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European Validation of Land Cover Changes in CLC2006 Project

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Abstract. CORINE Land Cover 2006 is the third European Land Cover inventory (1990s, 2000 and 2006). The number of participating countries is increasing, at present being 38. Countries (CH, IS, NO, TR) not participating previous CLC inventories have joined the CLC2006 project. The project is co-financed by the EEA and the member countries and covers 5,8 million km^2 of the European continent. Project was implemented by national teams. A Technical Team under ETC-LUSI was responsible for technical follow-up of the project. For production of CLC-Change$_{2000-2006}$ database "change-mapping first" visual photo-interpretation technology was applied by majority of countries. Scandinavian countries replaced part of labour-intensive photo-interpretation with GIS and image processing. CLC2006 database was usually produced in GIS by adding together revised CLC2000 and CLC-Change$_{2000-2006}$. National teams used multi-temporal (2 coverages) SPOT-4/5 and/or IRS-P6 imagery to derive the minimum 5 ha land cover changes that occurred between 2000 and 2006. Ortho-corrected satellite images provided a solid geometrical basis for mapping land cover changes based on the standard CLC nomenclature. Results show that land cover changed on 1,25% of the surface of Europe between 2000 and 2006, which is equivalent to the size of Lithuania. Forestry changes (forest felling and growth) constitute the largest change area as well as they provide the highest number of change polygons. Stratified random sampling was used for validating the database of CLC-Change$_{2000-2006}$, being the first change validation exercise in the history of CLC. The obtained 87,8%±3,3% overall accuracy (calculated using commission error only) based on 2405 samples is satisfying. Omission error was not possible to measure due to the very large sample size required, being the consequence of small change percentage.

Keywords. CORINE, land cover, land cover change, statistical validation

1. Introduction

From 1985 to 1990, the European Commission implemented the CORINE Programme (Co-ordination of Information on the Environment). During this programme an information system on the state of the European environment was established, nomenclatures and methodologies were developed and agreed at European level. The first CORINE Land Cover (CLC) project was implemented in most of the EU countries, as well as in the 13 partner countries in Central and Eastern Europe [1]. CLC data provide information on the physical characteristics of the earth surface. Images acquired by earth observation satellites are used as the main source data to derive land cover information.

Since the setting up of the European Environment Agency (EEA) and the establishment of the European Environment Information and Observation Network (EIONET), the responsibilities of the CORINE databases have been lying with the EEA.

The second CLC inventory was implemented within the IMAGE&CLC2000 project, based upon lessons learnt from the first CLC inventory, a list of user needs and the available satellite images. The overall aim was to produce an updated CLC database (CLC2000) and the database of land cover changes (LCC) between the first CLC inventory and 2000 (CLC-Change$_{1990-2000}$) [2].

The third CLC inventory (CLC2006) was the result of EEA's collaboration with the European Commission (EC) and the European Space Agency (ESA) on the implementation of the Fast Track Service on Land Monitoring (FTS LM) in line with the communication: "Global Monitoring for Environment and Security (GMES): From Concept to Reality" [3].

In its more than 20 years history CORINE Land Cover has maintained its basic technical specifications (e.g. nomenclature, geometric resolution [6]), but the way of technical implementation has significantly changed since the beginning. In CLC1990 photo-interpretation was carried out on plastic overlays placed on 1:100.000 scale satellite image printouts. Drawings on the plastic overlay had to be digitized in order to create a database. Deformation of the plastic often caused geometric distortion of land cover data. Today, "drawing" is done on screen - with a geo-referenced satellite image in the background - at a suitable scale selected by the interpreter, creating digital data in one step.

In CLC1990 ortho-correction was not routinely applied in producing the base image map for photo-interpretation. Today, with the availability of DEM at the appropriate resolution ortho-correction of satellite imagery is a standard process, providing higher geometric precision of the imagery.

Ancillary data in CLC1990 were mainly topographic maps and black-and-white photographs as hardcopy. Today, scanned topographic maps are commonly available, and national coverages of digital colour aerial photography are also frequently accessible.

Quality assurance was a difficult task in CLC1990 as checking of photo-interpretation had to carried out on the plastic overlay. Today, computer-assisted quality control – applied since the CLC2000 project – provides written, geo-located explanations regarding the problems. This is an efficient tool of standardizing / harmonizing production and understanding all over Europe.

Data dissemination has also been improved. Since CLC2000 data have had dual ownership (EEA and the country). Today CLC data are freely accessible from the EEA to any person or legal entity.

Chapter 2 introduces CLC2006 as part of the GMES FTS Land Monitoring. As the main purpose of this paper the methodology and results of validation of the European CLC-Change$_{2000\text{-}2006}$ product are presented in Chapter 3 and Chapter 4, respectively.

2. CLC2006 in the frames of GMES

In 2006, based on requirements of DG Environment, DG Agriculture and other users EEA started collaboration with the European Space Agency (ESA) and the European Commission (EC) in the implementation of the Fast Track Service on Land Monitoring under the umbrella of GMES [3]. CLC2006 is one of the components of GMES FTS LM [4] (Fig. 1, Table 1). DG JRC and ESA have defined and implemented the satellite data procurement and processing (IMAGE2006).

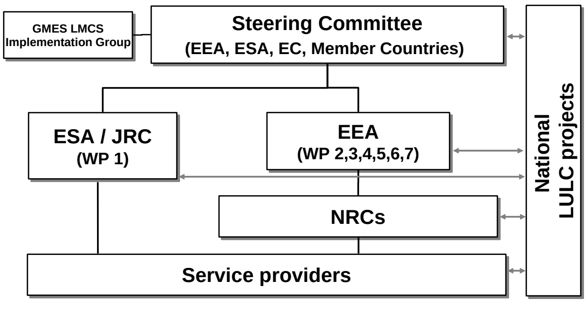

Figure 1: Organisational chart of GMES FTS Land Monitoring [4].

Table 1. GMES FTS Land Monitoring work packages and the overview of the role of partners [4].

Tasks	NRC	EEA	ESA	JRC	Data & service providers
WP1.1 Satellite data acquisition	x		O	x	O
WP1.2 Ortho-correction			O		O
WP1.3 Satellite image mosaic				O	O
WP2 In-situ and ancillary data collection	x	O			O
WP3.1 CORINE land cover change mapping 2000-2006	O	O			
WP4.1 Built-up areas and degree of soil sealing 2006	x	O			O
WP4.2 Forest area mapping (not implemented)					
WP5 Validation	x	O			
WP6 Data dissemination	x	O	x	x	
WP7 Project management	x	O	x	x	
O = leading organization x = organisation involved NRC = National Reference Centre					

2.1. IMAGE2006

Imagery from Landsat-7 satellite, used in CLC2000 project being unavailable at the time of project (due to malfunction), new sources of suitable satellite imagery had to be found for purposes of the GMES FTS Land Monitoring. As a result of agreements between satellite operators and ESA, imagery from two types of satellite has been acquired for purposes of CLC2006:

- SPOT-4&5 (French, 60 km swath width, 20 m pixels; VIS, NIR and SWIR bands), and
- IRS P6 (Indian, 141 km swath width, 23 m pixels; VIS, NIR and SWIR bands).

IMAGE2006 is a multi-temporal satellite image coverage with coverage-1 usually taken in summer, while coverage-2 in spring or autumn. According to specifications, the acquisition date of coverage-2 should be more than 6 weeks away from that of coverage-1 in order to provide an optimal basis for photo-interpretation. Altogether 2416 SPOT 4 and 5 images and 1283 IRS P6 images were acquired and ortho-rectified for the project [5]. Ortho-rectification was executed by DLR and Metria.

2.2. Geographical coverage

The GMES FTS Land Monitoring aimed to cover the EU27, neighbouring countries and all EEA Member countries, namely:

- Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom,

as well as the West Balkan countries, namely

- Albania, Bosnia and Herzegovina, Croatia, FYR of Macedonia, Montenegro, Serbia.
- Kosovo joined the project following her independence.

Four countries not participating previous CLC inventories joined the project (CH, IS, NO and TR). Greece did not participate. Thus altogether 38 countries were involved, covering 5,7 million km^2 of land area (Fig. 2).

National organisations responsible for technical implementation and technical project managers of the participating countries are listed in Annex 1.

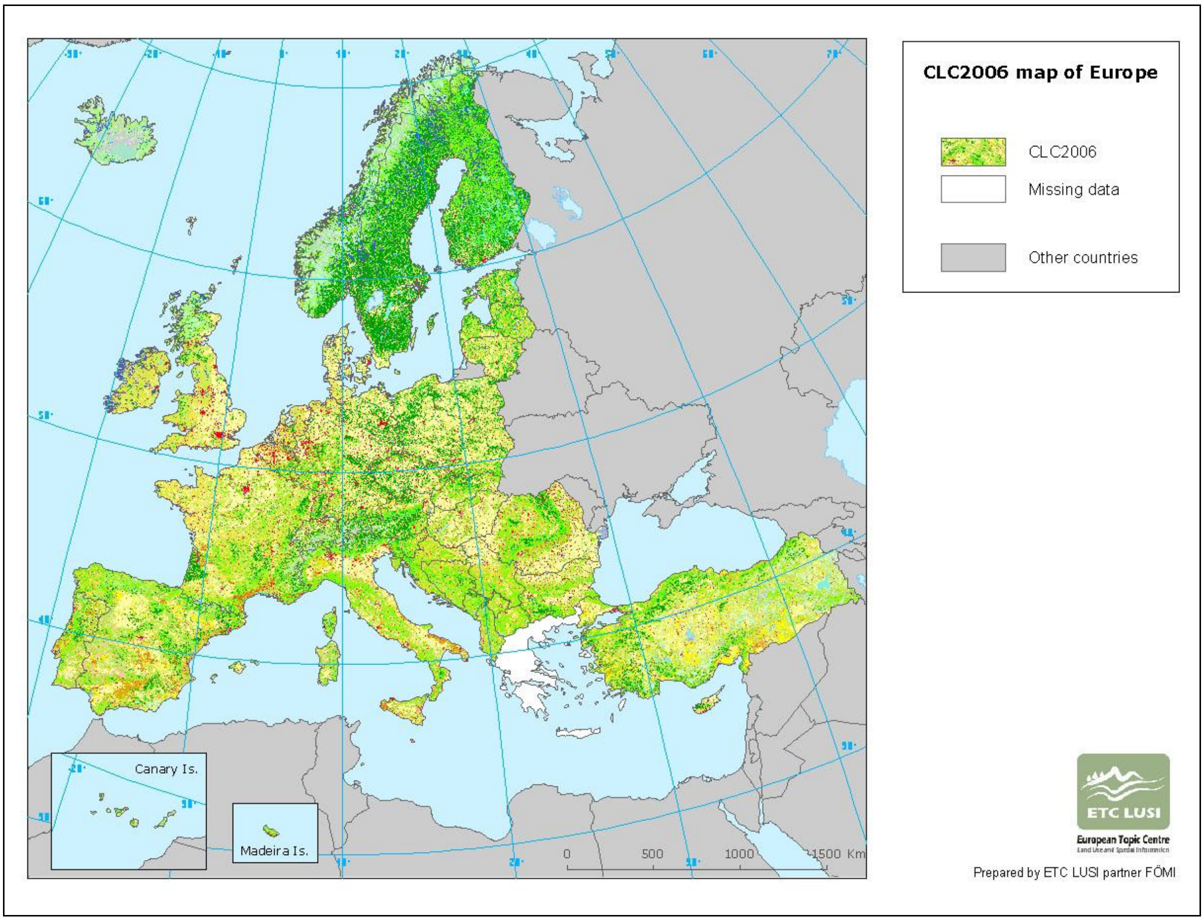

Figure 2: Coverage of the CLC2006 database

2.3. Mapping methodology

Basic parameters of CLC2006 are the same as those of previous CLC inventories [7] thus continuity with CLC1990 and CLC2000 is maintained:

- minimum mapping unit (MMU) is 25 hectares;
- minimum width of linear elements is 100 metres;
- standard CLC nomenclature, which includes 44 land cover classes on level 3. The five level-1 categories are: 1) artificial surfaces, 2) agricultural areas, 3) forests and semi-natural areas, 4) wetlands, 5) water bodies [7]. The list of standard CLC classes is presented in Annex 2.

CLC-Change$_{2000\text{-}2006}$ was the primary product of the CLC2006 project. The aim was to produce the European coverage of real land cover changes that

- are larger than 5 ha and wider than 100 m;
- occurred between 2000 and 2006;

- reflect real evolution process (e.g. urban sprawl, new forest plantation, new water reservoir).

The proposed method was computer-aided visual interpretation of satellite images [8]. Image classification based methods, as alternatives of visual interpretation, were not considered mature enough to handle the large number of CLC classes in the diverse geographic environment of Europe. National experts interpreted CLC changes directly on screen, by comparing IMAGE2000 and IMAGE2006 data in a dual-window environment. Delineation of changes was based on CLC2000 polygons in order to avoid creating sliver polygons and consequently false changes when producing CLC2006 database. Interpreters gave two CLC codes to each change polygon: code2000 and code2006. Change code pair thus shows the process that occurred in reality and thus may be different from the codes occurring on the CLC2000 map and / or in the final CLC2006 map, due to generalization applied in producing CLC2000 and CLC2006 [8]. The main benefits of this direct change-mapping approach are: (1) changes are interpreted directly (the interpreter has to think about what the real process was), (2) all changes larger than 5 ha can be easily delineated regardless of their geometric position (attached to an existing CLC2000 polygon or not). The weakness is that some small (< 5 ha) deficiencies of CLC2006 cannot be avoided [9].

In some countries (especially in Scandinavia) procedures different from visual photo-interpretation were used for deriving CORINE Land Cover data [10, 11, 12, 13]. These solutions combine national GIS datasets, satellite image processing, on-screen digitization (visual photo-interpretation) and GIS-based generalisation.

Table 2 summarises the main features of CLC-Change$_{2000\text{-}2006}$ database. Having the CLC-Change$_{2000\text{-}2006}$ database completed, CLC2006 is generated in an automated process [8]:

$$\text{CLC2006} = \text{CLC2000 } (+) \text{ CLC-Change}_{2000\text{-}2006}$$

Where (+) means the following operation: CLC2000 (revised) and CLC-Change$_{2000\text{-}2006}$ databases are intersected, then CLC-Change$_{2000\text{-}2006}$ polygons' code2000 is replaced by code2006. Finally, neighbours with identical code are unified and small (<25 ha) polygons are generalized according to a priority table [14].

Table 2. Figures characterising the CLC-Change$_{2000\text{-}2006}$ Europe database (V14)

Total changed area:	68 645 km^2
Part of Europe (without sea and ocean) that changed in 6 years	1,25 percent
Number of change polygons	352 987
Number of change types occurring	924
Number of change types providing 90% of total change area	73
Number of sporadic change types (each giving less than 0.1% of total change area)	845
Change types providing 50% of total change area	312-324, 23 473 km^2 311-324, 5 726 km^2 324-312, 5 702 km^2
Change types with the largest number of change polygons	312-324, 143 552 polygons 324-312, 33 429 polygons 311-324, 24 618 polygons

3. Validation strategy

After completing the previous CLC inventory, ETC-TE validated CLC2000 database by using LUCAS data, which provided results better than the 85% accuracy specification [15]. As the percentage of CLC changes between 2000 and 2006 is small, similar accuracy can be expected for CLC2006. Therefore in the CLC2006 project it was decided to validate only the database of CLC-Change$_{2000\text{-}2006}$, being the first change validation exercise in the history of CLC. Stratified random point sampling was chosen to select locations for independent visual photo-interpretation and comparison with the CLC-Change layer. This solution is considered to provide relevant information on the database quality with affordable effort. Some of the participating countries validated their national results independently using a similar method [16].

3.1. Sampling strategy

By validation of land cover changes we are looking for answer to the following basic questions:

a) Do the mapped changes represent real change process? (This is measured by commission error.)
b) Have all the changes been found? (This is measured by omission error.)

While commission error is relatively easy to estimate by sampling within CLC change polygons, reliable estimation of omission errors would require an enormous number of samples (Table 3) and effort.

Table 3. Number of samples required to estimate 15% omissions (with ± 5% standard deviation)

Selected change type in CLC-Change$_{2000\text{-}2006}$	Percent changes relative to CLC2000	Number of necessary samples	Number of samples expected to find the 15% omission error	Calculated omission error (related to class area)
133-112	40,5	100	10	14,7%± 4,4%
312-324	3,28	1 800	9	14,7%± 4,9%
231-211	0,24	25 000	9	15,0%± 5,0%
312-334	0,05	120 000	9	15,0%± 5,0%
211-512	0,01	600 000	9	15,0%± 5,0%
All changes	1,25	5 000	10	15,7%± 5,0%

Table 3 provides some representative change rates based on CLC-Change$_{2000\text{-}2006}$ statistics. There is only one level-3 class with high rate of changes: 40,5% of the CLC2000 class 133 changed to 112 class during the 2000-2006 period (meaning construction site changed to residential area). In this case an omission error around 15% could have been estimated with ± 4,4% standard deviation using only 100 samples. For all other cases the number of samples required for a meaningful result, obviously made the exercise difficult or not accomplishable. However, the practical evaluation of omitted changes of CLC2000 class 133 failed, due to unavailability of revised CLC2000 data in most of the countries.

Commission error is estimated by distributing random point samples within CLC change polygons. By this sampling design a further question on database quality can be answered, namely if the type of the change mapped is correct.

There are over 900 level-3 change types in the European CLC-Change$_{2000\text{-}2006}$ database (Table 2). As it is not possible to test all change types, some kind of selection or grouping of level-3 changes had to be done in order to provide an overall picture of accuracy of CLC-Change$_{2000\text{-}2006}$.

Therefore two kinds of sampling exercises were implemented:

- Sampling of level-1 changes. There are 25 different level-1 changes in CLC coming from the five level-1 CLC classes (Table 4). Maximum 100 randomly placed sampling points were selected for each level-1 change type. This makes up altogether 2405 samples. (The smallest change type (from class 1 to class 4 - abbreviated as 1-4) included only 5 small polygons.) These samples were used to estimate the commission error of CLC-Change$_{2000\text{-}2006}$ (level 3), grouped according to level-1 change types. In this exercise the whole population of CLC change polygons was sampled. Assigning the same number of samples to frequent change types (e.g. 2-1, 3-3), as to rare changes (e.g. 4-4, 5-5) provided a good statistical basis to avoid bias due to different population sizes of change types. In case of rare change types several sampling points could be placed into a single polygon.

Table 4. Number of CLC change polygons (upper figures) and percent of total area of CLC change types (lower figures) grouped on level 1 of the CLC nomenclature

		Year 2006					
		1	2	3	4	5	Sum
Year 2000	1	5573	834	651	5	287	7 350
		1,8%	0,36%	0,38%	0,00%	0,15%	2,70%
	2	3496	16 137	7 748	124	1 870	60 835
		7,6%	8,33%	2,65%	0,08%	0,57%	19,30%
	3	1091	7 748	261 572	422	1 038	281 741
		2,3%	2,48%	70,92%	0,13%	0,66%	76,51%
	4	147	1 010	1 090	11	86	2 344
		0,03%	0,34%	0,48%	0,06%	0,04%	0,95%
	5	243	85	294	62	33	717
		0,06%	0,05%	0,34%	0,04%	0,05%	0,55%
	Sum	51 880	25 814	271 355	624	3 314	352 987
		11,90%	11,56%	74,77%	0,31%	1,47%	100,0%

1: Artificial surfaces; 2: Agriculture; 3: Forests and semi-natural vegetation; 4: Wetlands; 5: Water

- Additional samples (about 100 samples for each case) for a number of level-3 change types of special interest were selected. The Land Cover Flow (LCF) scheme [17] was used to select which level-3 changes are to be considered. Based on CLC-Change$_{2000\text{-}2006}$ statistics, the largest constituents of each major LCF were identified (Table 5). In this exercise about half of all CLC change polygons were sampled. In two cases (LCF4 and LCF7) we have selected two change types under the same Land Cover Flow. These are balancing processes, which cause a close to equilibrium status in agriculture and forestry. In case of LCF4 (agriculture internal conversions) these are 231-211 and 211-231 (pasture changing to arable land and reverse, respectively). In case of LCF7 (forest creation and management) these are 312-324 and 324-312 (felling and growth of coniferous forest, respectively), the first being the most frequent change type of all. In LCF5 (new agricultural land) the largest constituent (324-244) has an uneven European coverage: CLC class 244 (agroforestry) being limited to practically the Iberian Peninsula, and its interpretation is usually not possible without local knowledge / high-resolution ancillary data. Therefore this change type was not examined.

Table 5. The nine main LCFs and their most dynamic level-3 CLC-Change constituents

Land Cover Flow	Name of the Land Cover Flow [17]	Sampled change	Percentage of change compared to CLC2000 class area
LCF1	Internal transformation of urban areas	133-112	40,5% of all 133 has changed
LCF2	Urban residential sprawl	211-112	0.06% of all 211 has changed
LCF3	Sprawl of economic sites and infrastructure	211-133	0,07% of all 211 has changed
LCF4	Agriculture internal conversions	231-211	0,24% of all 231 has changed
LCF4	Agriculture internal conversions	211-231	0,08% of all 211 has changed
LCF5	New agriculture land	324-244	0,09% of all 324 has changed
LCF6	Withdrawal of farming	211-324	0,07% of all 211 has changed
LCF7	Forest creation and management	312-324	3,28% of all 312 has changed
LCF7	Forest creation and management	324-312	2,24% of all 324 has changed
LCF8	Creation of new water bodies	211-512	0,01% of all 211 has changed
LCF9	Changes of land cover due to natural and multiple causes	312-334	0,05% of all 312 has changed

Based on the above considerations ten level-3 change types were selected for additional sampling (100 samples for each). This selection represents 49,7% of total CLC change area.

3.2. Materials used

In an optimal case reference data for validation consist of:

- Very high resolution (VHR) satellite imagery or orthophotos taken in years 1999-2001 at resolution better than resolution of IMAGE2000;
- VHR satellite imagery or orthophotos taken in years 2005-2007 at resolution better than resolution of IMAGE2006;
- Topographic maps at scale 1:50.000 or finer.

Field photographs from Eurostat LUCAS2006 project would have been very useful for the validation of 2006 status, but as they were used by some of the countries during the production (thus being not independent), they were not relevant for the validation. The large number of participating countries made it unrealistic to collect very-high-resolution orthophotos or satellite imagery and even topographic maps for the purposes of validation. Therefore validation was executed by re-interpretation of IMAGE2000 and IMAGE2006, supported by use of Google Earth (GE) imagery. Multi-temporal 5x5 km imagettes around each sample point were extracted from IMAGE2006 as well as from IMAGE2000. The date of each imagette was precisely known, as this was mandatory for the re-interpretation. GE proved to be an extremely useful support, especially due to its timeseries feature. In many parts of Europe GE provided the required very-high-resolution data for the validation (Fig. 3).

Figure 3: High resolution Google Earth (GE) images are often perfect data sources for validation. Left: September 2003, Right: September 2006. Arable land changed to construction site (Turkey).

3.3. Way of validation

The enhanced plausibility approach was selected to validate CLC-Change$_{2000\text{-}2006}$. In the first step the validation point was blindly interpreted by the validation expert, i.e. without knowing the delineation and CLC-Change attributes of the area. Interpretation meant answering: what type of valid (at least 5 ha) CLC change was visible in the surroundings of the sample point? In the second step outlines the CLC-Change database were displayed on the area and a new validation code should have been provided. In the second step the validating expert had to decide whether the mapped change was correct (OK) or not correct (NOK). Decision “Other” could be chosen if it was not possible to make a decision (i.e. missing or bad quality images). For the NOK case one of the following standard explanations could have been provided:

- No change
- No change, temporal difference only
- No change and CLC2000 code is not corrected
- Change exists, but with different attributes

4. Results of validation

Results of validation of CLC-Change$_{2000\text{-}2006}$ are presented in Tables 6 and 8. In both tables the accuracy figure is followed by standard deviation of accuracy figure. In Table 6 the figure of accuracy refers to percentage of cases when the change was found by the original photo-interpreter and the given attributes were correct. The last column shows the “importance” of the change type by providing the percent of the area of given change type relative to the total area of changes.

The overall accuracy was calculated as a weighted sum: change type accuracies were weighted with the relative area, meaning the share of change type within all changes. The overall accuracy of

CLC-Change$_{2000\text{-}2006}$ database (based on commission error only) is 87,8%, i.e. exceeds the target value of 85%.

Table 6. Accuracy figures for CLC-Change$_{2000\text{-}2006}$ grouped on level 1 (based on commission error only)

Level-1 class CLC2000	Level-1 class CLC2006	No. of samples used	Accuracy (%)	Standard deviation (%)	Size of the change type (% of total changes)
5	5	84	97,6	1,7	0,05
2	5	100	97,0	1,7	0,57
4	4	57	94,7	3,0	0,06
1	5	100	94,0	2,4	0,15
5	1	100	93,0	2,6	0,06
3	5	96	91,7	2,8	0,66
3	3	95	89,5	3,2	70,92
3	4	100	88,0	3,4	0,13
1	1	92	88,0	3,3	1,81
2	3	99	87,9	3,3	2,65
4	1	95	87,4	3,4	0,03
4	2	85	87,1	3,6	0,34
4	3	98	86,7	3,4	0,48
1	2	99	84,9	3,6	0,36
2	1	98	83,7	3,7	7,67
2	2	97	83,5	3,8	8,33
4	5	95	82,1	3,9	0,04
3	1	98	80,6	4,0	2,32
5	3	99	79,8	4,0	0,34
3	2	95	77,9	4,3	2,48
2	4	93	74,2	4,5	0,08
1	3	98	66,3	4,8	0,38
1	4	5	60,0	21,9	0,00
5	2	93	59,1	5,1	0,05
5	4	89	21,4	4,3	0,04
Overall Accuracy		2 260	87.8	3.3	100.00

More than 2/3 of the level-1 change types have accuracy higher than 85% (with standard deviation taken into account). In Table 6 these change types are listed above the bold line. The most frequent of these successfully mapped change types are emphasized here:

- The far largest change types are the internal changes in level-1 class forest / semi-natural (3-3; dominated by forest clearcut and forest growth). Almost ¾ of all changes belong to this type, therefore its 89,5% accuracy is very important.
- Agricultural area changed to forest / semi-natural area (2-3; e.g. afforestation).
- Internal changes within artificial areas (1-1; e.g. construction site changed to residential area).
- Agricultural area changed to water (2-5; e.g. new reservoir on agricultural land).
- Forest / semi-natural area changed to water (3-5; e.g. new reservoir on area originally covered by sclerophyllous shrub).
- Wetland changed to forest / semi-natural class (4-3; e.g. afforestation on peatland).
- Wetland changed to agriculture (4-2; e.g. peatland converted to arable land).
- Artificial areas changed to agricultural land (1-2; e.g. reclamation of mineral extraction sites).
- Agricultural area turned to artificial surface (2-1; e.g. highway construction on agricultural land).
- Internal conversions within agriculture (2-2; e.g. arable land turned to olive plantation).

There are eight change types on the lower end of the accuracy list (below bold line in Table 6). Two of them almost reached the 85% accuracy; 2 others are between 70-80%, while four change types have accuracy below 70%. In this latter group three change types have marginal frequency.

Remarkable change types with accuracies below 85%:

- Forest-semi-natural area changed to artificial surface (3-1; e.g. new highway replacing former forest, almost reached the 85% limit).
- Water changed to forest / semi-natural area (5-3; e.g. changes of unregulated rivers, almost reached the 85% limit).
- Forest / semi-natural area changed to agriculture (3-2; e.g. forest changed to arable land).
- Artificial area changed to forest / semi-natural area (1-3; e.g. reclamation of mineral extraction site by forest) is the least accurately mapped significant level-1 change type.

Table 7. Summary statistics of samples used in validation

Validation case	Explanation of error	Not OK; no-change samples	No. of samples
OK			1859
Not OK; no change			229
	Temporal difference only	51	
	CLC2000 code not correct	28	
	No specific explanation	150	
Not OK; Change exists, but wrong attributes			172
Other (not interpretable)			145
Total:		229	2405

The summary statistics of samples in Table 7 show that:

- 1859 samples (77,3 %) were proved to be correctly mapped by the validation, 401 (16,7%) were found not to be correct, while 145 (6 %) were not interpretable.
- Considering not-correct cases, 229 were judged as "no-change" (57,1%), while 172 (42,9%) were evaluated as "change exists but wrong attributes".
- A significant number of errors (51 out of 229) refer to short-term (seasonal or shorter) differences in land cover misinterpreted as CLC change. This fact underlines the need of further training on mapping CLC changes.
- Still there are errors (28 out of 229) related to mistakes of CLC2000. Because these mistakes are usually inherited by CLC2006, the "retrospective" correction is important in the next CLC update.

Considering the ten level-3 changes selected as "flagships" of major land cover flows we found that all but two change types were above the 85% accuracy limit (with standard deviation taken into account). The following five change types have extra high accuracy (above 90%):

- Arable land converted to construction site (belonging to "urban residential sprawl").
- Arable land converted to water body (belonging to "creation of new water bodies").
- Coniferous forest burnt (belonging to "changes of land cover due to natural and multiple causes").
- Construction of residential area finished (belonging to "internal transformation of urban areas").
- Coniferous forest changed to transitional woodland-shrub (felling) (belonging to "forest creation and management"). This is the largest level-3 change, providing more than 1/3 of area of all CLC changes.

Table 8. Accuracy figures for selected level-3 CLC changes (based on commission error only)

CLC2000 class	CLC2006 class	No. of samples	Accuracy (%)	St.dev. (%)	Size of the change class (% of total change area)	Represented Land Cover Flow
211	133	101	96,0	1,9	1,08	LCF3
211	512	100	96,0	2,0	0,20	LCF8
312	334	96	93,8	2,5	0,50	LCF9
133	112	100	93,0	2,6	0,71	LCF1
312	324	110	92,7	2,5	34,21	LCF7
211	324	100	83,0	3,8	1,11	LCF6
211	112	96	82,3	3,9	0,97	LCF2
211	231	100	82,0	3,8	1,30	LCF4
324	312	99	76,8	4,2	8,25	LCF7
231	211	97	76,3	4,2	1,34	LCF4
Total:	-	999	-	-	49,67	-

Two change types were mapped with accuracy lower than 85%:

- Growth of coniferous forests (belonging to “forest creation and management”). This change type concerns rather significant area in Europe. Mapping it consistently is difficult without in-situ data.
- Pasture/set-aside land changed to arable land (belonging to “agriculture internal conversions“). Its consistent mapping is difficult without in-situ / more multi-temporal data.

Level-3 changes presented in Table 8 constitute almost 50% of all CLC change area. As not the whole CLC change polygon population was sampled in this second exercise, overall accuracy was not calculated.

5. Conclusions

Executed under the GMES FTS Land Monitoring program, CLC2006 was the third land cover mapping project of the European territory. It has provided updated, harmonized land cover and land cover change information for 5,7 million km^2 of the European continent. Good quality multi-temporal satellite imagery, adequate reference data (topographic maps, orthophotos, LUCAS-2006 data etc.), national expertise from the 38 participating countries and strong coordination on behalf of EEA were key elements of the successful implementation. The proposed “change-mapping first” photo-interpretation technology was applied by the majority of countries. Scandinavian countries used more GIS-based data compilation and image processing and less labour-intensive photo-interpretation. Land cover changed on 1,25 % of the surface of Europe between 2000 and 2006, changed area thus being equivalent to the size of Lithuania. Forestry changes (forest felling and growth) occupy the largest area among the changes, providing also the highest number of change polygons.

Validation exercise, deriving commission error of the CLC-Change$_{2000\text{-}2006}$ database was executed by ETC-LUSI. This was the first time a CLC-Change layer was validated. Due the low percentage of changes, deriving omission errors would have required extremely large number of samples and consequently much labour. Therefore deriving omission errors was out of the scope of this study.

Method of stratified random sampling was applied to select samples for validating CLC-Change$_{2000\text{-}2006}$ database. This solution is considered to provide relevant information on the database quality with affordable effort. Samples were interpreted using IMAGE2000, IMAGE2006 and Google Earth imagery. Samples were selected based on two different arrangements of the change population.

(1) 100 sample points were selected from inside each of the 25 level-1 change types, thus representing the whole change polygon population.

(2) 100 samples were selected from each of the 10 “highly important” level-3 changes. The Land Cover Flow scheme was used to determine which changes are to be sampled. This sampling represents almost 50% of the whole change polygon population.

The overall accuracy (based on commission error only) of the CLC-Change$_{2000\text{-}2006}$ database is 87,8% ±3,3%, i.e. exceeds the target value of 85%. 17 of the 25 change type groups have accuracy higher than 85%, 13 types of which having accuracy higher than 90%, including the largest level-1 change class (internal changes in forest and semi-natural vegetation). Among the less accurate change types two almost reached the 85% accuracy; two others have accuracy between 70% and 80%, while four change types are below 70% accuracy. In this latter group three change types have marginal frequency.

Considering the ten level-3 changes selected as “flagships” of major land cover flows we found that all but two change types had more than 85% accuracy (based on commission error). Five change types have accuracy above 90%, including the largest level-3 change type (felling of coniferous forests). Two change types were mapped with accuracy lower than 85%: (1) growth of coniferous forests, and (2) conversion of pasture/set-aside land to arable land.

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Annex 1 Implementing organisations and project managers

country	implementing organisation	technical project manager
Albania	Centre of Agricultural Technology Transfer, Albania GeoVille Austria	Vangjo Kovaci Nina Schuldner
Austria	Umweltbundesamt (Enviroment Agency Austria)	Gebhard Banko
Belgium	IGN Belgium	Yvan Van der Vennet
Bosnia and Herzegovina	University of Sarajevo	Hamid Čustović
Bulgaria	Geomatics Department, Bulgaria Academy of Sciences	Anton Stoimenov
Croatia	GISDATA d.o.o. OIKON	Ivana Lampek Vladimir Kušan
Cyprus	MANRE, Environment Service	Nicos Siamarias
Czech Republic	Help Service – Remote Sensing spol. s.r.o.	Stanislav Holý
Denmark	National Environmental Research Institute (NERI)	Michael Stjernholm
Estonia	Regio AS	Helle Koppa
Finland	Finnish Environment Institute (SYKE)	Pekka Härmä
France	Systèmes d'Information à Référence Spatiale (SIRS)	Lionel Mequignon
Germany	Deutsches Zentrum für Luft- und Raumfahrt (DLR)	Manfred Keil
Hungary	Institute of Geodesy, Cartography and Remote Sensing (FÖMI)	Gergely Maucha
Iceland	National Land Survey of Iceland (LMI)	Kolbeinn Árnason
Ireland	ERA Maptec Ltd.	Martin Critchley
Italy	Università degli Studi del Molise	Gherardo Chirici
Kosovo	EvroGeomatika (Serbia)	Ivan Nestorov
Latvia	Envirotech	Harijs Baranovs
Liechtenstein	Umweltbundesamt (Enviroment Agency Austria)	Gebhard Banko
Lithuania	Institute of Ecology of Vilnius University	Daiva Vaitkuvienė
Luxemburg	GeoVille Luxemburg	Stefan Kleeschulte
Macedonia	GOVe d.o.o.	Zoran Velickov
Malta	Malta Environment and Planning Authority (MEPA)	Saviour Formosa
Montenegro	Geological Survey of Montenegro	Slobodan Radusinovic
The Netherlands	Alterra,Wageningen University and Research Centre	Gerard Hazeu
Norway	Norwegian Forest and Landscape Institute	Linda Aune-Lundberg
Poland	Instytut Geodezji i Kartografii (IGiK)	Elzbieta Bielecka
Portugal	Instituto Geográfico Portuguęs (IGP)	Mário Caeteno
Romania	Danube Delta National Institute (DDNI)	Jenica Hanganu
Serbia	EvroGeomatika	Ivan Nestorov
Slovak Republic	Slovak Environmental Agency (SAŽP)	Nada Machova
Slovenia	GISDATA d.o.o.	Sandra Radi Goljak
Spain	IGN Spain	Antonio Arozarena
Sweden	METRIA, National Land Survey of Sweden	Jan-Peter Mäki
Switzerland	Bundesamt für Umwelt (BAFU)	Tom Klingl
Turkey	Ministry of Forest and Environment	Ahmet Çivi
United Kingdom	Centre for Ecology and Hydrology (CEH)	Ian Simson

Annex 2: CORINE Land Cover nomenclature (European Commission, 1993)

LEVEL 1	LEVEL 2	LEVEL 3
1. ARTIFICIAL SURFACES	1.1. Urban fabric	1.1.1. Continuous urban fabric
		1.1.2. Discontinuous urban fabric
	1.2. Industrial, commercial and transport units	1.2.1. Industrial or commercial units
		1.2.2. Road and rail networks and associated land
		1.2.3. Port areas
		1.2.4. Airports
	1.3. Mine, dump and construction sites	1.3.1. Mineral extraction sites
		1.3.2. Dump sites
		1.3.3. Construction sites
	1.4. Artificial, non-agri-cultural vegetated areas	1.4.1. Green urban areas
		1.4.2. Sport and leisure facilities
2. AGRICULTURAL AREAS	2.1. Arable land	2.1.1. Non-irrigated arable land
		2.1.2. Permanently irrigated land
		2.1.3. Rice fields
	2.2. Permanent crops	2.2.1. Vineyards
		2.2.2. Fruit trees and berry plantations
		2.2.3. Olive groves
	2.3. Pastures	2.3.1. Pastures
	2.4. Heterogeneous agricultural areas	2.4.1. Annual crops associated with permanent crops
		2.4.2. Complex cultivation patterns
		2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation
		2.4.4. Agro-forestry areas
3. FOREST AND SEMI-NATURAL AREAS	3.1. Forests	3.1.1. Broad-leaved forest
		3.1.2. Coniferous forest
		3.1.3. Mixed forest
	3.2. Scrub and/or herbaceous associations	3.2.1. Natural grassland
		3.2.2. Moors and heathland
		3.2.3. Sclerophyllous vegetation
		3.2.4. Transitional woodland-scrub
	3.3. Open spaces with little or no vegetation	3.3.1. Beaches, dunes, sands
		3.3.2. Bare rocks
		3.3.3. Sparsely vegetated areas
		3.3.4. Burnt areas
		3.3.5. Glaciers and perpetual snow
4. WETLANDS	4.1.Inland wetlands	4.1.1. Inland marshes
		4.1.2. Peat bogs
	4.2.Marine wetlands	4.2.1. Salt marshes
		4.2.2. Salines
		4.2.3. Intertidal flats
5. WATER BODIES	5.1. Inland waters	5.1.1. Water courses
		5.1.2. Water bodies
	5.2. Marine waters	5.2.1. Coastal lagoons
		5.2.2. Estuaries
		5.2.3. Sea and ocean