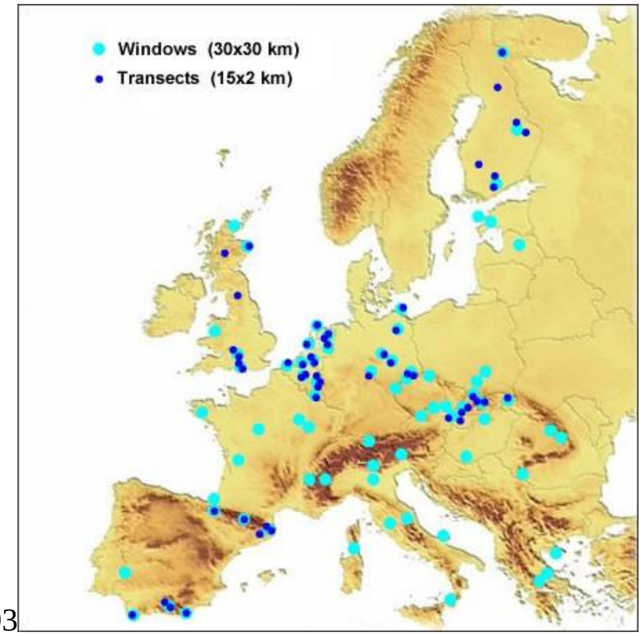


Figure 3. The location of windows and transects interpreted

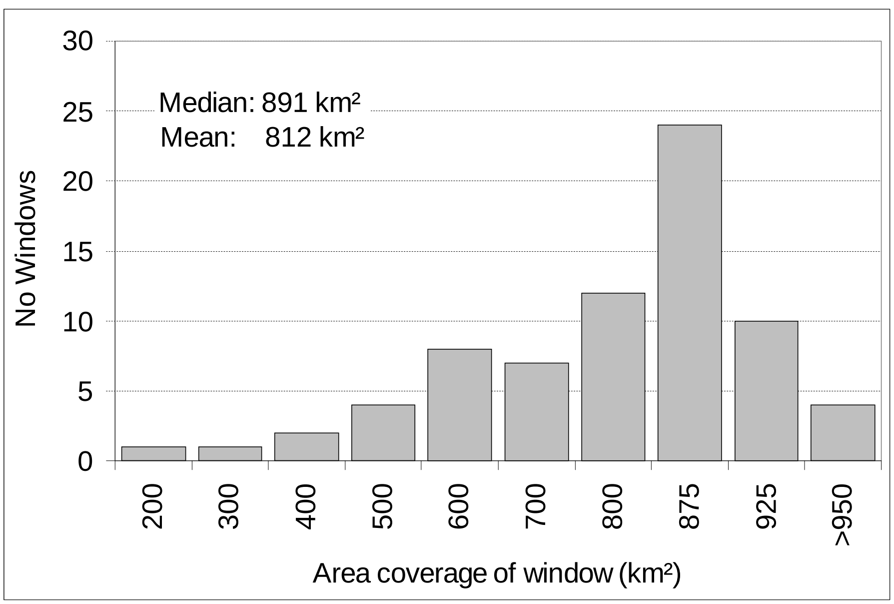


Figure 4. The area coverage distribution of the window sites.

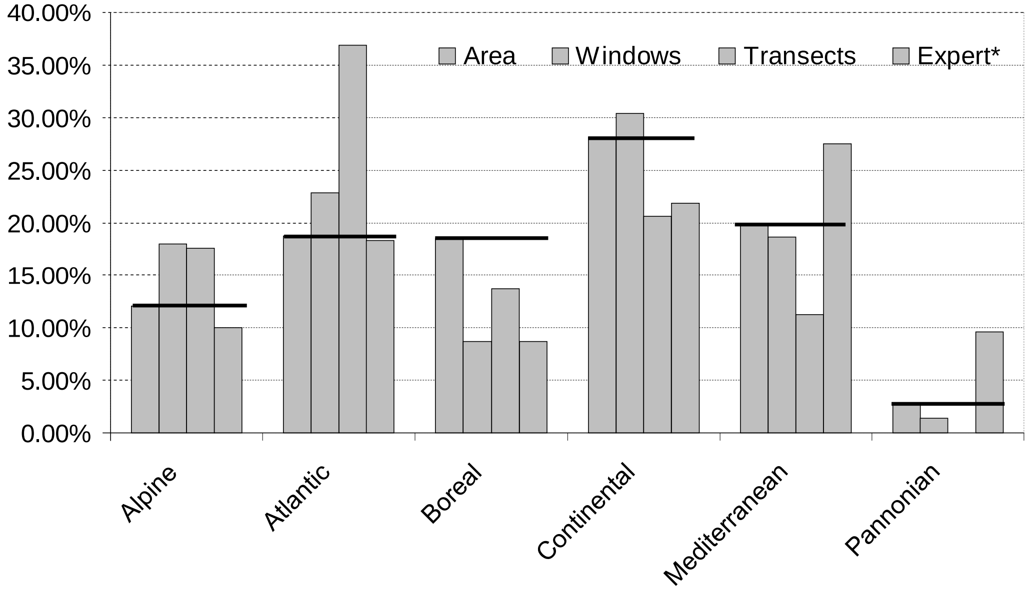


Figure 5. The relative area distribution per BRME zone, compared with the relative area distribution achieved by the transect and window sites and the relative distribution of the original super-set of sites (Expert).

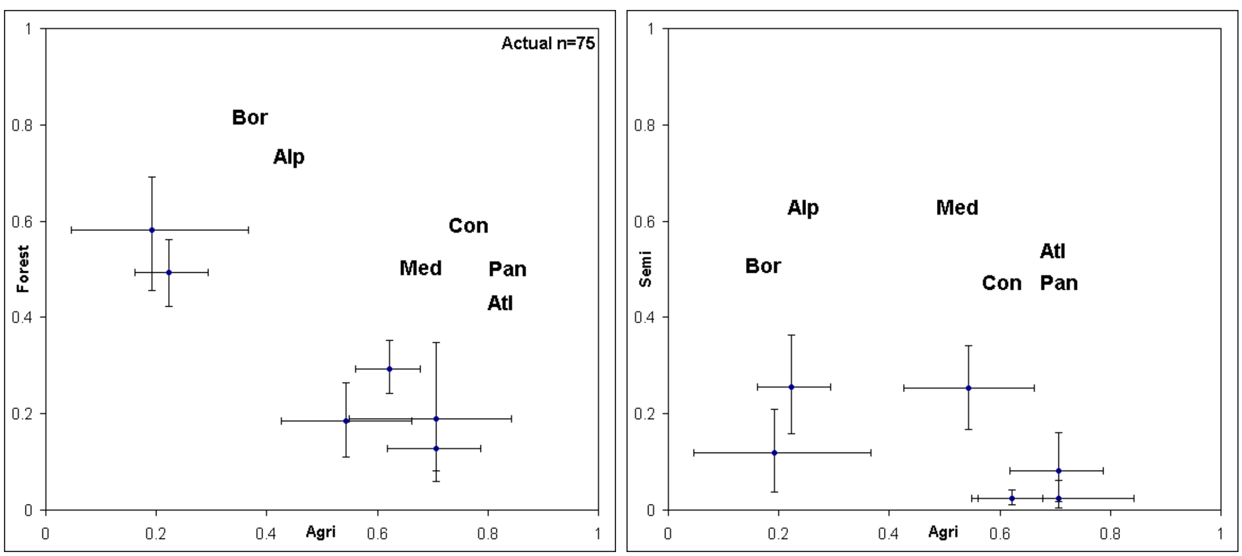
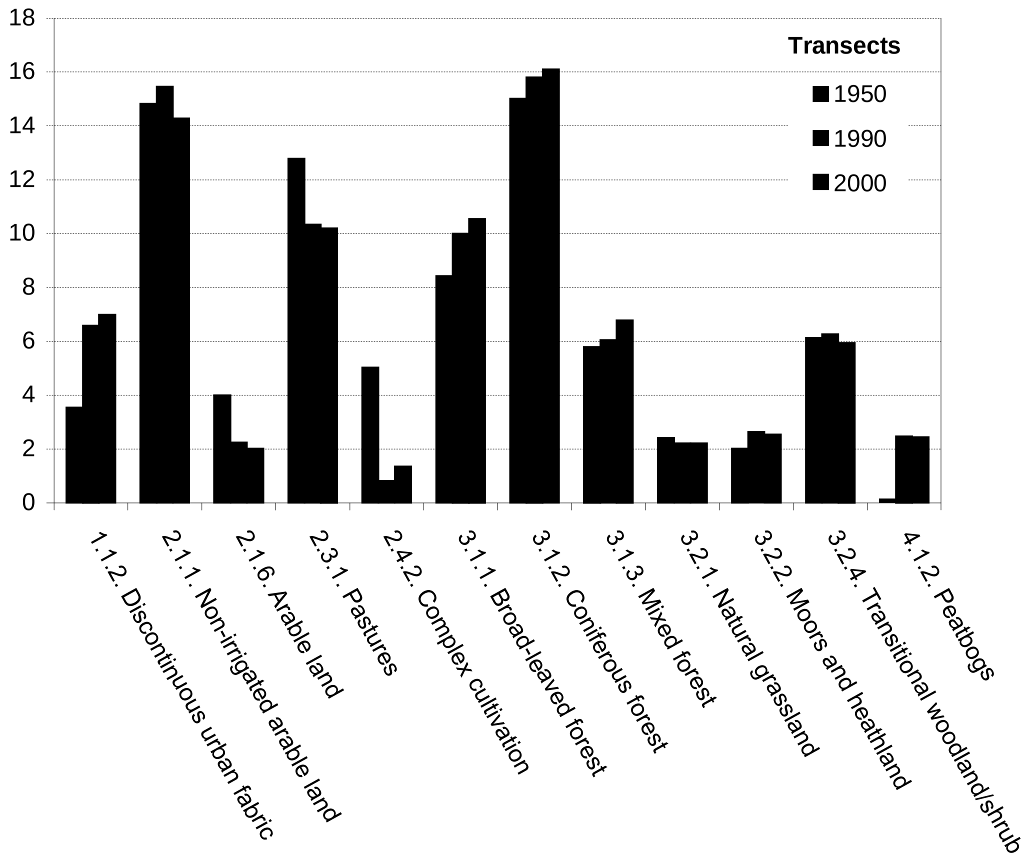


Figure 6. An analysis routine was established to randomly sample a set of 75 (30km x 30km) grid cells which were then used as the population to derive mean CORINE land cover proportions (Agriculture, Forest and Semi-Natural) for each BRME zone of Europe. This routine was repeated 1000 times for each BRME zone to represent the possible range of results that could have been derived if different sets of windows or transects had been selected. The 1000 mean proportion results for each BIOPRESS land cover aggregation were sorted and the 50th and 950th were extracted as estimates of the variability within the BRME zone. The figure shows the mean cover proportions and variability of (a) Agricultural classes against Forest classes and (b) Agricultural classes against Semi-natural classes.


18
16
14
12
10
8
6
4
2
0
Transects
1950
1990
2000
1.1.2. Discontinuous urban fabric
2.1.1. Non-irrigated arable land
2.1.6. Arable land
2.3.1. Pastures
2.4.2. Complex cultivation
3.1.1. Broad-leaved forest
3.1.2. Coniferous forest
3.1.3. Mixed forest
3.2.1. Natural grassland
3.2.2. Moors and heathland
3.2.4. Transitional woodland/shrub
4.1.2. Peatbogs

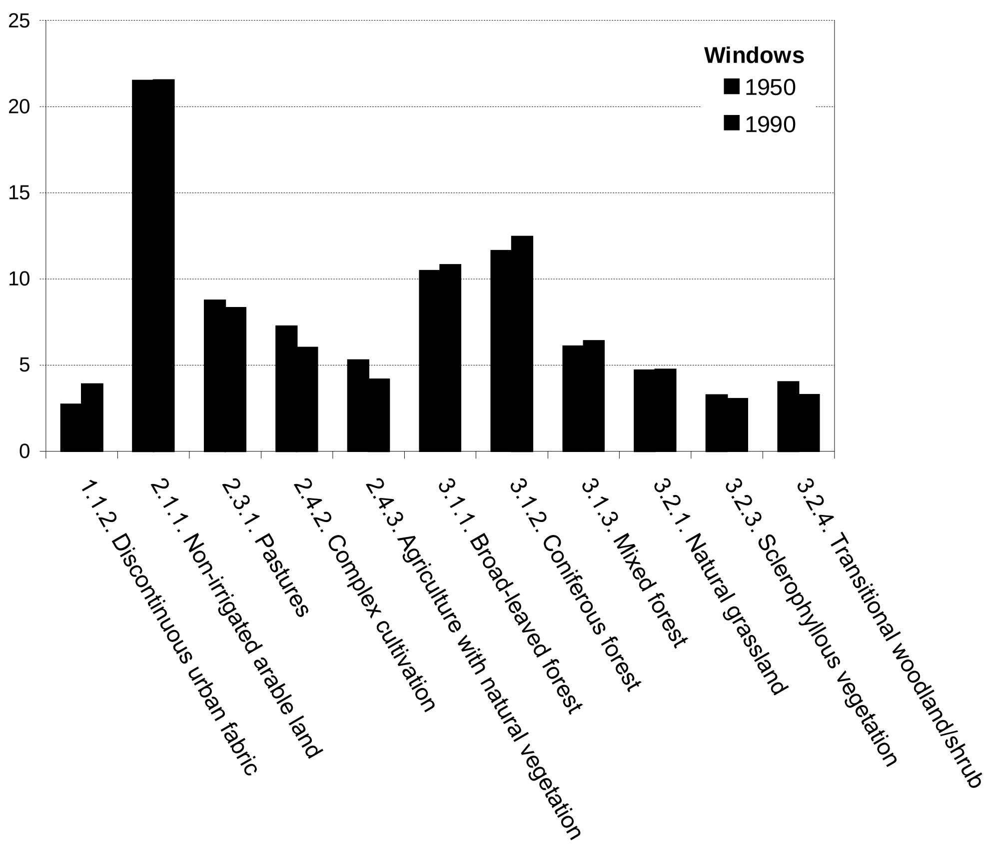

25
20
15
10
5
0
Windows
1950
1990
1.1.2. Discontinuous urban fabric
2.1.1. Non-irrigated arable land
2.3.1. Pastures
2.4.2. Complex cultivation
2.4.3. Agriculture with natural vegetation
3.1.1. Broad-leaved forest
3.1.2. Coniferous forest
3.1.3. Mixed forest
3.2.1. Natural grassland
3.2.3. Sclerophyllous vegetation
3.2.4. Transitional woodland/shrub

Figure 7. Total area (%) of CLC level 3 (44 classes) cover types found in transects (top) and in windows (bottom) for 1950, 1990 and 2000 (transects only). Only the cover types corresponding to the 10 highest coverage percentages at any one time point are shown.

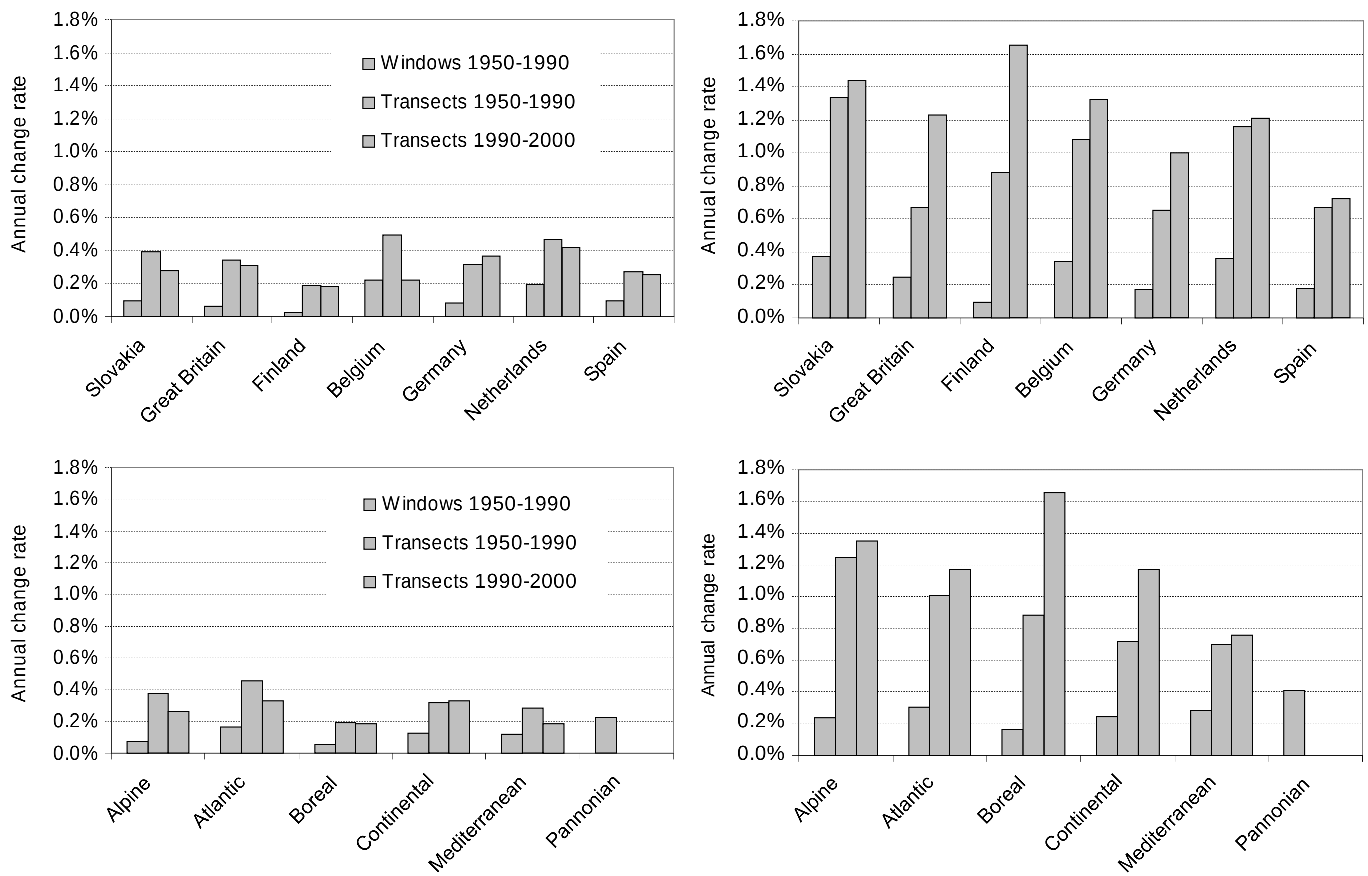
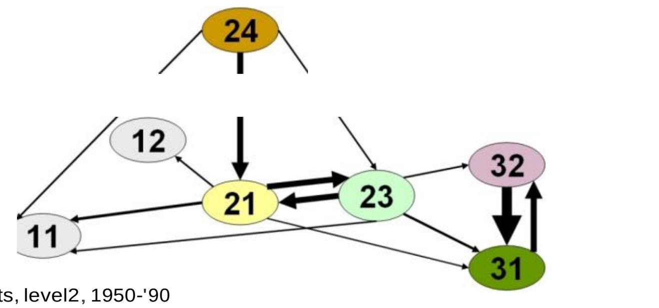
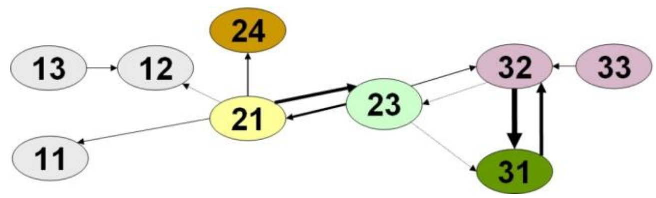


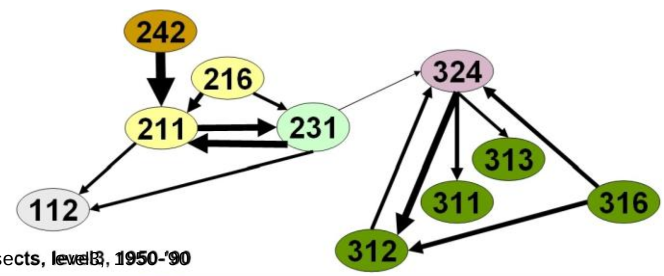
Figure 8. Annual rate of change detected at CORINE Land Cover level 1 (left) (5 classes) and level 3 (right) (44 classes) calculated per country (top) and per biogeographical (BRME) zone (bottom).



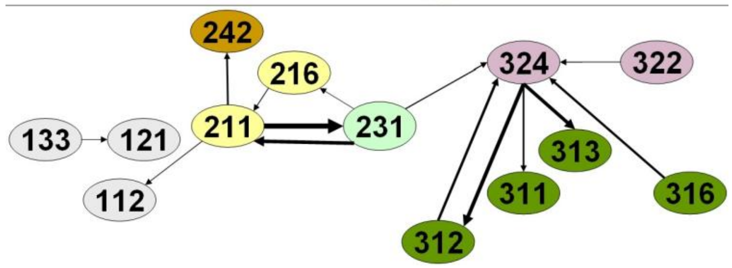
Transects, level2, 1950-'90



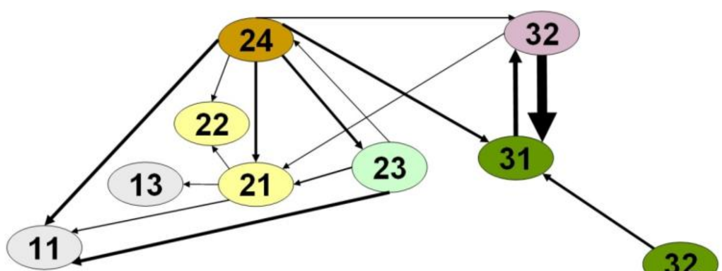
sects, level2, 1990-'00



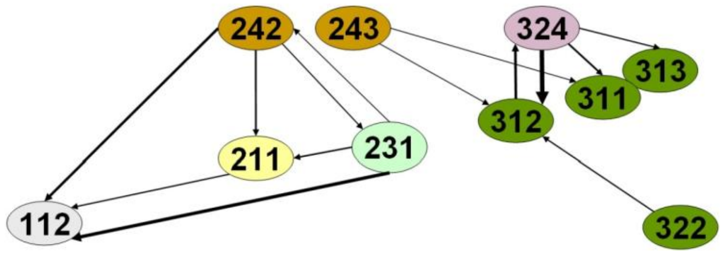
Transects, level3, 1950-'90



nsects, level3, 1990-'00



Windows, level 2, 1950-'90



..wiDdows, level 3, 1950-'90

Figure 9. The largest cover flows observed at level 2 (15 classes) and level 3 (44 classes) from the windows (2 10,000 ha for 1950-1990) and transects (2 1300 ha for 1950-1990; 2 300 ha for 1990-2000) in terms oftotal area changed. The thickness ofthe arrows is relative proportional to the total area changed observed. The complete listing of the CORINE level 3 class headings can be found in Table 8.

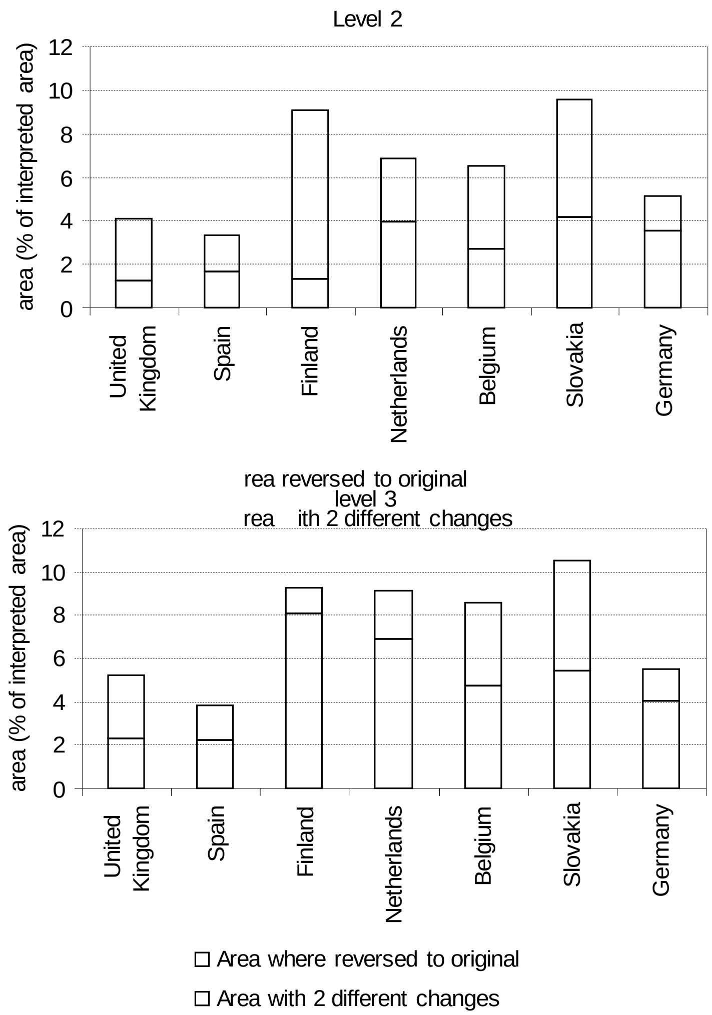


Figure 10. Proportions of interpreted transect area which has undergone changes twice as observed from level2 (15 classes) and level 3 (44 classes).

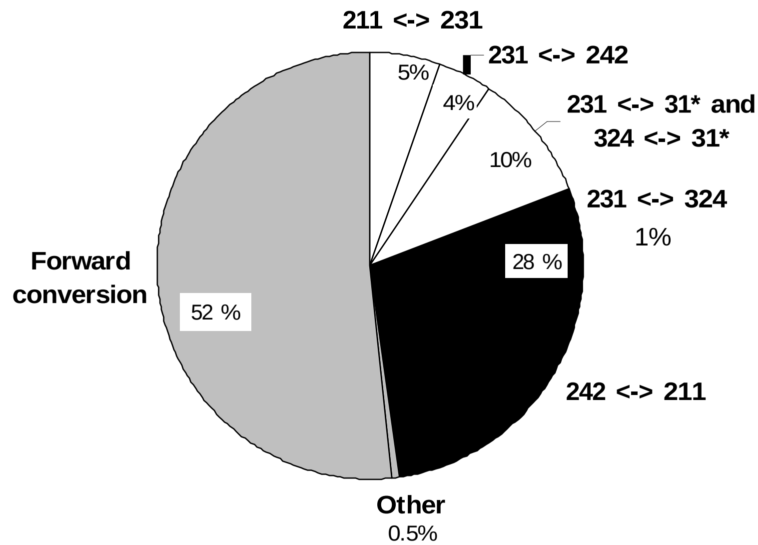


Figure 11. The main types and area proportion of inverse conversion observed from the transects in Slovakia. The complete listing of the CORINE level 3 class headings can be found in table 8.

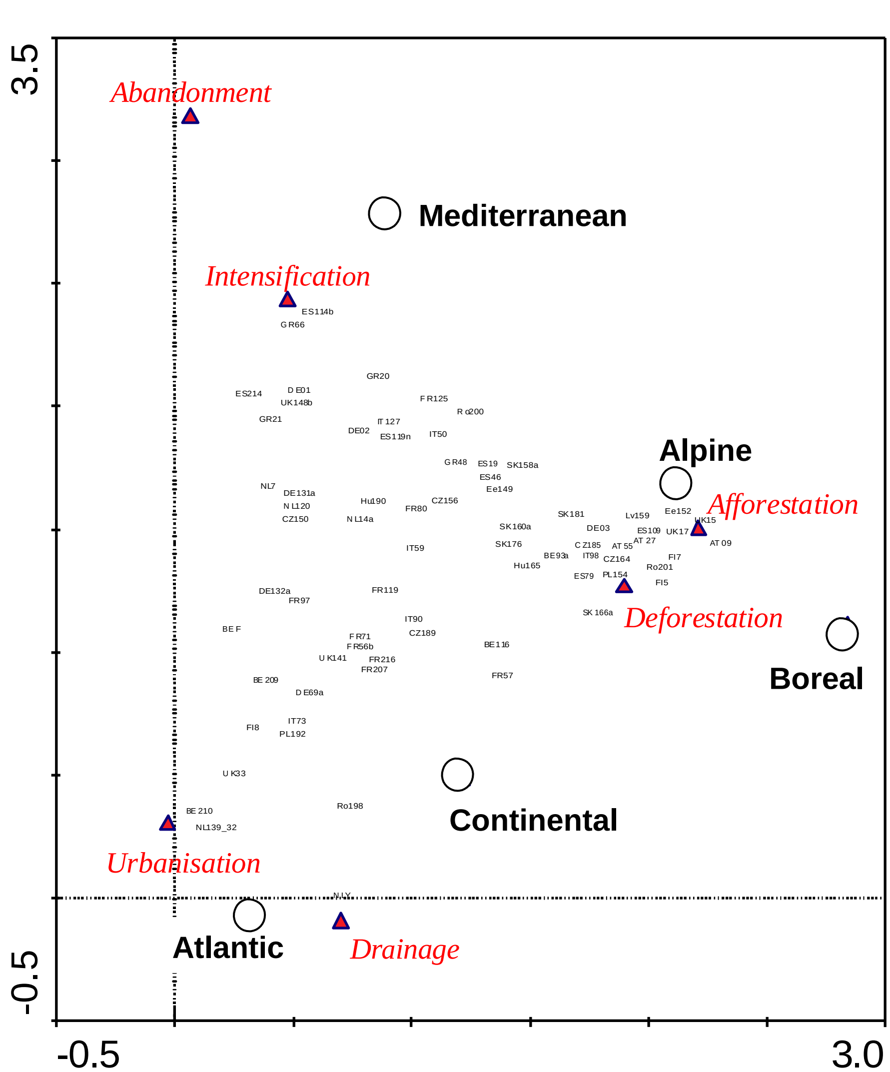


Figure 12. First ordination plan of a detrended correspondence analysis applied on the % of interpreted window area changed grouped by 6 main pressures (urbanisation, drainage, afforestation, deforestation, abandonment and intensification).

Table 1. Land cover changes 1990-2000 for Europe in hectares as a cross-tabulation between CLC1990 (rows) and CLC2000 (columns) (Source: http://www.eea.europa.eu. Copyright EEA, Copenhagen, 2005)

	CLC1: Artificial surfaces	CLC2: Agricultural Areas	CLC3: Forest and semi natural areas	CLC4: Wetlands	CLC5: Water bodies
CLC1: Artificial surfaces	16,083,082	27,327	52,535	1,238	21,773
CLC2: Agricultural Areas	814,803	198,159,187	406,744	11,000	51,678
CLC3: Forest and semi natural areas	151,337	368,496	134,252,861	7,136	36,154
CLC4: Wetlands	2,495	9,556	110,830	4,552,371	16,228
CLC5: Water bodies	5,479	5,037	8,604	16,782	4,549,544

Table 2. Statistics directly extracted from the MURBANDY/MOLAND database. Source: Lavalle, Demicheli et al. 2002.

City	Total area: (km2)	Total urban area (CLC 1.*.*) (km2)		Total green urban area (CLC 1.4.1) (km2)		Urban sprawl: increase in artificial area (%) during the 40/50 years study period	Loss of natural and agricultural land due to sprawl vs. total area (%) during the 40/50 years study period
		1950s	1990s	1950s	1990s		
Algarve	781.5	32.2	119.1	0.2	0.7	270.4	11.4
Setubal	22.6	3.3	11.2	0.2	0.3	243.3	33.1
Palermo	223.1	27.8	86.5	3.5	5.6	211.0	26.0
Bratislava	462.7	40.8	123.3	1.1	2.1	202.6	18.1
Grenoble	193.4	31.1	91.4	4.1	5.1	193.5	31.2
Helsinki	1041.5	135.0	326.0	13.3	29.3	191.0	25.6
Padua-Venice	515.5	69.7	188.9	4.4	9.7	171.0	23.1
Iraklion	29.8	9.0	21.7	0.1	0.1	139.7	41.3
Porto	197.5	51.3	121.5	2.3	5.2	136.8	35.7
Bilbao	169.6	27.4	61.4	0.7	1.9	124.2	20.6
Nicosia	75.9	24.8	52.0	0.7	1.2	109.6	36.6
Tallinn	1070.1	88.3	182.1	7.1	15.5	106.1	10.0
Milan	325.2	114.5	233.4	4.3	16.6	103.8	37.0
Dublin	676.8	163.1	319.3	21.2	52.1	95.8	22.7
Lyon	311.6	122.8	222.6	17.6	14.5	81.2	32.7
Brussels	1308.8	318.6	560.3	15.7	17.9	75.9	19.3
Marseille	328.3	93.5	150.2	9.5	4.6	60.7	17.6
Copenhagen	665.0	242.7	386.1	9.3	16.0	59.1	19.4
Prague	797.6	186.9	288.4	11.0	13.5	54.4	13.2
Munich	797.8	246.7	357.0	20.8	30.9	44.7	14.3
Vienna	841.8	249.7	341.1	14.8	19.5	36.6	11.5
Dresden	1256.7	231.1	314.1	52.1	44.0	36.0	7.3
Sunderland	199.7	84.6	106.7	11.0	16.1	26.1	12.9
Ruhrgebiet	352.6	219.8	273.9	4.6	12.2	24.6	18.8

Table 3. The distribution and area coverage of windows and transects on a country by country basis. Highlighted countries contain transects.

Country	Windows		Transects		Bio-geographical region
	No.	Mean size (km²)	No.	Mean size (km²)	
Austria	3	806.08			Continental, Alpine
Belgium	5	872.82	8	33.88	Continental, Atlantic
Czech Rep.	5	867.50			Continental
Estonia	2	784.09			Boreal
Finland	3	897.99	8	30.91	Boreal
France	9	660.76			Atlantic, Continental, Alpine, Mediterranean
Germany	6	805.99	9	30.81	Continental
UK	5	864.08	8	26.48	Atlantic
Greece	4	764.68			Mediterranean
Hungary	2	412.46			Panonian
Italy	6	900.71			Mediterranean
Latvia	1	895.69			Boreal
Netherlands	5	813.69	9	30.59	Atlantic
Poland	2	1587.58			Continental
Romania	3	438.72			Continental, Alpine
Slovakia	5	826.95	9	31.47	Alpine
Spain	7	847.66	9	29.70	Mediterranean, Alpine
Total	73	59296.93	59	1806.76	

Table 4. Overall thematic consistency for all transects

	1950	1990	2000
CLC L3	54%	55%	53%
CLC L2	80%	81%	82%
CLC L1	91%	91%	91%

Table 5. Thematic consistency for a selection of individual transects

	Transect label	CLC 50			CLC 90			CLC 00		
		L1	L2	L3	L1	L2	L3	L1	L2	L3
Spain	ES 2	94%	83%	32%	97%	92%	30%	97%	95%	32%
Finland	FI 2	98%	96%	52%	99%	87%	54%	99%	88%	53%
UK	UK 8	90%	73%	70%	91%	77%	74%	91%	79%	77%

Table 6. Change accuracy for all validation points

		Controller	
		Change	No Change
Local Interpreter	Change	25%	9%
	NoChange	14%	52%

Table 7 Proportion (%) of CLC level 1 cover types observed in 1950 and 1990

CLC class level 1	1950		1990	
	windows	Transects	windows	Transects
1. Artificial surfaces	3.77	6.57	5.79	12.76
2. Agricultural areas	46.16	38.58	43.66	30.41
3. Forest and semi-natural areas	45.27	46.16	45.54	48.62
4. Wetlands	0.80	3.57	0.69	3.98
5. Water bodies	4.00	4.01	4.31	4.23
Not interpreted	0.00	1.11	0.01	0.00
Total %	100.00	100.00	100.00	100.00

Table 8

CORINE Land Cover - level 3 classes	
1.1.1. Continuous urban fabric	3.1.1. Broad-leaved forest
1.1.2. Discontinuous urban fabric	3.1.2. Coniferous forest
1.2.1. Industrial or commercial units	3.1.3. Mixed forest
1.2.2. Road and rail networks and associated land	3.2.1. Natural grassland
1.2.3. Port areas	3.2.2. Moors and heathland
1.2.4. Airports	3.2.3. Sclerophyllous vegetation
1.3.1. Mineral extraction sites	3.2.4. Transitional woodland/shrub
1.3.2. Dump sites	3.3.1. Beaches, dunes, and sand plains
1.3.3. Construction sites	3.3.2. Bare rock
1.4.1. Green urban areas	3.3.3. Sparsely vegetated areas
1.4.2. Sport and leisure facilities	3.3.4. Burnt areas
2.1.1. Non-irrigated arable land	3.3.5.Glaciers and perpetual snow
2.1.2. Permanently irrigated land	4.1. 1. Inland marshes
2.1.3. Rice fields	4.1.2. Peatbogs
2.2.1. Vineyards	4.2.1. Salt marshes
2.2.2. Fruit trees and berry plantations	4.2.2. Salines
2.2.3. Olive groves	4.2.3. Intertidal flats
2.3.1. Pastures	5.1. 1. Water courses
2.4. Heterogeneous agricultural areas	5.1.2. Water bodies
2.4.1. Annual crops associated with permanent crops	5.2.1. Coastal lagoons
2.4.2. Complex cultivation	5.2.2. Estuaries
2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation	5.2.3. Sea and ocean
2.4.4. Agro-forestry areas	