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

38

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59

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

61

62Abstract

63

64BIOPRESS ('Linking Pan-European land cover change to pressures on Biodiversity'), a
65European Commission funded 'Global Monitoring for Environment and Security' project
66produced land cover change information (1950–2000) for Europe from aerial photographs and
67tested if this information is suitable for monitoring habitats and biodiversity. The methods and
68results related to the land cover change work are summarised. Changes in land cover were
69established through 73 window and 59 transect samples distributed across Europe. Although the
70sample size was too small and biased to represent the spatial variability observed in Europe, the
71work highlighted the importance of method consistency, the choice of nomenclature and spatial
72scale. The results suggest different processes are taking place in different parts of Europe: the
73Boreal and Alpine regions are dominated by forest management; abandonment and intensification
74are mainly encountered in the Mediterranean; urbanisation and drainage are more characteristic
75of the Continental and Atlantic regions.

761 Introduction

77

78Our environment is continuously undergoing change caused by a combination of social,
79economic and natural processes which operate at all scales from the local to the global. The
80present most prominent changes we are witnessing and which have recently been confirmed by
81the fourth IPCC summary report (IPCC 2007) are those caused by global climate change. Not
82least important and related to climate change are the changes in the use of our environment and
83natural resources. The Convention on Biological Diversity which was agreed in 1992, and more
84recently, the UN Millennium Ecosystem Assessment, which carried out a first global ‘scientific
85appraisal of the condition and trends in the world’s ecosystems and services they
86provide’(Millenium Ecosystem Assessment 2005), demonstrate a growing international
87awareness in the importance of maintaining ‘healthy’ ecosystems to preserve life as we know it
88today.

89

90 In Europe several national and international legal mechanisms (e.g. Amsterdam Treaty
911997, Habitats Directive, EU Common Agricultural Policy) have been set up to protect the
92European environment, ensure sustainable use of its natural resources and maintain an acceptable
93level of biodiversity. Protection requires monitoring and so in Europe these mechanisms have
94encouraged the establishment of a wide range of, often unconnected national and regional,
95environmental monitoring activities. Without a common method and/or reference point it has
96been difficult to consolidate or compare the findings of such activities to build up an overview of
97the environmental changes occurring across Europe.

98

99 GMES (Global Monitoring for the Environment and Security,
100http://ec.europa.eu/gmes/index_en.htm) and INSPIRE (Infrastructure for Spatial Information in

101the European Community, <http://www.ec-gis.org/inspire/>) are initiatives which began shortly
102after the start of the millennium. GMES is driven jointly by the European Space Agency and the
103European Commission and aims to establish a European capacity for monitoring the environment
104by 2008. This involves, amongst others, the consolidation of existing national, regional
105monitoring networks and the development of benchmark datasets. INSPIRE recently delivered
106the European INSPIRE directive, which entered into force on 15 May 2007, laying down rules
107for the establishment of an infrastructure for spatial information in Europe, 'in support of
108environmental policies and policies or activities which may have a direct or indirect impact on
109the environment'. With the establishment of a global commitment to the Global Earth
110Observation System of Systems (GEOSS) in 2005, GMES and INSPIRE became part of Europe's
111contribution to GEOSS.

112

113 This paper gives an overview of a European Commission funded GMES project
114BIOPRESS ('Linking Pan-European land cover change to pressures on Biodiversity'). The initial
115focus of BIOPRESS was to produce a standardised historical (1950–2000) land cover change
116product that would be extendable to the pan-European level and to identify and report to GMES
117the technical, scientific, all aspects of data accessibility, data quality, organisational, legal and
118institutional hurdles encountered at each stage of the development and production process.
119BIOPRESS also tested the hypothesis that remotely sensed derived land cover is suitable for
120monitoring habitats and biodiversity. The aim of this paper is to summarize the key steps and
121main results related to the land cover change work. Further publications from the team have
122presented specific methodological developments and more detailed results (e.g. Thomson et al.
1232007).

124

1252 Background

126

127The clearest indication of a change in the environment is when the land cover changes.
128Information on land cover and land cover change is believed to be one of the benchmark datasets
129which requires a common approach in recording across countries because of its value as an
130environmental change indicator (Wickham *et al.* 2000; Weber and Hall 2001; Pereira and Cooper
1312006). At global, continental and regional level, land cover type products have and are being
132produced which are different in terms of their spatial cover and scale and class definition, their
133characteristics being determined by the purpose for which they were created and the adopted
134method. The 1 km IGBP land cover map, for example, was the first global land cover map at a
1351 km resolution which was produced using satellite imagery (i.e. 1 km Advanced Very High
136Resolution Radiometer on board the NOAA satellite series) acquired in 1992-93 (Loveland and
137Belward 1997). Its 17 cover classes are restricted in number and detail by the source data used
138and its reliability varies with cover class as this map was specifically produced to establish the
139global distribution of the main forest types (Loveland *et al.* 1999). Subsequent global land cover
140maps, also derived from satellite imagery, are the 1 km Global Land Cover 2000 database
141(derived from 1 km SPOT Vegetation sensor data on board the ENVISAT satellite) and the 1 km
142MOD12Q1 product (derived from the 1 km Moderate Resolution Image Spectroradiometer on
143board the TERRA and ACQUA satellites) (Friedl *et al.* 2002). Realising the varying needs of
144different user communities MOD12Q1 represents the globe in five different land cover
145classifications, one of which is the IGBP classification, another is an 11 class Plant Functional
146Type classification. The 300 m GlobCover LC v2 product (Arino *et al.* 2005, GlobCover Land
147Cover v2 2008 database) is currently the most recently developed global product. It is derived
148from time series of MERIS - ENVISAT imagery acquired from December 2004 to June 2006 and
149exploits variations in phenology to distinguish thematic cover classes that are compatible with the

150FAO Land Cover Classification System, also referred to as the UN Land Cover Classification
151System (LCCS) (Di Gregorio and Jansen 1998).

152

153 The first land cover map produced for Europe is the CORINE land cover map (CLC)
154which again was derived from satellite imagery acquired in the 1990'ies (i.e. 30 m Thematic
155Mapper sensor on board the Landsat satellites). But this is where similarities end. The CORINE
156land cover map (CLC1990) is produced through manual interpretation and has a minimum
157mapping unit of 25 ha for area features and minimum width of 100 m for linear features
158(Heymann *et al.* 1993). At its highest thematic level (level 3) it shows 44 classes which describe
159land cover and use. CORINE land cover has recently been updated using Thematic Mapper
160imagery acquired in 2000 and a CORINE land cover 2006 is currently under production. Another
161more recent source of land cover and use data for Europe is provided by the Lucas Survey (Land
162Use/Cover Area frame statistical Survey) which was first carried out in 2001-03 and repeated in
1632005-07. In contrast with the satellite based approaches listed above this survey uses a statistical
164sampling framework (i.e a two stage sampling design based on an 18 km x 18 km grid and relies
165on field surveys and aerial photography to determine the class membership of grid points
166(Gosepath *et al.* 2003). Even though the grid point density is relatively high, LUCAS cannot
167deliver spatial statistics.

168

169 Land cover change can be determined using a wide variety of approaches which can be
170grouped into three main categories: post classification comparison, updating or backdating from a
171base line classification and direct detection of change by combining multi-temporal source data
172(i.e. mostly airborne or satellite imagery). (Coppin *et al.* 2004) provide a comprehensive review,
173including technical advantages and disadvantages, of the post classification comparison and
174direct change detection approaches that have been developed to date. Both types of approaches

175generally are based on automated image processing and classification techniques. Backdating or
176updating from a baseline classification is very much associated with manual interpretation of
177aerial or satellite imagery. The main issue with post classification comparison is that the accuracy
178of the change detection will be at best as good as the combined accuracy of the two independent
179classifications (Coppin *et al.* 2004), while, backdating and updating are affected by the accuracy
180of the baseline classification. The direct detection methods are designed to circumvent this
181problem, but rely more heavily on consistency (with respect to for example timing of acquisition,
182quality, sensor type) in the source data. Although the general consensus is that reliable change
183detection requires consistency in the used source data and classification system between time
184points, one small advantage of post classification comparison is that, if the independent land
185cover products are based on different classification systems it still is possible to derive change
186statistics provided that the classification systems are thematically linked (i.e. harmonised, (Wyatt
187and Gerard 2001). (Comber *et al.* 2004; Fisher *et al.* 2006) advocate a fuzzy, probabilistic
188approach, whilst (Lepers *et al.* 2005) who were synthesising global land cover change
189information and were dealing with 49 different data sets, would adopt the definitions of a
190particular data set which would vary with the type of change that was under scrutiny. The other
191approaches inherently assume the use of the same classification system at each time point. In this
192case, the initial choice or design of a classification system (land cover and or use) is crucial as
193there is no such thing as a standardised land cover classification system that will satisfy all
194possible national, European or global stakeholders concerned with environmental monitoring.
195The FAO land cover classification system based on a system of attributes (Di Gregorio and
196Jansen 1998) is one of the best attempts to date to provide a common but still flexible system.

197

198 Both IGBP and CORINE land cover are some of the few global/continental land cover
199products which can provide change statistics for a ten year period. CLC2000 was produced

200through the manual updating of CLC1990. In this case the updating was also seen as an
 201opportunity to correct for errors observed in the 1990 layer (Perdigao and Annoni 1997). As a
 202result CORINE updating produced simultaneously a CLC2000 layer, a corrected CLC1990 layer,
 203and change detection statistics observed over a 10 year period. Table 1 below gives the change
 204statistics calculated for CLC thematic level 1, the lowest thematic level. The table shows that
 205‘Agricultural Areas’ underwent the biggest changes: ~814 thousand ha (i.e. 0.2 % of the 359
 206million ha with CORINE coverage) was lost to ‘Artificial Surfaces’ and while in some areas of
 207Europe ~ 406 thousand ha was converted to ‘Forest and semi natural areas’, in other areas
 208~ 368 thousand ha of ‘Agricultural Areas’ were reclaimed from ‘Forest and semi natural areas’.

209

210

Insert Table 1

211

212 With respect to Europe, there have been three additional instances where change detection
 213was carried out for a period longer than ten years. Two of these activities focused on obtaining
 214change information for certain key areas of Europe: the European coastline (i.e 1970-1990, the
 215LACOAST project, (Perdigao and Christensen 2000)) and the peri-urban zone of 25 large cities
 216(i.e.1950-1990, the MURBANDY/MOLAND project, (Lavalle *et al.* 2001; Lavalle *et al.* 2002)
 217and were both based on the manual backdating of CLC1990 using MSS (Multi-Spectral Scanner
 218on board the early Landsat satellites) and aerial photography respectively. The LACOAST results
 219showed an urban gain along most parts of the European Coastline mainly at the cost of
 220agricultural and forested areas (Figure 1). MURBANDY/MOLAND found a general increase in
 221urban sprawl ranging from 25 % (Ruhrgebiet, Germany) to 270 % (Algarve, Portugal) of the
 222original urban area recorded in the 1950s with an average of 117 % (Table 2). The average loss of
 223natural and agricultural land to urban sprawl was 22.0 % with Iraklion, Greece losing the most
 224(41.3 %) and Dresden, Germany the least (7.3 %). The third instance carried out manual

225backdating of CLC1990 with 1970s MSS imagery for four neighbouring Eastern European
226Countries, namely, Czech Republic, Slovakia, Romania and Hungary (Feranec *et al.* 2000). The
227work highlighted national variations, where, although deforestation was the most important
228change for Czech Republic, Slovakia and Hungary, the net amount of forest lost would vary from
22952.5 %, to 25.9 % and 10.1 % respectively. Both Romania and Slovakia witnessed substantial
230losses and gains of intensively cultivated land, respectively 26.2 % and 23.5 % loss and 21.6 %
231and 34.3 % gain. This also occurred in Hungary and the Czech Republic, but to a lesser extend.

232

233

Insert Figure 1

234

Insert Table 2

235

236 BIOPRESS's focus was to determine how past changes in land cover from 1950 to 2000
237may have impacted on habitats and their associated biodiversity. Similarly to LACOAST and
238MURBANDY/MOLAND a manual backdating approach was adopted, but the aim of BIOPRESS
239was to capture overall patterns of change that had occurred in the main bio-geographical zones of
240Europe, with a focus on protected areas, and to develop ways of converting this information into
241measures of impact on biodiversity. Aerial photography was chosen as this was the only type of
242data that remained consistent from the 1950s to the present.

243

2443 **Methodology**

245

246The applied method was designed to produce land cover change information collected in an
247operational and consistent manner from samples which are representative of the main bio-
248geographical regions of Europe and including areas of importance for European biodiversity
249(NATURA 2000 sites - European (Commission 2003)). Land cover is classified according to the

250CORINE Land Cover nomenclature with 44 classes at the highest level 3 (Heymann *et al.* 1993).

251Change was captured by means of ‘backdating’ where the older dataset is compared against the
252most recent. There were two approaches with different scale of interpretation:

253 For regions (‘windows’) of circa 30 km x 30 km in size, aerial photographs of the 1950s
254 were compared against CLC90. A minimum mapping unit of 25 ha was used which is in
255 line with the standard CORINE Land Cover minimum mapping unit.

256 For transects of 2 km x 15 km, aerial photography from 1950, 1990 and 2000 were
257 interpreted at a more spatially detailed minimum mapping unit of 0.5 ha.

258

259The whole process involved 5 key steps:

260 the selection of NATURA 2000 sites to position the windows and transects,

261 the search, acquisition and pre-processing of aerial photographs,

262 the manual interpretation of the photographs

263 the assessment of the quality of the interpretation and

264 the storage of interpretation results and its associated data and metadata in a central

265 database.

266

2673.1 *Sampling of sites*

268

269To ensure that the results of the analysis of land cover change could be interpreted in the wider
270European context, windows and transects that are truly representative of the diversity of
271European biogeography would have to be selected. However, the diversity in land cover and
272related local landscape features across Europe is very high and not randomly distributed so that a
273representative sample would need to be stratified and large in size. Several external factors
274constrained the sampling strategy. Budgetary constraints required an approach which aimed at

275 ensuring the highest benefit from a limited (i.e. affordable) number of sample sites. Stakeholders
276 were expecting the data not only to describe general patterns of change across the European
277 countryside, but also to provide comparisons between changes inside and outside protected nature
278 reserves (i.e. NATURA 2000 sites). As a result the NATURA 2000 network became the starting
279 point from which the windows and transect sites were selected. The Biogeographical Regions
280 Map of Europe (BRME) (<http://www.eea.europa.eu>) was used for stratification providing close
281 linkage to the Habitats Directive, Birds Directive, Emerald Network and NATURA 2000.

282

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

290

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

25

299 Each transect is located inside a super-set window site and contains at least part of a
300 NATURA 2000 site.

301 Select two representative transects for each of the four pre-defined Annex-I habitat types.

302 For additional transects, nationally important NATURA 2000 sites should be considered.

303 Transects should represent a gradient of pressures on land cover starting from the edge of
304 a NATURA 2000 site and bearing towards an intensively used area.

305

3063.2 *Aerial photography*

307

308The search criteria for the aerial photography were:

309 Photo cover for the windows must include the NATURA 2000 centre point.

310 The location of the windows can be shifted and/or rotated provided that the NATURA
311 2000 centre point is at least 5 km from the edge of the photo cover. The location of
312 transects can be shifted as long as selection criteria (see above) are not compromised.

313 The photographic coverage is at least 75 % of the window. Cloud coverage is less than
314 10 % and imagery is snow free.

315 The timeframe for windows is between 1943 and 1959 and for transects between
316 1943-1959, 1988-1992 and 1998-2002.

317 The scale of the photographs is between 1:25000 and 1:60000 and between 1:10000 and
318 1:25000 for windows and transects respectively.

319

320 It was clear from the beginning that these preset criteria combined with external factors
321such as data availability, accessibility and cost would affect the final number of windows and
322transects. Also depending on the source of the photos, pre-processing was expected to involve

323any number of the following steps: (1) scanning of hard copy, (2) introducing fiducial marks, (3)
324ortho-rectification, and mosaicking.

325

3263.3 *Manual photo interpretation*

327

328The problem with most European data sets is that they are inconsistent across regions and/or
329countries. In this project one of the main steps taken to achieve consistency was the design of two
330manuals for photo interpretation (Feranec *et al.* 2004; Feranec *et al.* 2004b): one clarifying the
331CLC level 3 class definition with respect to 1:25 000 a 1:60 000 scale panchromatic aerial photos
332(minimum mapping unit of 25 ha) and providing rules for backdating CLC90 with photos
333(Windows), another describing the CLC level 3 classes with respect to 1:10 000 a 1:25 000 scale
334photos (minimum mapping unit of 0.5 ha) and providing rules for change detection from photo–
335to–photo interpretation (transects). The other steps taken to ensure consistency were training of
336the interpreters and quality assessment.

337

338 The interpretation approach adopted for the Windows was to overlay the CLC90 polygons
339on mosaics of 1950s photos and to focus on identifying change. The original 1990s Landsat
340scenes from which CLC90 is derived were, where available, used to distinguish real changes
341from changes due to errors in the CLC90 database. Only the changes believed to be real were
342recorded. The resulting output was a CLC50 to CLC90 change matrix for each window. The
343approach adopted for the transects was to interpret the most recent aerial photographs first and
344then backdate (Figure 2). The first interpretation has polygons labeled with the land cover of
3452000 (CLC00). In the second interpretation, using the aerial photos of 1990 (CLC90), only new
346lines are added. The newly created polygons receive a label with the land cover of 1990 and also
3472000. For polygons that did not change, the attributes of CLC00 are copied to CLC90. When the

29

348interpretation of 1990 is finished the same procedure can be followed for 1950 (CLC50). This
349ensures that the interpreter only adds lines and creates polygons if the land cover has changed.
350The results are polygons with multiple attributes which were used to produce change statistics.

351

352

Insert Figure 2

353

354**3.4 Quality Assessment**

355

356Quality assessment provides a measure of accuracy of the interpretations. The general principle
357of any quality assessment (QA) procedure consists of comparing the obtained results with
358independent data. However, especially for the 1950s, no comparable independent dataset exists,
359so the QA procedures that were developed aimed at establishing a measure of consistency
360between interpreters. For the windows, an independent expert (controller) would reinterpret
361sampled areas (5 km x 5 km verification units) that were identified within a selection of windows
362by placing a square grid 5 km x 5 km over the window area and looking for 5 km x 5 km areas
363which include the most commonly occurring types of land cover changes of the country the
364window represented or where strange and unexpected types of changes were observed. The
365windows selected were those which showed the highest rate of change within one country. In
366total circa 7 % of the total area interpreted was verified. The consistency R (%) for a given
367window was calculated as: $R = A/N * 100$ where A is the number of identical changes (i.e. in both
368size and type) and N is the number of all changes in given window identified by controller and
369interpreter. A window is rejected and returned to the interpreter for improvement when its
370consistency rate is below 85 %.

371

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

$$380 \quad \hat{p}_c = \frac{a_c}{n_c * 6}$$

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

$$385 \text{ and } \quad \hat{p} = \frac{a}{n * 6}$$

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

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

391

392 **Results**

393

394 *4.1 Window and transect sites*

396 Aerial photos of the 1950s were obtained, processed and interpreted for 73 window sites and 59
397 transect sites. The 73 windows are distributed across 17 countries, 36 are located in the eight
398 partner countries and 37 outside partner countries (Figure 3 and Table 3). The total interpreted
399 window area is 59297 km² and the total interpreted transect area is 1807 km². While for the
400 transect sites full area coverage was achieved in most cases (i.e. 30 km² per transect) the resulting
401 area interpreted per window site depended on the available photo-coverage and CLC90 coverage
402 (Figure 4). 36 of the 73 windows achieved more than 750 km² coverage. The lowest coverages
403 achieved were for windows in Hungary and Romania. The exceptionally large average size of
404 windows in Poland is caused by the merging of two partially overlapping windows into one.

405

Insert Figure 3, Table 3 and Figure 4

406

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

413

Insert Figure 5

414

415 The variability of the BRME zones and the window and transects sites in terms of
416 CORINE land cover class proportions was investigated in detail to assess the use of the BRME as
417 a spatial framework for extrapolating the land cover and land cover change data measured from
418 the sites. Figure 6 shows that the sample size is too small to differentiate between the
419 biogeographical regions due to the large variability in land cover distributions within the regions

420 and the sites. The use of the NATURA 2000 network as the focus for the sampling has also
421 influenced the results returned by the windows and transects as both are biased toward semi-
422 natural conditions. As a result both the window and transect sites are less representative of the
423 BRME zones as a whole than a random stratified sample would be.

424

Insert Figure 6

425

426 Although the BRME was considered to be the most suitable stratification for BIOPRESS
427 given its wide user support and the small number of zones, the overall conclusion of the analysis
428 was that the nature of the BRME and BIOPRESS sampling scheme were not appropriate for
429 extrapolation of land cover change results across Europe with any reasonable level of confidence.
430 The real issue is the number of samples and their distribution. The window areas probably
431 represent no more than 1.5 % of Europe which is inadequate for a region with such varied
432 landscapes molded by nature and humans. At a workshop (Jongman, personal communication) a
433 team of experts estimated that approximately 5250 sites of 1 km² in size distributed in a stratified
434 random manner using the much more detailed 350 class European landscape database for
435 stratification (i.e. LANMAP2 (Jongman *et al.* 2006) would provide a statistically reliable
436 estimate of all European habitats (i.e 15 sites of 1 km² per stratum). If the aim is to compare the
437 situation inside and outside protected nature reserves an additional sample set representative of
438 the nature reserves would have to be added.

439

440 4.2 *Quality of interpretation*

441

442 A total of 204 verification units were assessed located in 43 of the 73 windows. The average
443 acceptable consistency rate achieved was 94 %. Table 4 gives the overall thematic consistency
444 calculated for the three time points and the three CLC classification levels, using the results from

445all grid points of all transects. As the resulting number of grid points differed between individual
446transect, a transect specific weighting was assigned to each point. The weighting factor was
447defined as the total transect area, divided by the number of validation points. The time point was
448found to have no influence on thematic consistency. Increasing thematic detail at the other hand
449has a high impact, causing a reduction in interpreter's consistency from 91 % at level 1 to ~ 54 %
450at level 3.

451

Insert Table 4

452

453 At individual transect level, the thematic consistency shows the same trends as observed
454for the overall thematic consistency. However, due to the specific landscape characteristics of
455some of the sites we found in some cases that interpretations at CLC level 1 and 2 achieved
456similar levels of consistency which were very different from the consistency achieved at level 3,
457whilst other transects show similar consistency at level 2 and 3 (e.g. Table 5). Table 6 shows the
458overall consistency in detecting change at CLC level 3. In 77 % of the cases the local interpreter
459and the controllers agree on the changes. In 14 % of the cases the controller found changes that
460were not detected by the local interpreter and 9 % of changes are identified by the local
461interpreter but not by the controller.

462

463 Overall, the interpretation team managed to maintain a high level of interpretation
464consistency. This means that the team's interpretation of cover classes and their changes were
465found to be either consistently correct or incorrect. At CLC levels 1 and 2 consistency is very
466high (~91 % and ~81 % respectively). At CLC level 3 only ~ 54 % of the time the interpreters
467agree on the cover class. The QA enabled us to identify which classes at what thematic level
468where prone to confusion. For example, the importance of the conversion between arable field
469and grassland is expected to be inflated as the quality assessment highlighted a consistent

470confusion between grassland and arable fields. The main causes for confusion for both, the
471window and transect interpretations, were ambiguous CLC class definitions, and the similar
472appearance of CLC classes on panchromatic aerial photography. An error propagation analysis
473(not shown here) based on the QA results also enabled us to establish that aerial photo quality
474was another main factor introducing confusion. What we were not able to establish, due to lack of
475independent reference data, is how often and in which cases interpreters agreed wrongly.

476

Insert Table 5 & Table 6

477

478**4.3 Observed land cover and land cover changes**

479

480Although the size and location of the samples did not allow for an extrapolation across Europe to
481produce a European map of change, the data collected still produced some interesting results.
482Table 7 shows that the European landscape is mainly a mixture of agricultural land (~ 30 %
483+ ~ 10 % pastures), forests (~ 35 % + ~ 11 % semi-natural areas) with an increasing amount of
484urban fabric (~ 7 %). Figures from the ‘DOBRIS assessment’ which were estimated from an
485aggregated (to a 250 m grid) and generalized CORINE land cover 1990, suggest a higher
486proportion of land covered by arable land and a smaller proportion covered by urban fabric:
487forest cover 33 %, arable land 24 %, extensive agriculture and mixed land use 24 %, permanent
488crops 15 %, permanent grassland 2 % and urban areas 1 % (Stanners and Bordeau 1995). The
489agricultural areas have seen a decrease in areas of complex cultivation, whilst forested areas show
490an increase for all forest types (broadleaved, conifer and mixed forests) and a slight decrease in
491transitional woodland and shrub (Figure 7).

492

Insert Table 7, Figure 7, Figure 8

493

494 The total extent of land cover changes that have occurred within all windows account
495 only to an average of 10 % of the total measured area (the average is taken from the three
496 thematic interpretation levels). In other words, 90 % of the measured window areas have shown
497 no change of land cover at all. Increasing the spatial resolution from 25 ha minimum mapping
498 (windows) unit to 0.5 ha minimum mapping unit (transects) invariably led to an average of 2.8
499 times more area being identified as having changed. This increase represented on average 7 % or
500 25 % of the total area when interpreted at level 1 (five cover classes: Artificial areas, Agricultural
501 areas, Forests and semi-natural areas, Wetlands, Water bodies) or level 3 (44 cover classes)
502 respectively. An increase in thematic detail, from 5 cover classes in level 1, to 44 classes in level
503 3, not only caused an increase in the amount of change detected but also altered the trends
504 observed in the annual rate of change (Figure 8). Where at level 1 the transect data is suggesting a
505 slow down in the most recent ten years, at level 3 changes in the last ten years are more evident in
506 particular for Belgium, Germany and UK. The aggregated level 1 does not provide evidence of
507 changes happening at a finer thematic level as shown from the analysis done at level 2 and 3.
508 This suggests that many of the changes have occurred within the more general landscape level 1
509 categories of build up, agricultural land and forest/semi-natural land.

510

511 The dynamics of the changes can be better understood when analysing the land cover
512 flows for the windows and transects. With a classification system of 15 (level 2) or 44 classes
513 (level 3) theoretically 210 or 1892 different types of land cover change are possible. Figure 9
514 show the largest cover flows observed in level 2 and level 3 from the windows (≥ 10000 ha or 0.2
515 % of total interpreted area for 1950-1990) and transects (≥ 1300 ha or 0.7 % of total interpreted
516 area for 1950-1990; ≥ 300 ha or 0.2 % of total interpreted area for 1990-2000) in terms of total
517 area changed. The most important land cover conversions were found to be the following:

43

518 From heterogeneous agricultural areas (24 or 242, 243) to urban fabric (11 or 112), to
519 arable land (21 or 211) and to forest (31 or 311, 312).

520 From arable land (21 or 211) and pastures (23 or 231) to urban fabric (11 or 112) or
521 industrial, commercial, and transport units (12).

522 From shrub and/or herbaceous vegetation association (32 or 324) to forests (31 or
523 311,312,313), and its inverse conversion, i.e. from forest to shrub and/or herbaceous
524 vegetation association.

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

526 From pastures (231) to shrub and/or herbaceous vegetation association (324).

527 From arable (211) land to pastures (231) and its inverse conversion.

528 The importance of the latter conversion highlighted may have been inflated by the consistent
529 difficulty in differentiating grassland from arable field on panchromatic photography, even
530 though rotation between arable crops and grasslands is common practice in many European
531 countries. From the flows it is not clear how many of the inverse conversions observed relate to
532 opposite changes which are occurring in different places or to areas which have been converted
533 back to their 1950s state. Figure 10 shows the proportion of the interpreted transect area that
534 underwent change twice subdivided into the proportion that has reversed back to its original
535 1950s state (i.e. inverse conversion) and the proportion that changed into a different state twice
536 (i.e. forward conversion). At thematic level 2, Finland and Slovakia showed both, the largest
537 proportion of interpreted area that underwent change twice and the largest proportion of area
538 showing an inverse conversion. Interestingly at thematic level 3 the overall area proportions have
539 increased substantially for all countries except Finland, but more striking, for Finland the area
540 proportion undergoing forward and inverse conversion is reversed. Further investigation and
541 comparison of the Finland and Slovakia cases show different patterns of change which are
542 dependent on the history and economy of the region. For Finland, where forest management is a

543 key part of its economy, the inverse conversions at level 2 and the forward conversions at level 3
 544 represent in most instances the same changes which are associated to a forest type 'A' (e.g. 313)
 545 – non-forest (324) – forest type 'B' (e.g. 312) conversion. Slovakia, at the other hand, shows a
 546 large proportion of inverse conversions at both thematic levels 2 and 3. Here, previously
 547 collectivized and intensified arable land has, since 1990, slowly been reclaimed, abandoned or
 548 restituted to co-operatives (Kuemmerle *et al.* 2006), which could explain the proportions of land
 549 (28 % and 4 % of land that underwent change twice – Figure 11) showing an inverse conversion
 550 from 242, 'complex cultivation' to 211, 'non-irrigated arable land' and back and 231, 'pastures'
 551 to 242 'complex cultivation' and back. Forest management is likely to be the main explanation
 552 for the transitions from 231 and 324, 'transitional woodland shrub' to 31*, 'forest' and back.

553

Insert Figure 9, Figure 10 and Figure 11

554

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

5591. Agricultural Intensification: includes agricultural conversions as well as cases in which
 560 human-altered areas become transformed into a more intensive practice by changing the
 561 natural cover.

5622. Land Abandonment: includes the cropping cessation and conversion into early successional,
 563 herbaceous habitats. The transition to woody, later-successional habitats has been considered
 564 as a Mediterranean extension of afforestation.

5653. Afforestation: includes the conversion of open (more or less natural) habitats into forests or
 566 macchias.

5674. Deforestation: we have distinguished deforestation from afforestation instead of considering
568 the first as a relaxation of the second. Both are in fact affecting biodiversity in different ways.

5695. Drainage: in a broad sense, includes all changes affecting aquatic habitats that are
570 transformed into more terrestrial ones: disappearance of wetlands, but also changes in rivers
571 and in estuarine areas. We have included land gain from intertidal and sea areas in the
572 Netherlands, as well as the lost of peatlands drained due to agricultural practices or replaced
573 by forests in Finland.

5746. Urbanisation: includes the transformation to urban covers but also to related covers (road
575 system, leisure areas, construction sites, etc.)

576

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

5945 Discussion

596Because of the sampling size and a bias towards areas containing nature reserves, it was not
597possible to produce statistical reliable estimates of land cover change for the six BRME regions
598of Europe based on the BIOPRESS sites. BIOPRESS was a demonstration project testing a
599methodology that could be applied to monitoring habitats and their biodiversity from pan-
600European land cover change on an operational basis if adequate sampling was provided. In this
601context, the project produced some interesting results. The degree of thematic detail and level of
602spatial detail of the land cover measured will determine the type, amount and rate of change
603detected. It will also to a certain extent determine the reliability of the results, although other
604factors such as clarity of definition and the quality of the source data will also play a role. The
605original choice of nomenclature used to define the land cover, the characteristics of the imaging
606system and the capability of this system to distinguish the classes defined by the nomenclature is
607important. For long term land cover change detection, consistency in methodology is key, so the
608solution is either to have a nomenclature designed independent of the imaging system used or to
609rely on the long term availability of similar and affordable imagery (with respect to spatial and
610spectral resolution) (Duhamel 1998).

612 BIOPRESS, LACOST and MOLAND/MURBANDY agree that Europe has witnessed
613an increase in urban sprawl, mainly in the form of discontinuous buildup. Interestingly
614BIOPRESS found that this is mainly at the cost of arable land (211, 231 or 242) whilst
615LACOST also highlights losses of forest to urban and MURBANDY losses of natural areas to
616urban. Bearing in mind that all three findings are based on biased samples – LACOST having

617 focused on a 10 km coastline buffer coastline, MOLAND/MURBANDY on large urban centers
618 and BIOPRESS on areas near or surrounding nature reserves - the results suggest that
619 urbanisation is widespread across Europe but that the losers to urban sprawl will depend on the
620 local context.

621

622 The BIOPRESS results show different types of changes dominating different regions in
623 Europe. These are likely to have been the result of different social, political and economic
624 processes. One particular example was highlighted in this paper, showing hints picked up by
625 BIOPRESS from the observed differences between Finland and Slovakia. Other more localized
626 and detailed studies clearly demonstrate the importance of these processes at national and local
627 level and their impact on the evolution of the local landscape. For example, (Kuemmerle *et al.*
628 2006) found distinct differences in the economic and political processes and subsequent changes
629 that occurred following the breakdown of the Soviet Union between three neighbouring Eastern
630 European countries. (Mottet *et al.* 2006) who studied the land use history of eight farms in the
631 French Pyrenees confirmed 'remoteness' to be an important generic cause of land cover/use
632 change in the European mountain areas but also detected local specific dynamics. A stratification
633 of the European landscape should therefore, where relevant, take into consideration local social,
634 economic and political backgrounds (Jongman *et al.* 2006).

635

636 The methods implemented by BIOPRESS (and LACOAST and MOLAND/
637 MURBANDY) are only able to determine conversions from one cover type into another. Land
638 cover modifications, where 'more subtle changes affect the character of the land cover without
639 changing the cover itself', are generally more common than land cover conversions (Copin and
640 Lambin 2004) and often have a significant negative or positive impact on habitat quality and
641 biodiversity. A good example of land cover modification is the case of agricultural

642intensification. The ‘agricultural intensification’ detected by BIOPRESS does not include, the
643subtle changes in, for example, ploughing frequency and fertilizer and pesticide use. Since the
644ultimate aim of BIOPRESS was to assess how changes in the land cover had impacted on the
645habitats and their biodiversity, the original idea was to capture some of the subtle changes
646through the integration of social and economic indicators with the land cover change matrices.
647However we soon found out that (i) there was very little of such data available for the 1950s, (ii)
648the more recent data found for Europe varied significantly in spatial and temporal coverage, scale
649and semantics and (iii) many datasets came with a price tag. Another GMES funded project
650EUROSION which required a wide variety of coastal related data experienced similar stumbling
651blocks (EUROSION 2003). Still, BIOPRESS, in its second phase, was required to assess the
652impact of land cover change on habitats and their biodiversity. Land cover type products derived
653from remote sensing are often listed as a ‘biodiversity’ or ‘environmental’ indicator suitable for
654determining trends in habitats and landscape level biodiversity. BIOPRESS demonstrated, by
655incorporating the land cover change data into biodiversity impact tables (methods and results not
656shown in this paper) that, although data such as the CLC product can provide valuable
657information with potential for improvement, there are clear limitations associated to this
658approach.

659

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661

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674

6757 **References**

676Arino, O., Trebossen, H., Achard, F., Leroy, M., Brockman, C., Defourny, P., Witt, R., Latham,
 677 J., Schmullius, C., Plummer, S., Laurent H., Goryl P., Houghton, N. 2005: *The*
 678 *GLOBCOVER Initiative. In Proceedings of the MERIS (A)ATSR Workshop 2005 26 - 30*
 679 *September Esrin, Frascati: European Space Agency.*

680Comber, A., Fisher, P., Wadsworth, R. 2004: Assessment of a semantic statistical approach to
 681 detecting land cover change using inconsistent data sets. *Photogrammetric Engineering*
 682 *and Remote Sensing* 70, 931-938.

683European Commission, 2003: *Natura 2000 and forests: 'Challenges and opportunities'.*
 684 *Interpretation Guide.* Luxembourg, Office for Official Publications of the European
 685 Communities.

686Coppin, P., Jonckheere, I., Nackaerts, K., Muys, B., Lambin, E. 2004: Digital change detection
 687 methods in ecosystem monitoring: a review. *International Journal of Remote Sensing* 25,
 688 1565-1596.

689Di Gregorio, A., Jansen, L.J.M. 1998: *Land Cover Classification System (LCCS): Classification*
 690 *Concepts and User Manual.* Rome: Environment and Natural Resources Service, Soil

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

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

694 EuroSION, 2003: *EuroSION Dataset Structure Description, Commission Contract nr:*
695 *B4-3301/2001/329175/MAR/B3.* Toulouse: EADS S&DE.

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

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

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

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

707 Friedl, M. A., McIver, D.K., Hodges, J.C.F., Zhang, X.Y., Muchoney, D., Strahler, A.H.,
708 Woodcock, C.E., Gopal, S., Schneider, A., Cooper, A., Baccini, A., Gao, F., Schaaf, C.
709 2002: Global land cover mapping from MODIS: algorithms and early results. *Remote*
710 *Sensing of Environment* 83, 287-302.

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

713 Gosepath, A., Saradeth, S., Relin, A., Richter, R. 2003: *LUCAS Lot 6, Role of photo*
714 *interpretation in the LUCAS survey.* Munich: European Commission Statistical Office of

715 the European Communities, Eurostat, Unit F-2 Statistics on Agriculture, Environment and
716 Energy.

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

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

725 Jongman, R. H. G., Bunce, R. G. H., Metzger, M.J., Mucher, C.A., Howard, D.C, Mateus, V.L.
726 2006: Objectives and applications of a statistical environmental stratification of Europe.
727 *Landscape Ecology* 21, 409-419.

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

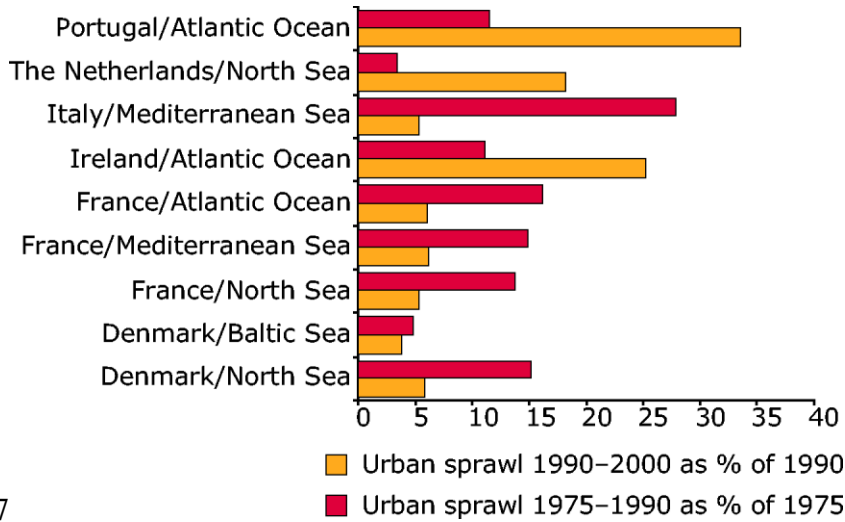
731 Lavallo, C., Demicheli, L., Kasanko, M., McCormick, N., Barredo, J., Turchini, M., da Graça
732 Saraiva, M., Nunes da Silva, F., Loupa Ramos, I., Pinto Monteiro, F., Caetano, M. 2002:
733 *Towards an urban atlas. Assessment of spatial data on 25 European cities and urban*
734 *areas*. Copenhagen: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

735 Lavallo, C., Demicheli, L., Turchini, M., Casals-Carrasco, P., Niederhuber, M. 2001: Monitoring
736 megacities: the MURBANDY/MOLAND approach. *Development in Practice* 11,
737 350-357.

- 738Lepers, E., Lambin, E., Janetos, A., DeFries, R., Achard, F., Ramankutty, N., Scholes, R. 2005:
739 A synthesis of information on rapid land-cover change for the period 1981-2000.
740 *Bioscience* 55, 115-124.
- 741Loveland, T.R., Belward, A.S. 1997: The IGBP-DIS global 1km land cover data set, DISCover:
742 first results. *International Journal of Remote Sensing* 18, 3289-3295.
- 743Loveland, T. R., Zhu, Z., Ohlen, D.O., Brown, J.F., Reed, B.C., Yang, L. 1999: An Analysis of
744 the IGBP Global Land-Cover Characterization Process. *Photogrammetric Engineering*
745 *and Remote Sensing* 65, 1021-1032.
- 746Millenium Ecosystem Assessment. 2005: Ecosystems and human well-being: Synthesis.
747 Washington, DC.: Island Press.
- 748Mottet, A., Ladet, S., Coque, N., Gibon, A. 2006: Agricultural land-use change and its drivers in
749 mountain landscapes: A case study in the Pyrenees. *Agriculture Ecosystems &*
750 *Environment* 114, 296-310.
- 751Perdigao, V., Annoni, A. 1997: *Technical and methodological guide for updating CORINE Land*
752 *Cover data base*. Brussels: Joint Research Centre, European Commission.
- 753Perdigao, V., Christensen, S. 2000: *The LaCoast Atlas: Land Cover Changes in the European*
754 *Coastal Zones*. Ispra, Italy: European Commission, Joint Research Centre, Space
755 Applications Institute.
- 756Pereira, H.M., Cooper, H.D. 2006: Towards the global monitoring of biodiversity change. *Trends*
757 *in Ecology & Evolution* 21, 123-129.
- 758Provost, F., Kohavi, R. 1998: Guest editors' introduction: On applied research in machine
759 learning. *Machine Learning* 30, 127-132.
- 760Stanners, D., Bordeau, P. 1995: *Europe's environment; The Dobris assessment*. Copenhagen:
761 European Environment Agency.

- 762 Thomson, A.G., Manchester, S.J., Petit, S., Swetnam, R.D., Smith, G.M., Wadsworth, R.A.,
763 Gerard F.F. 2007: The use of digital aerial photography and CORINE-derived
764 methodology for monitoring recent and historic changes in land cover. *International*
765 *Journal for Remote Sensing* 28, 5397-5426.
- 766 Weber, J.L., Hall, M. 2001: *Towards spatial and territorial indicators using land cover data*.
767 Copenhagen: European Environment Agency.
- 768 Wickham, J. D., O'Neill, R.V., Jones, K.B. 2000: Forest fragmentation as an economic indicator.
769 *Landscape Ecology* 15, 171-179.
- 770 Wyatt, B., Gerard, F.F. 2001: What's in a Name? Approaches to the inter-comparison of Land
771 Use and Land Cover Classifications. In Groom G., editor, *Strategic Landscape*
772 *Monitoring for the Nordic Countries*. Copenhagen: Levison & Johnson & Johnson,
773 113-121.
- 774

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781 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>).

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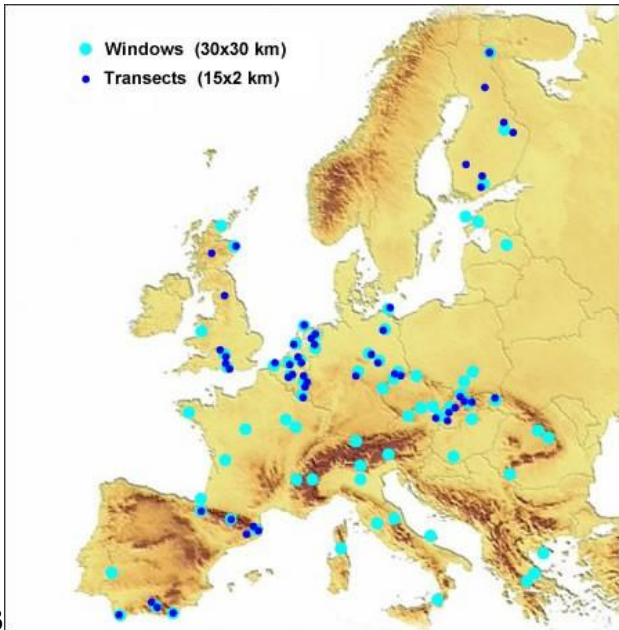


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788 Figure 2. Photo-to-photo interpretation (transects), left, 1998; middle, 1986 photo with 1986 interpretation added to 1998 polygons; right, 1953 photo with 1953 interpretation added to 1986 and 1998 polygons.

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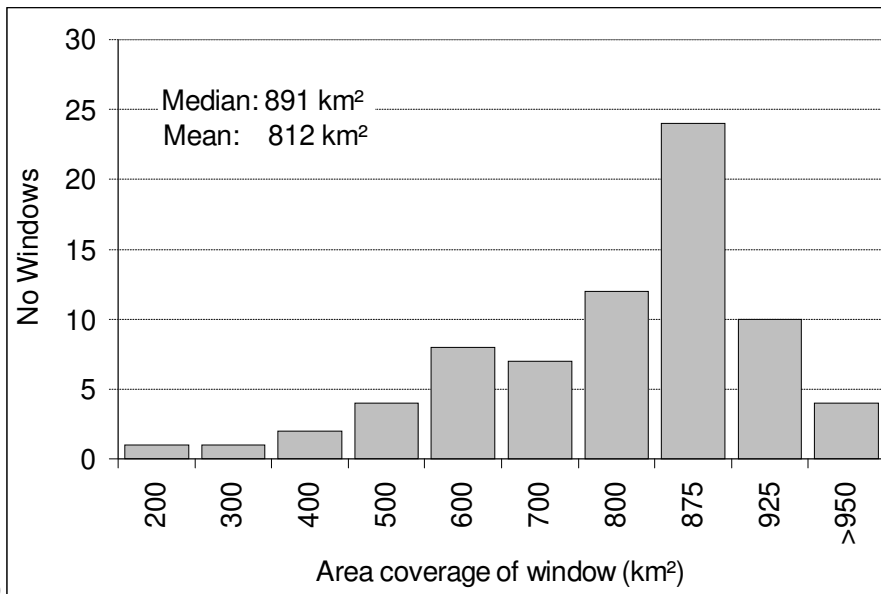
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795 Figure 3. The location of windows and transects interpreted

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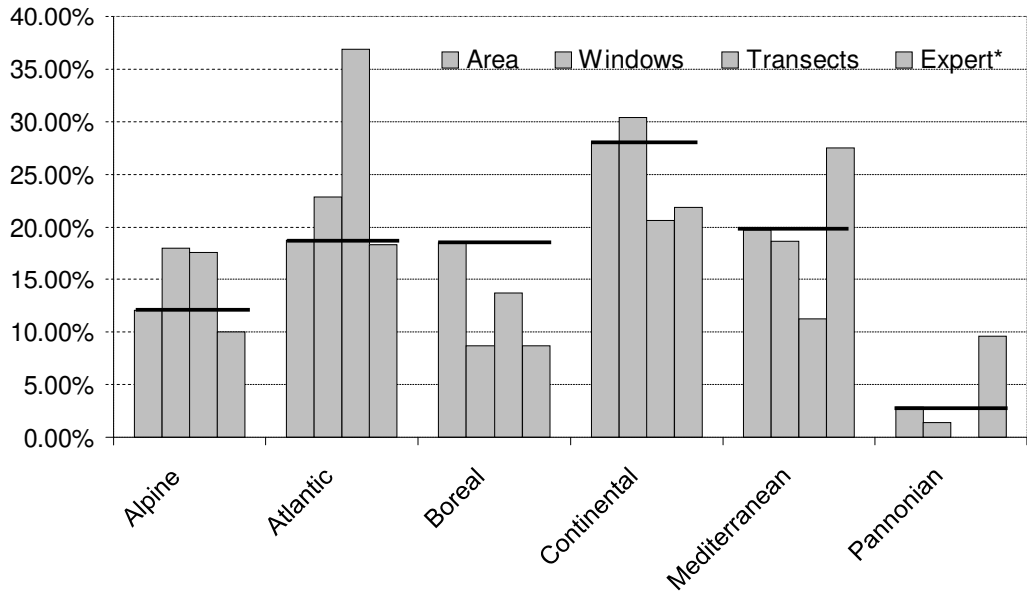
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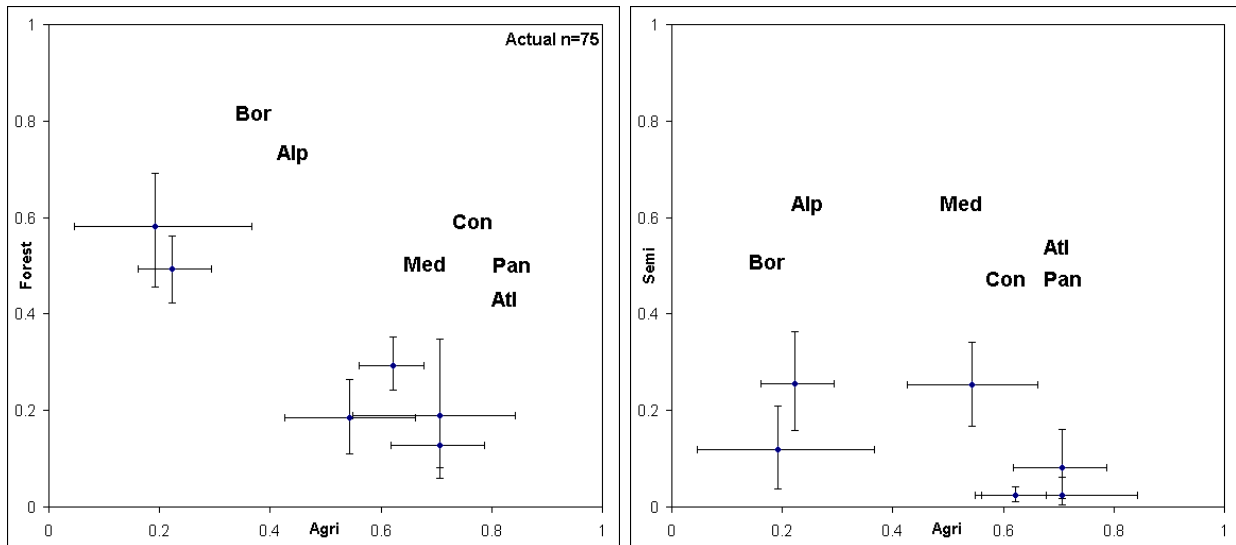
801 Figure 4. The area coverage distribution of the window sites.

802



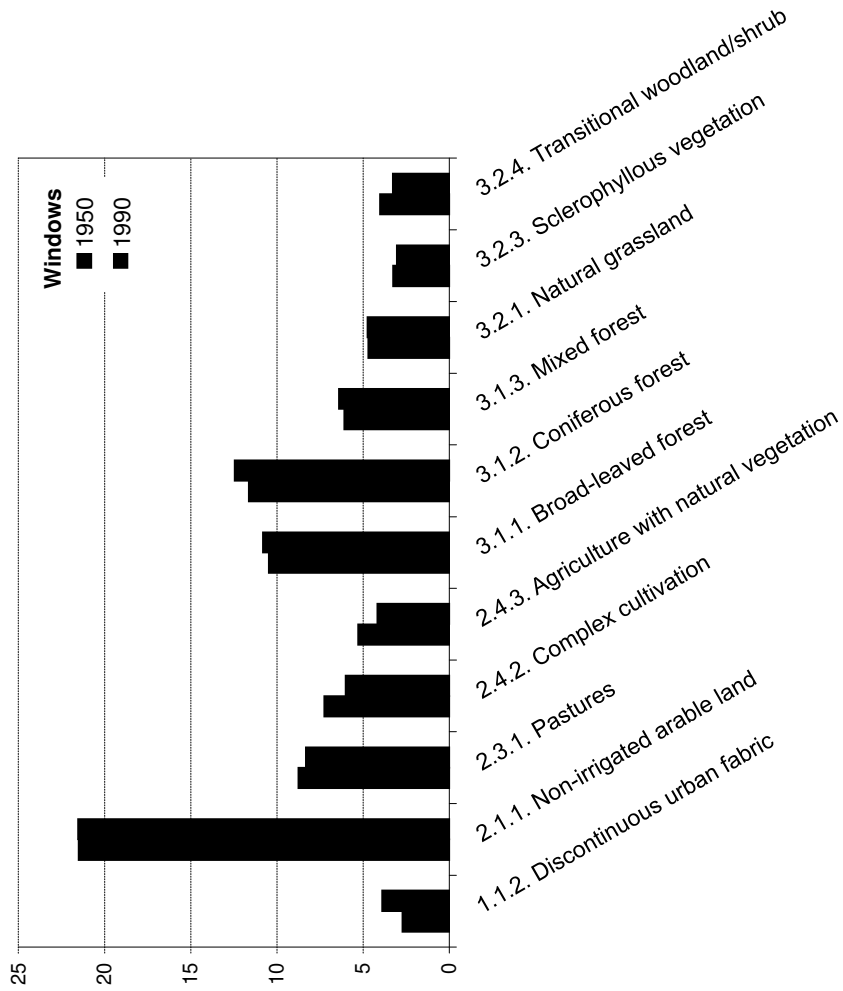
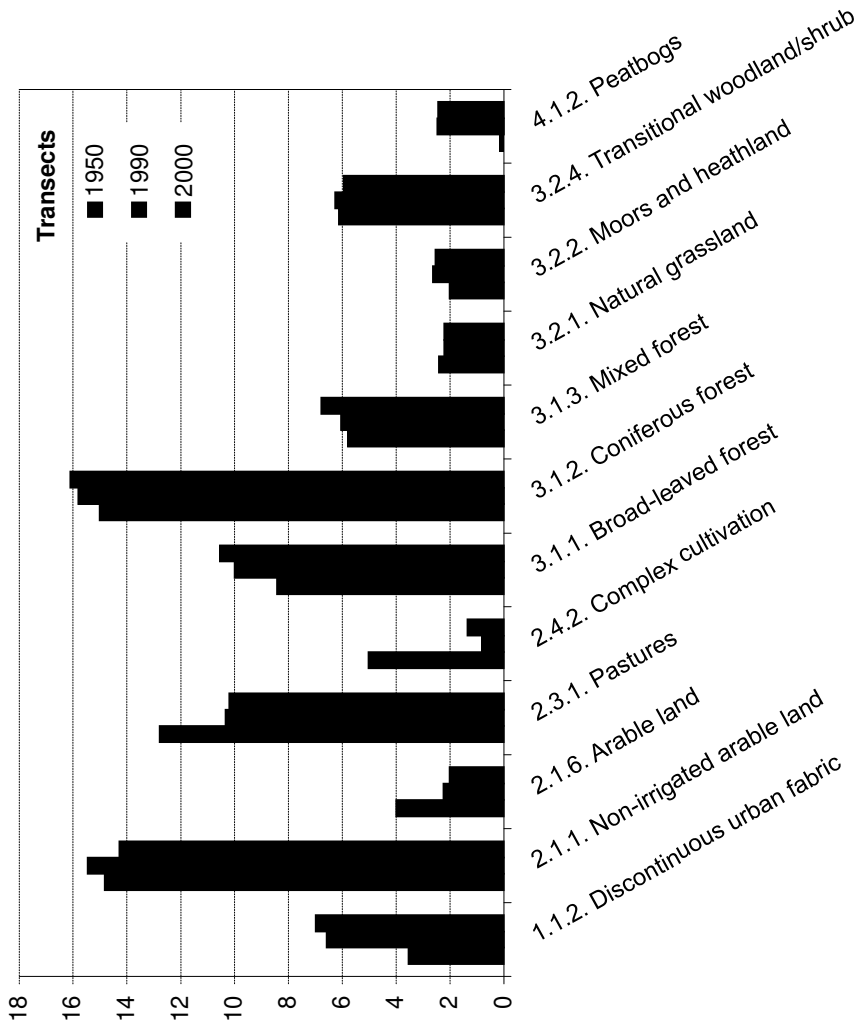
803
 804 Figure 5. The relative area distribution per BRME zone, compared with the relative area
 805 distribution achieved by the transect and window sites and the relative distribution of the original
 806 super-set of sites (Expert).

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814 Figure 6. An analysis routine was established to randomly sample a set of 75 (30km x 30km)
 815 grid cells which were then used as the population to derive mean CORINE land cover proportions
 816 (Agriculture, Forest and Semi-Natural) for each BRME zone of Europe. This routine was
 817 repeated 1000 times for each BRME zone to represent the possible range of results that could
 818 have been derived if different sets of windows or transects had been selected. The 1000 mean
 819 proportion results for each BIOPRESS land cover aggregation were sorted and the 50th and
 820 50th were extracted as estimates of the variability within the BRME zone. The figure shows the
 821 mean cover proportions and variability of (a) Agricultural classes against Forest classes and (b)
 822 Agricultural classes against Semi-natural classes.



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827

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

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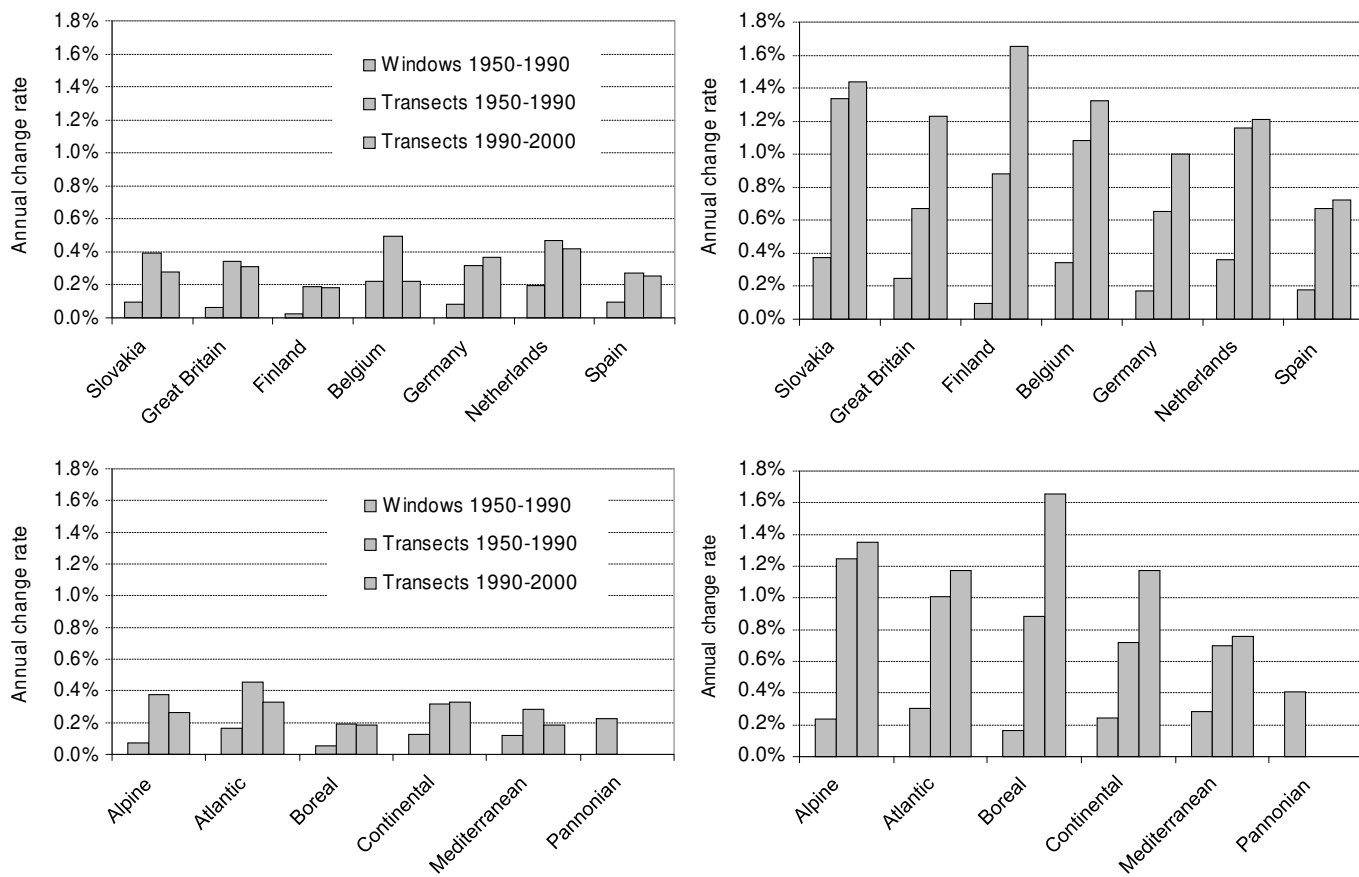
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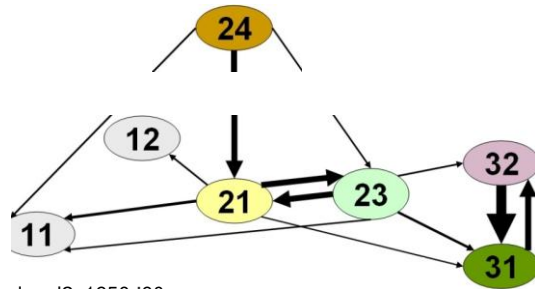
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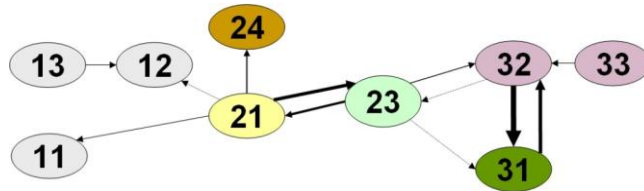
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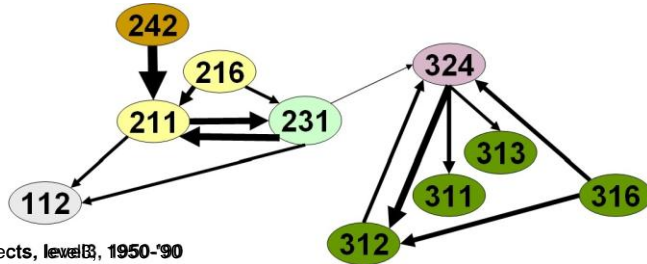
841 Figure 8. Annual rate of change detected at CORINE Land Cover level 1 (left) (5 classes) and
842 level 3 (right) (44 classes) calculated per country (top) and per biogeographical (BRME) zone
843 (bottom).



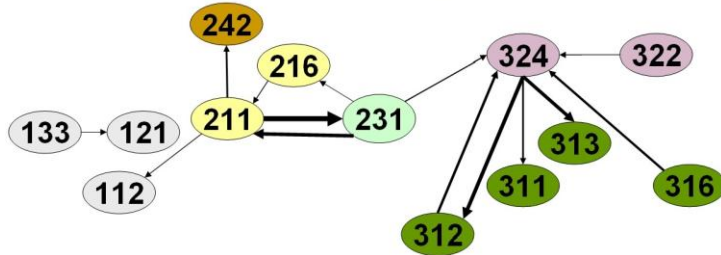
Transects, level2, 1950-'90



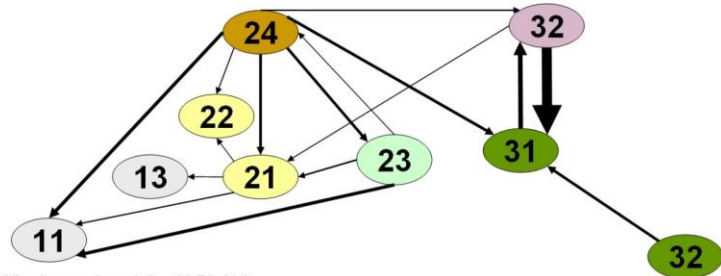
sects, level2, 1990-'00



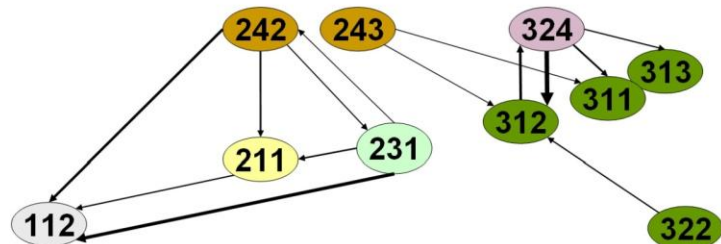
Transects, level3, 1950-'90



nsects, level3, 1990-'00



Windows, level 2, 1950-'90



..wiDdows, level 3, 1950-'90

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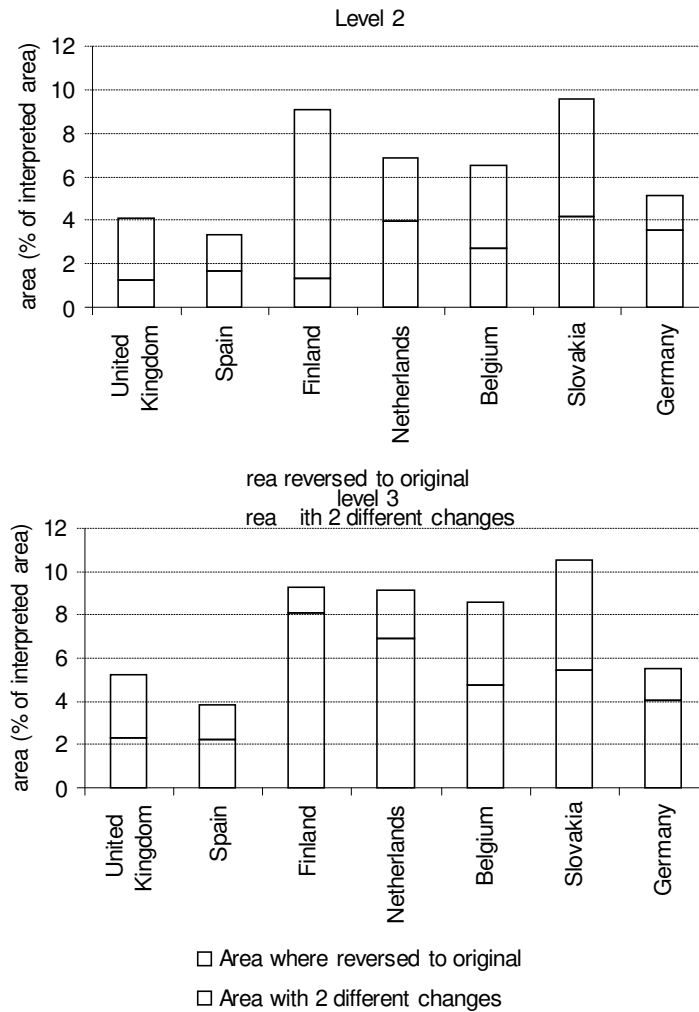
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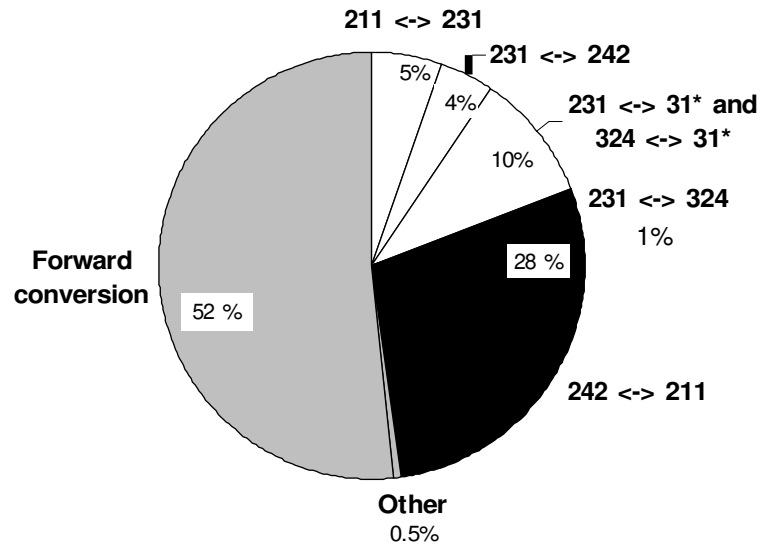
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850

851Figure 9. The largest cover flows observed at level 2 (15 classes) and level 3 (44 classes) from
852the windows (2 10,000 ha for 1950-1990) and transects (2 1300 ha for 1950-1990; 2 300 ha for
8531990-2000) in terms of total area changed. The thickness of the arrows is relative proportional to
854the total area changed observed. The complete listing of the CORINE level 3 class headings can
855be found in Table 8.



857
858 Figure 10. Proportions of interpreted transect area which has undergone changes twice as
859 observed from level 2 (15 classes) and level 3 (44 classes).
860
861



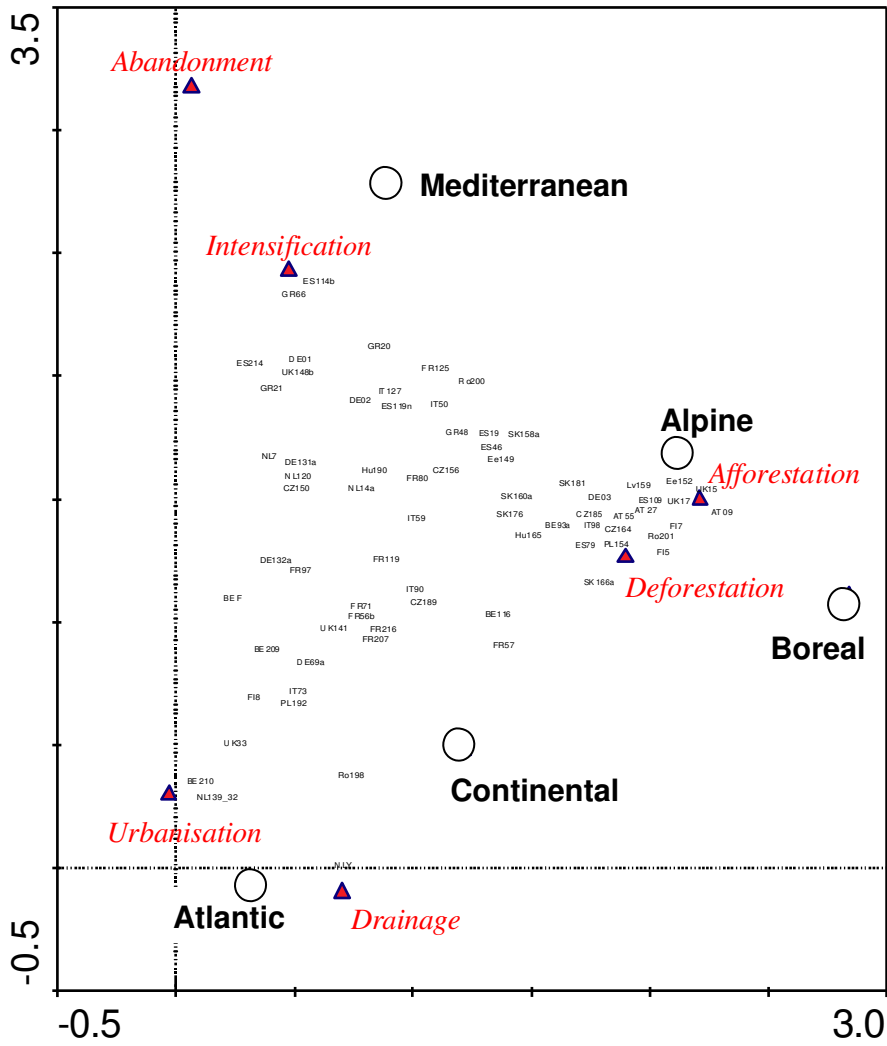
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863

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

866

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869

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

873

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877Table 1. Land cover changes 1990-2000 for Europe in hectares as a cross-tabulation between
878CLC1990 (rows) and CLC2000 (columns) (Source: <http://www.eea.europa.eu>. Copyright EEA,
879Copenhagen, 2005)

880

	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

881

882

883Table 2. Statistics directly extracted from the MURBANDY/MOLAND database. Source:
884Lavalle, Demicheli et al. 2002.

885

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

886

87

887Table 3. The distribution and area coverage of windows and transects on a country by country
888basis. Highlighted countries contain transects.

889

Country	Windows		Transects		Bio-geographical region
	No.	Mean size (km ²)	No.	Mean size (km ²)	
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	

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891

892Table 4. Overall thematic consistency for all transects

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

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898Table 5. Thematic consistency for a selection of individual transects

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	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%

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902

903Table 6. Change accuracy for all validation points

904

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

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44

905Table 7 Proportion (%) of CLC level 1 cover types observed in 1950 and 1990
906

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

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911Table 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	

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