Documenting Typical Land Cover Changes in Europe

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Abstract. This paper gives an introduction to the "manual" compiled by the authors to document mapping of major CORINE Land Cover (CLC) change types in order to support the 4th CLC inventory, which is implemented under GIO (GMES Initial Operations) between 2011 and 2013. CLC and CLC change data provide information on the physical characteristics of the earth surface and are widely used by the EEA and its member states in reporting, indicator development and environmental modelling. The paper relies on the results of change mapping implemented during the 3rd CLC inventory between 2007 and 2011 in 38 European countries. Considering all CLC changes in Europe between 2000 and 2006, 1.24% of the area has changed, covering 70 824 km^2. The number of change polygons is above 350 000. Based on the statistics of CLC-Change$_{2000\text{-}2006}$ database, the most frequent CLC change types - providing 90% of all change area - were selected to be included in the manual for discussion. Change processes are discussed in a standardized way (example of which is given in the paper), including textual description, interpretation example(s) and a list of frequent interpretation mistakes. Examples and mistakes are illustrated by screen-shots of real interpretation cases collected during verification missions. The "knowledge base" of the work is more than 100 verification missions the authors conducted to the participating countries of former CLC inventories. Discussions with experts of the national CLC teams were exceptionally important in shaping the content of the work.

Keywords. GMES, CORINE Land Cover, land cover changes, satellite imagery.

1. Introduction

1.1. Background

CORINE Land Cover (CLC) data provide information on the physical characteristics of the earth surface. CLC and CLC-Change data are widely used by the European Environmental Agency (EEA) and its member states in reporting, indicator development and environmental modelling. Currently, the 4th CLC inventory is under implementation as part of GIO (GMES Initial Operations). Major technical specification (nomenclature [see: Annex 1], MMUs) of CLC inventories has remained unchanged since the 1st inventory, ensuring comparability of inventories over time [1]. The brief history of CLC is summarized in Table 1.

Since the 1st change mapping, EEA has placed a strong emphasis on mapping CLC changes with higher detail than CLC. This is reflected in the size of the Minimum Mapping Unit, which is 25 ha in CLC and 5 ha in CLC-Change databases. For technical realization the "change mapping first" technology has been preferred and applied by majority of participating countries since the CLC2006 project [2].

The main benefits of the "change-mapping first" approach are that (1) changes are interpreted directly and manually (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 (whether attached to an existing CLC polygon or not). The weakness is that some small (< 5 ha) deficiencies of new CLC (CLC2012) cannot be avoided [3].

Table 1. Brief history of CLC inventories.

Inventory	Duration	No of countries	Main features
CLC1990	1988-1998	26	1st inventory; drawing on plastic overlay
CLC2000	2001-2005	28	Computer-aided photointerpretation (drawing on screen); correction of geometry; 1st change mapping
CLC2006	2007-2011	38	2nd change mapping with improved methodology
CLC2012	2013-2014	39	No major change in methodology

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 (1) were larger than 5 ha and wider than 100 m; (2) occurred between 2000 and 2006; (3) reflected real evolution process (e.g. urban sprawl, new forest plantation, new water reservoir). Similar concept will apply to the CLC2012 project as well.

CLC mapping (nomenclature and technology) has been originally designed for visual photointerpretation as method of implementation, which has meant computer-assisted photointerpretation (CAPI) since CLC2000. Since the mid-2000s however, several semi-automated methods of deriving CLC data have emerged, especially to avoid the high labour cost of photointerpretation, improve repeatability and provide compatibility with national datasets. These build on available higher-resolution national thematic land cover and land use data and are characterized by advanced image classification, GIS integration and generalization techniques. Methodologies are unique to each country as being dependent on available national in-situ data. “Semi-automatic” means that human interaction is still needed in producing CLC, because the complex nomenclature cannot be implemented fully automatically with sufficient accuracy. Change mapping requires even more significant human interaction to eliminate commissions (false changes) from change database.

In CLC2006, 5 out of 38 countries applied semi-automated methods successfully, while the majority applied computer-assisted photointerpretation. Changes were derived using CAPI by even more countries. Only 3-4 countries derived forestry changes through computerized processing of remotely sensed data and other changes by using in-situ information [4], [5], [6], [7]. These changes were controlled visually on satellite images. In CLC2006 project only a single country has performed a semi-automatic change detection to map CLC changes [5]. The number of countries using semi-automated methods is foreseen to increase in the next inventories.

1.2. Purpose of the manual

There is a consolidated manual regarding the use of the standard CLC nomenclature [8]. A similar document about mapping CLC changes was felt to be useful in order to further improve harmonization of mapping CLC changes in Europe, as well as to help users in understanding processes depicted by change code pairs. We aimed to provide guidelines that:

- clearly explain which processes are depicted by CLC change code pairs
- provide a number of interpretation examples from different geographical regions
- draw attention to and help to avoid most common mistakes of mapping the given change process.

Major users of this manual are aimed to be:

- technical staff of CLC national teams, in order to help them harmonize results and detect mistakes more easily
- photointerpreters carrying out next inventories (CLC2012 and on) by traditional CAPI method, in order to help them better understanding of processes and avoid mistakes
- teams aiming to implement semi-automated methods, in order to help them understand which processes are meant to be mapped as CLC change and to identify possible mistakes (a separate chapter deals specifically with mistakes resulting from these methods)
- users of CLC change data.

The “knowledge base” of this Manual is the more than 100 verification missions the authors, as members of the CLC Technical Team of the European Topic Centre on Land (in CLC2000 project named ETC-Terrestrial Environment and ETC-Land use and Spatial Information, in CLC2006 project ETC-Spatial Information and Analysis), conducted to the participating countries during CLC2000 and CLC2006 projects.

The aims of these missions were:

- To assist the national team to produce the CLC2006 databases and to assure a homogenous implementation across Europe.
- Corrective goal: reveal and discuss specific problems occurred during the production in order to correct databases if necessary, and hereby assure a harmonized European CLC database.
- Provide the EEA with information about the overall quality of the work performed by the country.

Discussions with experts of the national teams were exceptionally important in shaping the content of the Manual.

2. Methods

2.1. Definition of CORINE Land Cover change

CORINE Land Cover is implemented in Europe in 5 – 10 - year periods (Table 1). This fits rather well to the observed CORINE Land Cover Change dynamics, which is below 1% change per year for all countries, except Portugal, where the change rate is 1.4% per year [9]. Repetition of CLC in every 5-6 years in the future seems to be a good compromise between CLC dynamics, user needs and financial constraints.

Logically, CLC changes should characterize those changes of the earth surface that have longer than yearly/seasonal periodicity. Urban sprawl, plantation of olive trees to replace arable land, melting of glaciers or creation of a new water reservoir are such long-term land cover changes to be mapped as CLC change. On the other hand, transient changes and short-term periodical changes are phenomena not to be mapped as CLC change.

Transient changes (lasting only for short time), not to be mapped as CLC change:

- Changes along rivers due to floods (temporary inundations)
- Changes inland due to heavy rains (temporary water-logging)

Periodical changes are where LC status alternates between two different land covers. Several processes have periodicity shorter than 1 year, therefore are not to be considered as CLC change:

- Water level changes in coastal areas due to tidal phenomena (high tide, low tide)
- Changes in lake / wetland area due to seasonal water level differences
- Regular changes of water cover of fishponds due to maintenance
- Seasonal phenological changes in forests (status of leaves)
- Seasonal phenological changes of natural grassland and sparse vegetation (green in spring, yellow in summer)
- Seasonal difference in crop development (bare soil, green crop, mature crop, harvested crop)
- Seasonal changes in annual snow cover (esp. high mountains and Northern Europe).

There are some changes that are periodic, but the periodicity is longer than 1 year or even longer than the CLC mapping repetition period. These processes have to be mapped, e.g.:

- Alternation of arable land and set-aside/pasture land (211-231, 231-211). Periodicity is usually several years, however being country/region dependent. (In countries where grass is planted as one-year (fodder) crop, being part of crop rotation, these changes are not considered to be CLC change.)
- Forest clearcut (31x-324) and new plantation growth (324-31x). After clearcutting minimum 5-10 years are needed for a new forest to develop.

2.2. Compilation and structure of the manual

Considering the 44 level-3 classes in CLC, theoretically 44 x 43 =1892 different CLC change types exist. Even if not all of them are possible or do actually happen (Table 2), there is no way to discuss hundreds of different change types.

Table 2. Figures characterizing the CLC-Change$_{2000\text{-}2006}$ Europe database (V15).

Total changed area:	70 824 km2
Part of Europe (without sea and ocean) that changed between years 2000 and 2006	1.24 percent
Number of change polygons	358 969
Number of change types occurring	935
Number of change types altogether providing 90% of total change area	73
Number of sporadic change types (each giving less than 0.1% of total change area)	853
Change types providing 50% of total change area	312-324, 24 547 km2 324-312, 6 311 km2 311-324, 5 729 km2
Largest change in Artificial surfaces group	133-112, 2492 polygons

Largest change in Agriculture group	231-211, 3210 polygons
Largest change in Forests and semi-natural group	312-324, 146 596 polygons
Largest change in Wetlands and Water groups	412-324 1017 polygons

Remark: regarding CLC codes see Annex 1

Based on the statistics of CLC-Change$_{2000\text{-}2006}$ database, the most important (i.e. most frequent) CLC change types – providing 90% of all change area - were selected for discussion in the Manual. In most of the cases several level-3 change types were grouped into a CLC change process for discussion, forming altogether 27 different CLC change groups (Table 3). Chapters 2-5 of the Manual discuss most frequent changes of the Artificial surfaces, Agriculture Areas, Forest and semi-natural areas, Wetlands and Water areas, respectively. An additional chapter discusses general technical issues.

Change processes are discussed in a standardized way, including the following items:

A) Textual description

- **Change process:** general description of the change process (e.g. construction process has finished) and list of change types gives as CLC code pairs (e.g. 133-121)
- **Overview and rationale:** short description of the change process and its significance
- **Number of changes** belonging to the change process in European CLC-Change$_{2000\text{-}2006}$: indicating the "importance" of the process in terms of CLC change polygons
- **Area of changes** belonging to the change process in European CLC-Change$_{2000\text{-}2006}$: indicating the "importance" of the process in terms of CLC change area
- **Type:** more detailed definition of the change process with reference to the relevant CLC level-3 classes, e.g. Construction of residential units finished: 133-112. Several types might be listed under a change process.

B) Interpretation example(s) in the form of the screen-shot(s) made by InterCheck tool [10] during CLC2006 - in exceptional cases CLC2000 - verification missions. In most of the examples dual window screen-shots are shown with IMAGE2000 and CLC2000 on the left side, and IMAGE2006 and CLC-Change Change2000-2006 on the right side. In a few cases, a CLC2000 example is shown with similar arrangement including IMAGE1990 and CLC-Change1990-2000 on the left, while IMAGE2000 and CLC2000 on the right. Reference year of satellite imagery is shown in small number on top left of the respective image windows (e.g. 2000, 2006).

C) List of frequent associated mistakes as observed during verification missions (usually with an example), followed by advice how to avoid these mistakes. Some of the mistakes are illustrated by screen-shots with arrangement similar to good examples. Caption of figures showing a mistake starts with the word "Mistake" and is written with red characters.

D) Particularity (optional): this includes additional, interesting example(s), which are not necessarily typical. Sometimes a particularity includes an example that does not belong to the 90% mentioned above.

Finally, Chapter 6 is about "Technical issues". This is a collection of typical mistakes that are usually not connected to a single discussed change process.

3. Results

3.1. Discussed change processes

As a result of this work conducted within the framework of ETC-SIA, a Manual of 150 pages has been compiled, illustrating 27 change groups/processes.
These are listed in Table 3.

Table 3. List of change processes described by the manual.

Change process	CLC-codes	Particularities	No. of change polygons	% total change area
Changes from the Artificial surfaces classes				
Construction process completed	133-112/121/122	133-142/411/512	4 227	1.38
Reclamation of mineral extraction sites	131-231/324/512	131-142/211/221/313/523	831	0.45
Changes from the Agriculture classes				
Urban-industrial sprawl on agriculture land	211/231/242/243-112, 211/231/242-121, 211/231/242/243-133, 211-122	212-124/142	26 453	5.47
New mineral extraction on agriculture land	211/231-131	-	2 592	0.60
Arable land turned to sport and recreation	211-142	-	499	0.20
Non-irrigated arable land turned to irrigated arable land	211-212	-	1 089	0.99
Vineyard / orchard replacing annual crop	211-221/222, 212-222	-	3 217	1.31
Permanent crop turned to arable land	221/222-211	-	831	0.32
Olive plantations replacing annual crop	211/242-223	-	1 725	0.90
Arable land – pasture rotation	211-231, 231-211	-	5 793	2.56
Diversification of agricultural land use	211/231-242	-	558	0.45
Afforestation on agriculture land	211/231/243-324	211-311	5 930	1.93
Abandonment or afforestation of agroforestry areas	244-324	-	335	0.20
New water body of arable land	211-512	-	800	0.20
Changes from the Forest and semi-natural classes				
Forest/semi-natural changed to mineral extraction site	312/324-131	-	1 507	0.29
Forest/semi-natural changed to construction site	312/321/323-133	-	1 294	0.35
Forest/semi-natural changed to arable land	312/321/323/324-211	311-211, 312-212/221, 321/212, 333-212	3 375	0.57
Forest/semi-natural changed to agroforestry	311/324-244	-	673	0.49
Clearcutting or damage of forests	311/312/313-324	-	192 854	47.19
Forest growth	324-311/312/313	-	66 537	17.47
Degradation of forests and shrubs by fire	311/312/313/323/324-334, 312/324-323	-	1 473	1.72
Afforestation, regeneration after damage, natural succession	321/322/323/333/334-324, 334-323	-	2 575	3.40
Melting of glaciers	335-332	335-512	589	0.33
Gravel, sand changing to river	331-511	331-523	118	0.22

Changes from Wetland and Water classes				
Peatland converted to arable land	412-211	-	949	0.29
Afforestation on peatland	512-324	-	1 017	0.44
River changing to gravel, sand	511-331	523-331	175	0.21

Remark: regarding CLC codes see Annex 1

In order to demonstrate the structure of manual, two change processes are shown in the following chapters. Figures show IMAGE2000 and CLC2000 in the left window and IMAGE2006 and CLC-Changes in the right window. Note that red characters in figure subscription indicate examples of mistakes.

3.1.1. Example 1: Reclamation of mineral extraction sites

Change process: Reclamation of mineral extraction sites: 131-231/324/512 (Regarding CLC codes see Annex 1)

Overview and rationale:

Reclamation of mineral extraction sites is the process of creating useful landscapes that meet a variety of goals, typically creating productive ecosystems (or sometimes industrial or municipal land) from mined land. After mining finishes, the mine area must undergo rehabilitation.

Mine rehabilitation aims to minimize and mitigate the environmental effects of modern mining. Backfilling the open pit mine, rehabilitation usually involves the movement of significant volumes of rock. Later the former open pit is covered with topsoil, and vegetation is planted to help consolidate the material [11].

Number of changes in European CLC-Change: 831 polygons
Area of changes in European CLC-Change: 0.45% of all change area

Type: Reclamation of mineral extraction sites by afforestation: 131-324
Interpretation example (Poland):

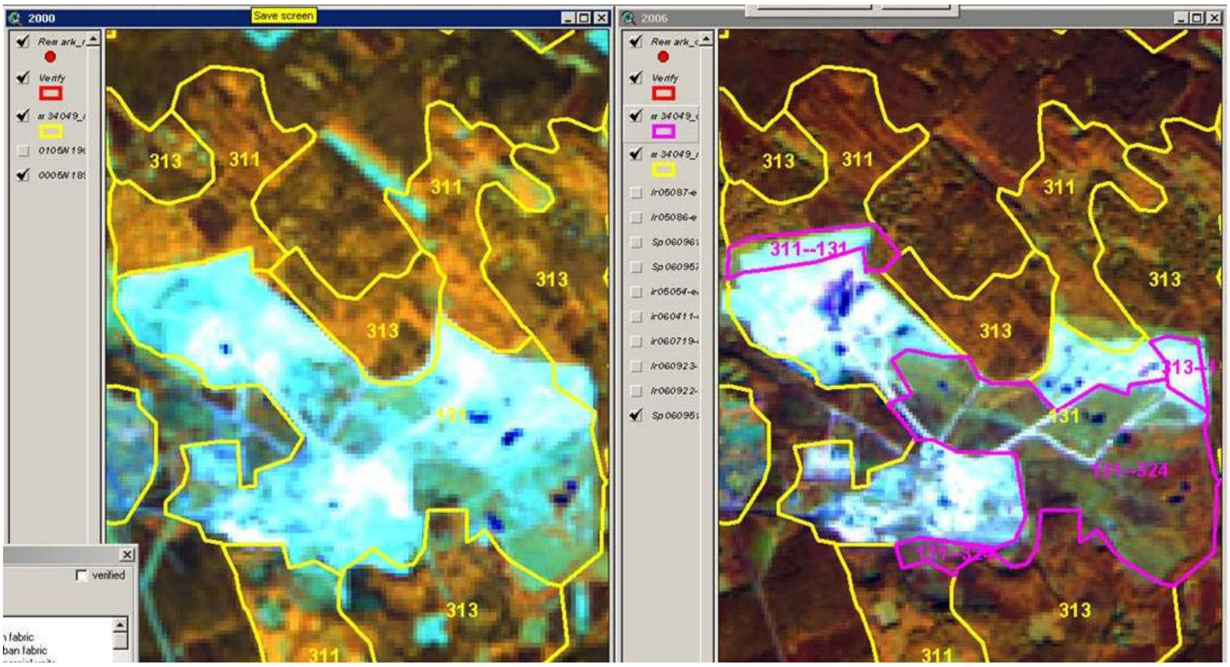

Figure 1: Bare areas in 2000 (left) indicating open-pit mining activities became vegetated by 2006 (right). The colour of new vegetation cover on the right is similar to the colour of neighbouring forests. We have a good reason to suspect that reclamation was done by afforestation. Because of the short time elapsed the forest is not mature yet (indicated also by IMAGE2006), therefore the right process is: 131-324. There are 405 polygons of this type covering 0.23 % of all changes in CLC-Change$_{2000\text{-}2006}$ Europe database.

Type: Reclamation of mineral extraction sites by grassland: 131-231
Interpretation example (Poland):

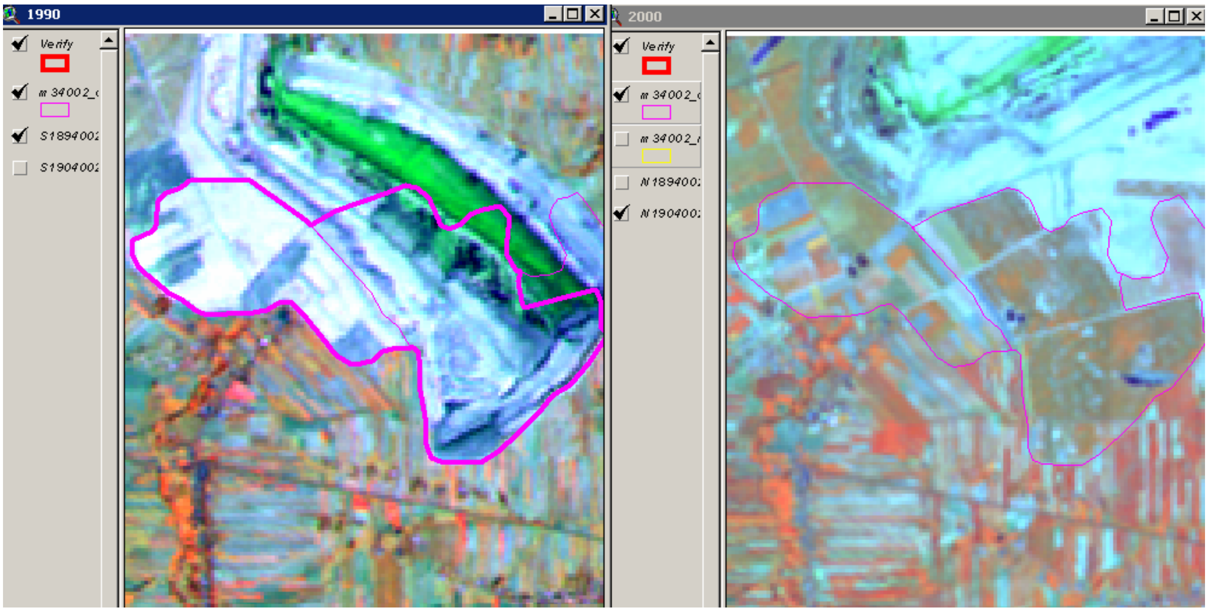

Figure 2: IMAGE1990 (left) shows a large mineral extraction area north from the agricultural landscape. Large part of the mineral extraction site was reclaimed by 2000, as shown by IMAGE2000 (right). The change with largest area is coded as 131-231. (The polygon in the west is 131-242, while the one in the east is 131-324). There are 235 polygons of the 132-231 type covering 0.11 % of all changes in CLC-Change$_{2000\text{-}2006}$ Europe database.

Type: Mineral extraction site converted to water body: 131-512
Interpretation example (Germany):

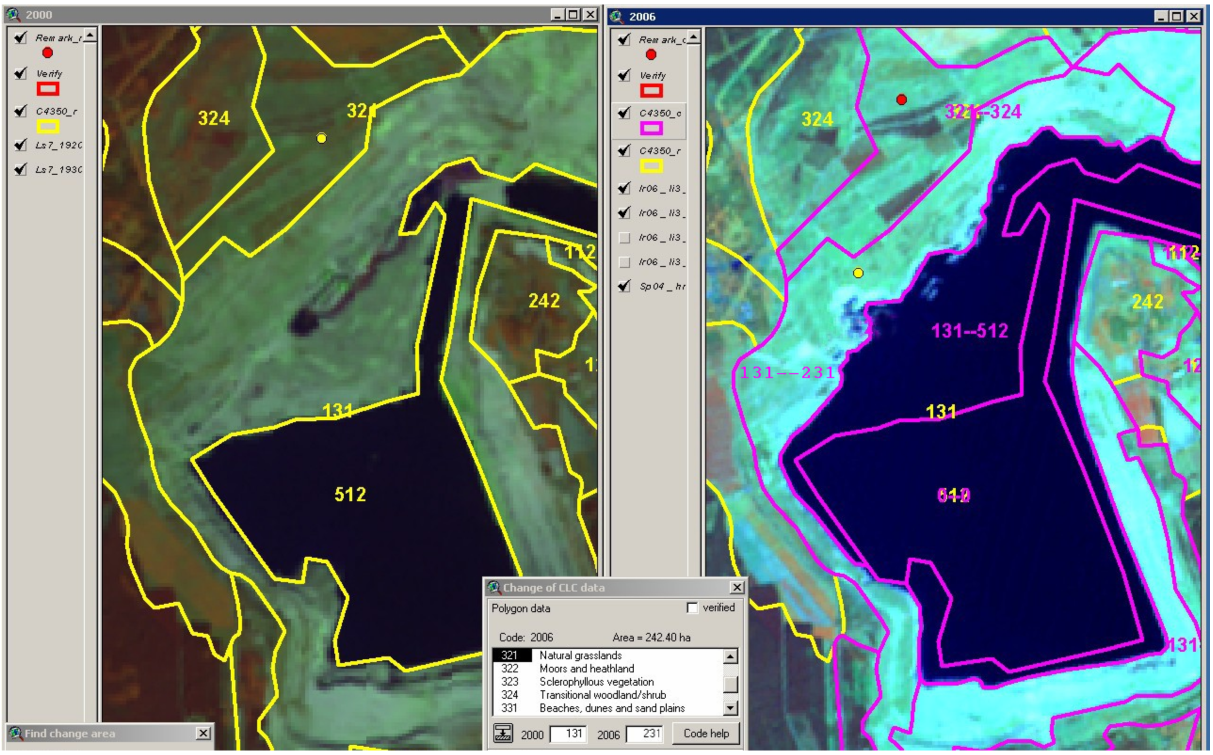

Figure 3: The open-pit mine in 2000 (left) lost parts of its area by two processes: enlargement of an already existing lake (131-512), and reclamation by grass (131-231). There are 191 polygons of 131-512 type covering 0.1 % of all changes in CLC-Change$_{2000\text{-}2006}$ Europe database.

Table 4. Frequent mistakes of mapping the “reclamation of mineral extraction sites” change process.

Frequent mistakes:	**How to avoid the mistakes**
Omitted mapping of reclamation process	All 131 polygons in the parent stock layer have to be examined if the mineral extraction site is still active. Special care should be paid to mineral extraction from lakes (e.g. gravel); if the mining activity is finished the area usually should be mapped as water body (512).
False changes applied for mapping of the reclamation process	The next general rules are to be followed: • 131-211 or 131-231 is a common process in case of reclamation of “non-toxic” extraction sites (e.g. gravel, sand). • In case of reclamation by grass use 131-231. Do not use 131-321, because this grass is artificial, under human impact. (Only exceptions are nature reconstruction processes, typical in e.g. NL) • Use 131-324 for any kind of reclamation by afforestation, even if trees are very small (high resolution images is useful to confirm plantation). • 131-333: use this in exceptional case only, if the mine is abandoned and no formal reclamation by grass or afforestation took place; i.e. reclamation is going as a natural process.

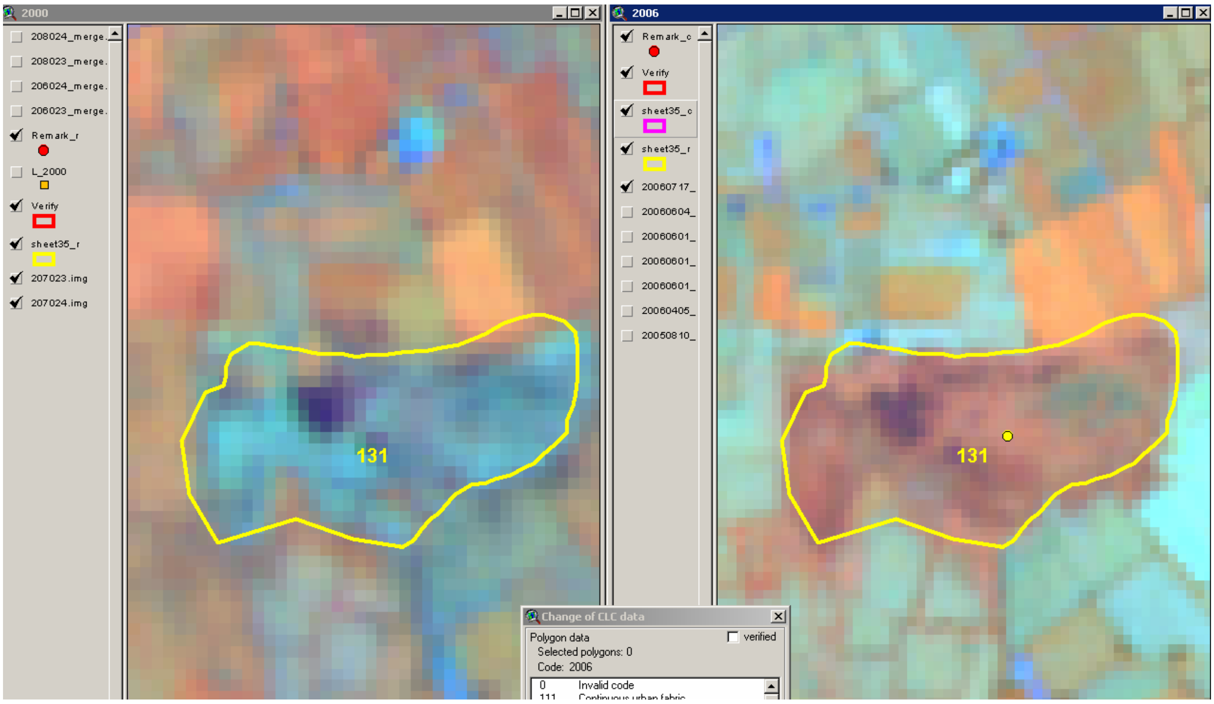

Figure 4: Mistake: missing mine reclamation. The mineral extraction site was active in 2000 (right), as indicated by the light colours. In 2006 (right) the site does not seem to be active mineral any more. Based on colour we can conclude that forest plantation was used for reclamation (131-324).

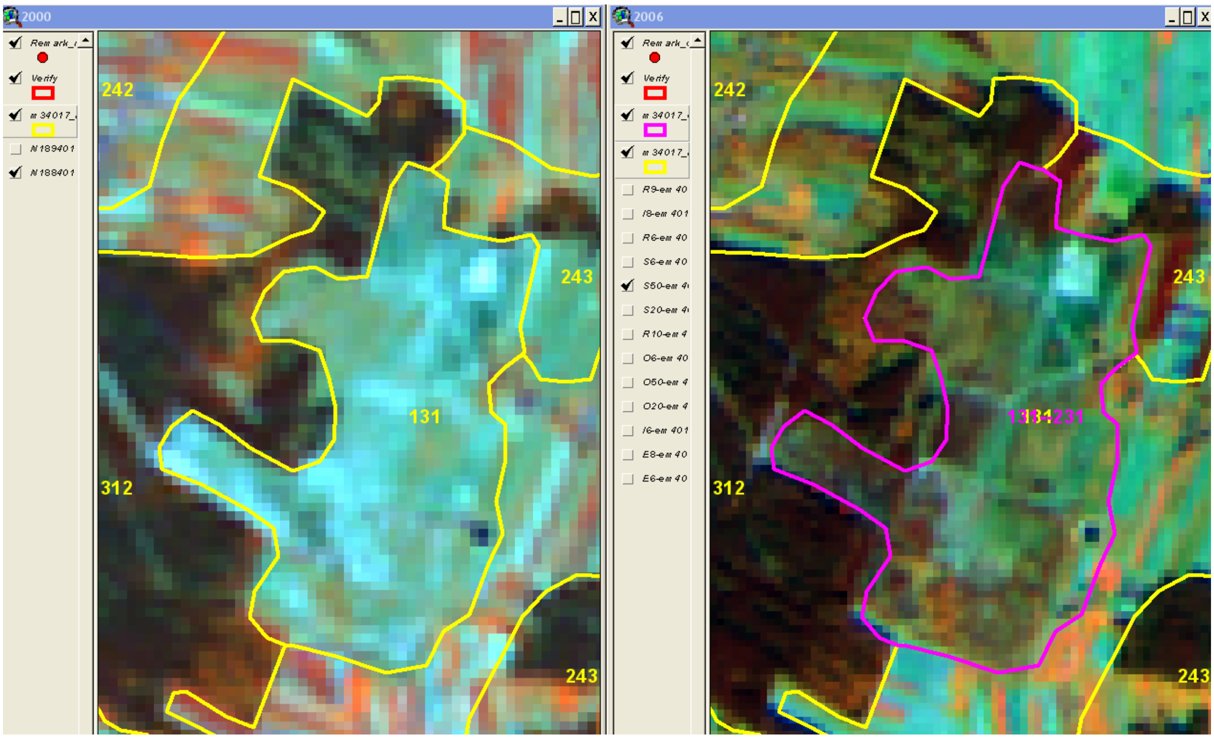

Figure 5: Mistake: The 131-231 code pair was used for characterizing the process, meaning reclamation of mineral extraction site (left) with grass. However, IMAGE2006 (right) indicates that reclamation was done by forest plantation. This is confirmed by colours, which are similar to neighbouring coniferous forest. Therefore the right process is 131-324.

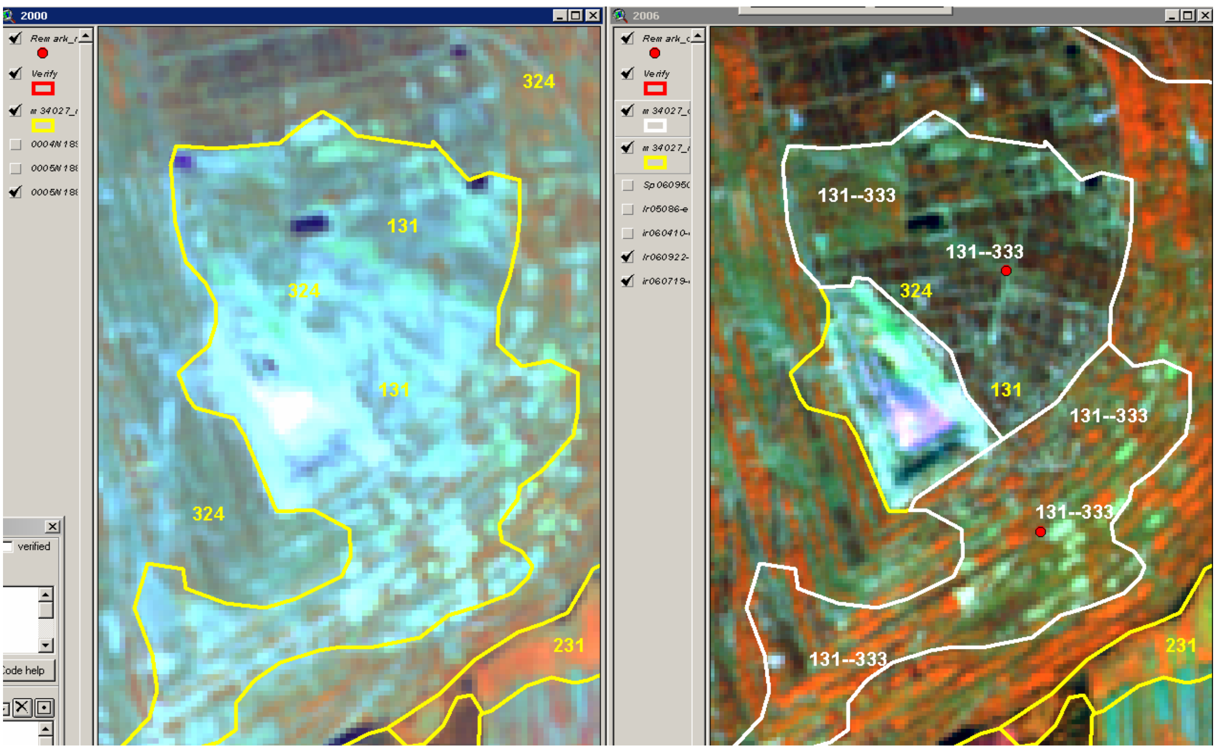

Figure 6: Mistake: Reclamation of a mineral extraction site (left, IMAGE2000) by afforestation (right, IMAGE-2006) wrongly mapped as 131-333, Rows of newly planted trees are clearly visible on 2006 image. Note that change polygon in the south is false, rows of forest plantation are visible already in 2000, therefore should have been mapped as correction of the old stock layer (CLC2000).

Particularity-1:
Type: Mineral extraction site reclaimed as (transformed to) sport and recreation facility: 131-142
Interpretation example (Denmark):

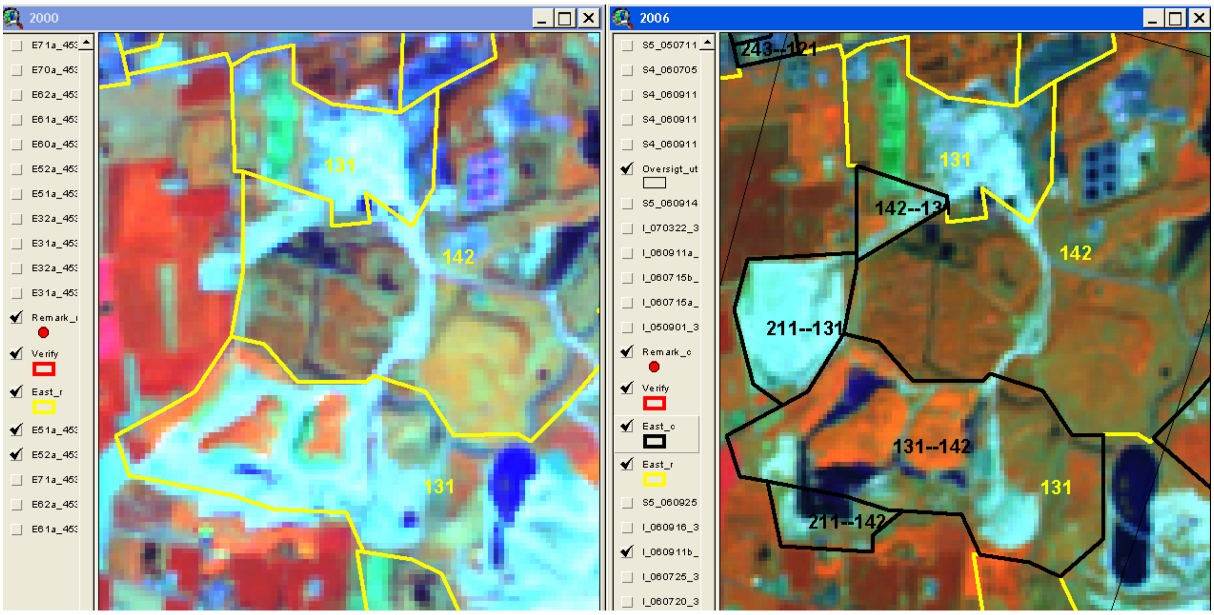

Figure 7: A mining area shown on IMAGE2000 (left) was transformed to sport and recreation area (IMAGE2006, right), as continuation of existing 142 establishments (golf courses and additional infrastructure) in the north and in the south. There are 16 polygons of this type covering 0.01 % of all changes in CLC-Change$_{2000\text{-}2006}$ Europe database.

Particularity-2:
Type: Mineral extraction sites converted to arable land: 131-211
Interpretation example (Germany):

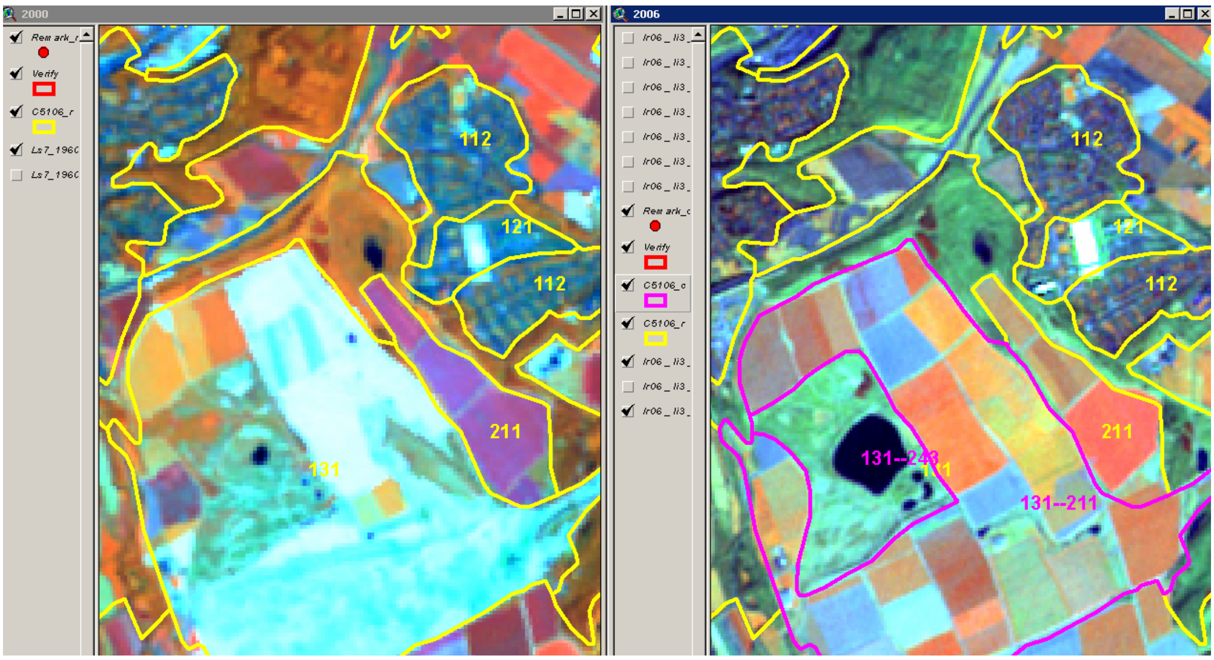

Figure 8: IMAGE2000 (left) shows a mining area in 2000 (see north-west part). According to IMAGE2006 (right) the mine has been reclaimed and a large new arable land was created. The field structure inside the mapped 131-211 polygon is similar to that east and south from the polygon. Reclamation with arable land suggests that mine used to produce non-toxic material. (Mistake: note, that there is a slight overestimation of the change area, in north-west corner of the change polygon the area was reclaimed as 211 already in 2000.) There are 164 polygons of this type covering 0.06 % of all changes in CLC-Change$_{2000\text{-}2006}$ Europe database.

Particularity-3:
Type: Mineral extraction sites converted to vineyard: 131-221
Interpretation example (Italy):

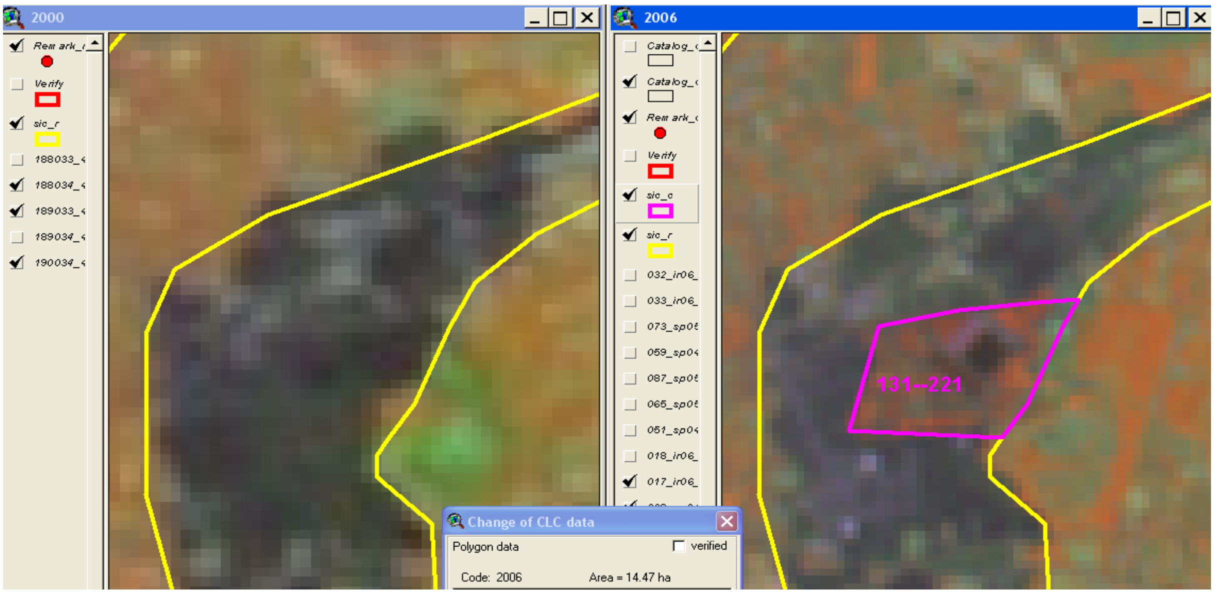

Figure 9: Part of a mineral extraction site (probably quarry) shown by IMAGE2000 was transformed to vine-yard, the same land cover as that of the surrounding site (IMAGE2006). Similarly to the previous example, reclamation with agricultural land use suggests that mine used to produce non-toxic material. There are 3 polygons of this type covering 0.00 % of all changes in CLC-Change$_{2000\text{-}2006}$ Europe database.

Particularity-4:
Type: New forest on mineral extraction sites: 131-313
Interpretation example (Turkey):

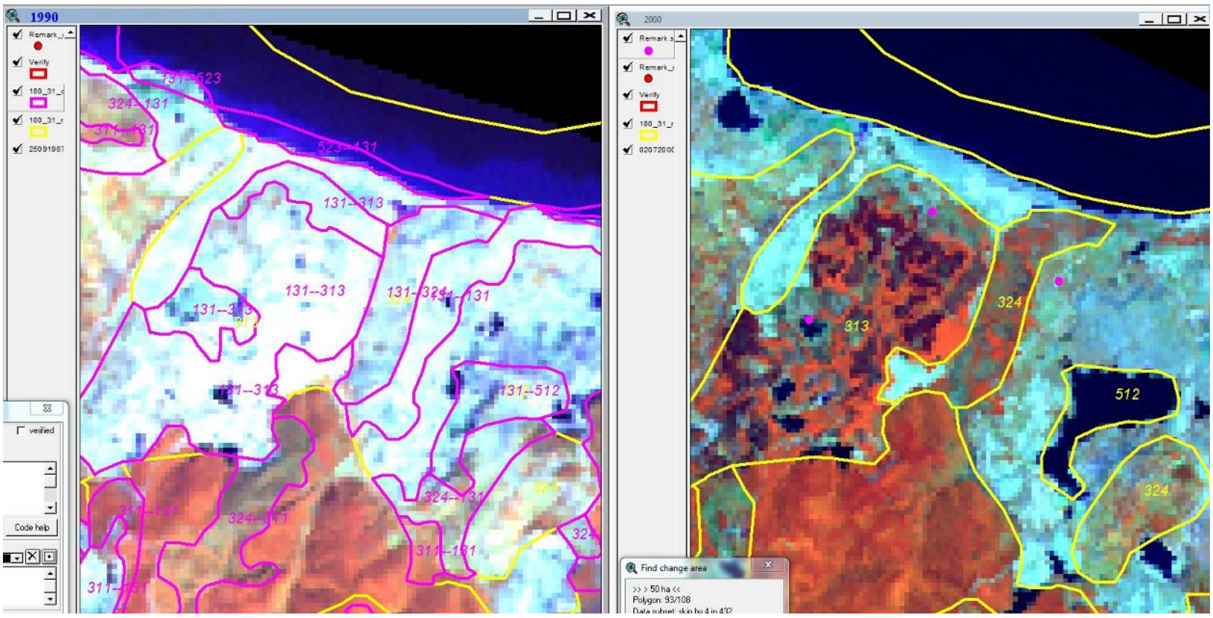

Figure 10: If the time lapsed between two CLC inventories is long or fast growing tree species are planted to reclaim the mine a mature forest might be observed on the former mine area. Left image was made in 1987, while right image was made in 2000. A large mixed forest replaced the former mineral extraction site (131-313). There is 1 polygon of this type covering 0.00 % of all changes in CLC-Change$_{2000\text{-}2006}$ Europe database.

Particularity-5:
Type: Mineral extraction sites reclaimed by inundation with seawater: 131-523
Interpretation example (Turkey):

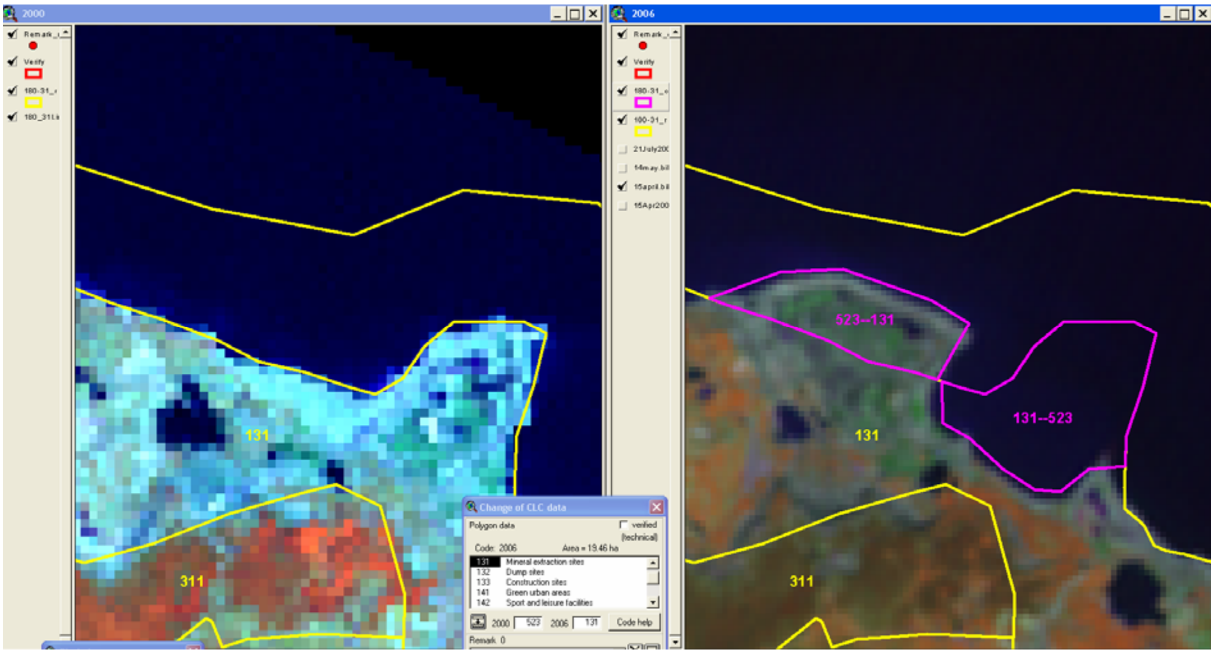

Figure 11: In 2000 (left) mineral extraction site (quarry) is seen on the coast. In 2006 (right) we see reclamation by inundation with seawater coded 131-523, as well as a new mining area 523-131. Evidence of conventional reclamation is also visible as vegetated area (not mapped) in the southeast. There are 3 polygons of the 131-523 type covering 0.00 % of all changes in CLC-Change$_{2000\text{-}2006}$ Europe database.

3.1.2. Example 2: Degradation of forests and shrubs by fire

Change process: Degradation of forests and shrubs by fire: 311/312/313/323/324-334, 312/324-323 (Regarding CLC codes see Annex 1)

Overview and rationale:

Wildfires in Europe typically (but not exclusively) occur in the Mediterranean areas, appearing in the news day by day in the dry summer season. Fire is the most important natural threat to forests and wooded areas of the Mediterranean basin. According to FAO Forest Fire assessment, 600.000 hectares are affected by fires annually in this region, with the frequency of fires continuously growing since the 1970's. Although natural causes (such as lightning) contribute to ignition of wildfires, in the Mediterranean basin major cause is human carelessness, such as discarded cigarettes, arson, sparks from equipment, fires left unattended. Prescribed fire ignited to prevent increased destruction by future fires is the third major cause. Wildfires, natural or anthropogenic have:

- ecological effect (destruction, changes of plant associations)
- economic effect (loss of timber and crops, damage to human property, negative effect on tourism and aviation, cost of detection and fire fighting)
- health effect (air pollution, casualties)
- climatic effect (greenhouse gases).

Wildfires in Scandinavia are mostly caused by natural phenomena. Peat fires do also have serious economic effect, but they are not detectable by remote sensing, which is otherwise the most important method of detection and damage assessment of surface fires. In CLC mapping only fires affecting forest and shrub are mapped, burnt grassland and agricultural crops are not coded as 334.

Number of changes in European CLC-Change: 1473 polygons
Area of changes in European CLC-Change: 1.72 %
Type: Wildfire in the Mediterranean area: 311-334 and 323-334
Interpretation example (Italy):

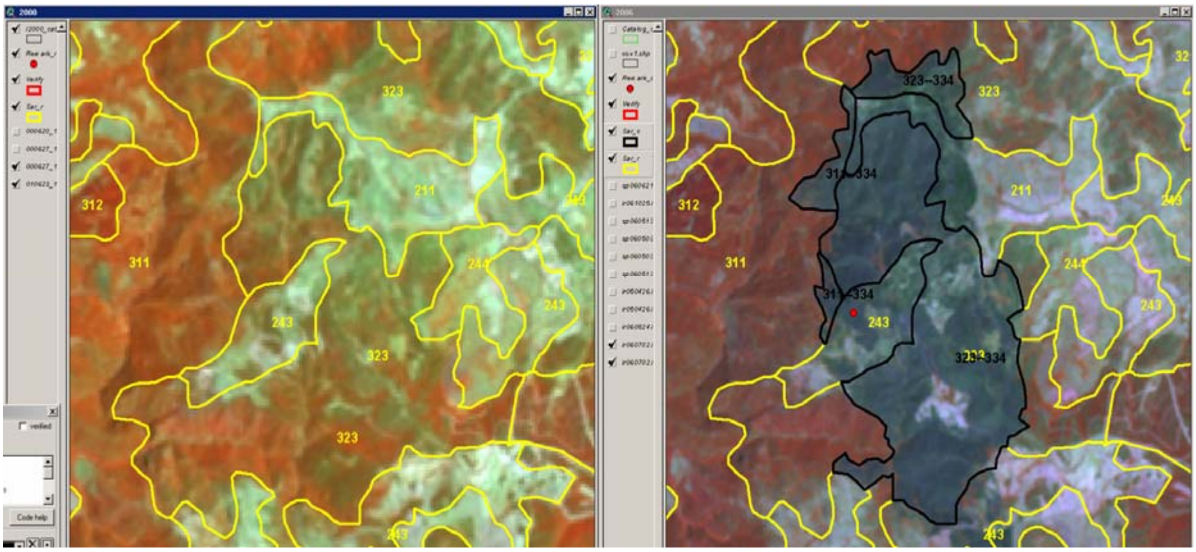

Figure 12: Nicely mapped forest fire (311-334 and 323-334) in the Mediterranean area. Code 334 should be used until the black (dark green) colour, characteristic of freshly burnt areas, is visible (as on 2006 image - right). Note that burnt agricultural areas (211, 243) are – correctly - not mapped as 334. 334 code should be used only for burnt forest (311, 312, 313) and shrubs (322, 323, 324, 333). There are 205 pieces of 311-334 polygons covering 0.18 % of all changes; and there are 148 pieces of 323-334 polygons covering 0.25% of changes in CLC-Change2000-2006 Europe database.

Type: Burnt coniferous forest (in temperate climate): 312-334
Interpretation example (Norway):

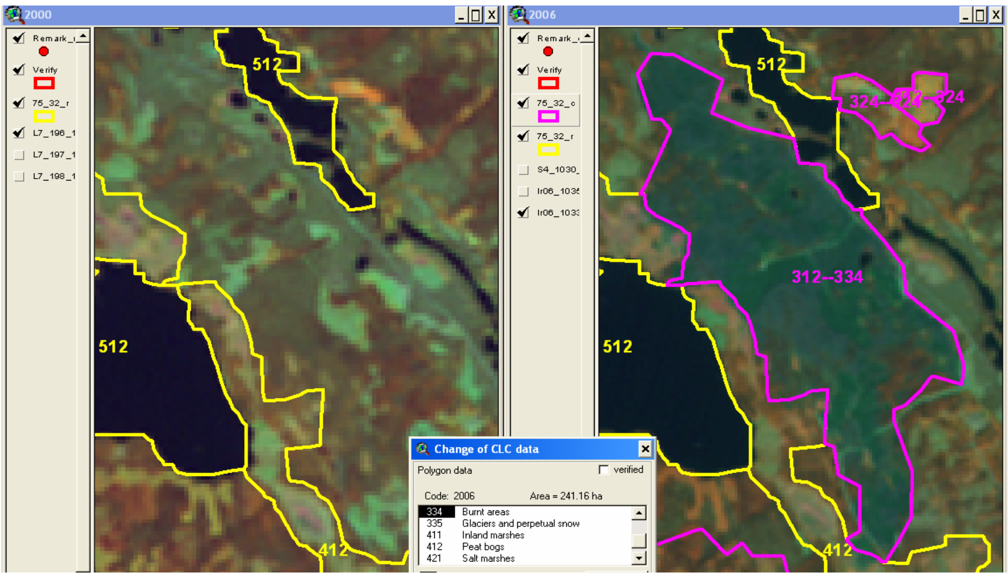

Figure 13: Forest fires occur also in Central Europe and in the Scandinavian areas, this being an example of the latter. A heterogeneous 312 area (left) became a homogeneous dark green patch by 2006 (right). The characteristic dark green colour is a mixture of spectral response from ashes and underlying rock / soil. Dark colour is often more difficult to recognize in such areas as the images are generally dominated by dark colours anyway. There are 321 polygons of 312-334 change covering 0.48 % of all changes in CLC-Change$_{2000\text{-}2006}$ Europe database.

Type: Transitional woodland-shrub changed to sclerophyllous vegetation as result of former wildfire: 324-323

Interpretation example (Spain):

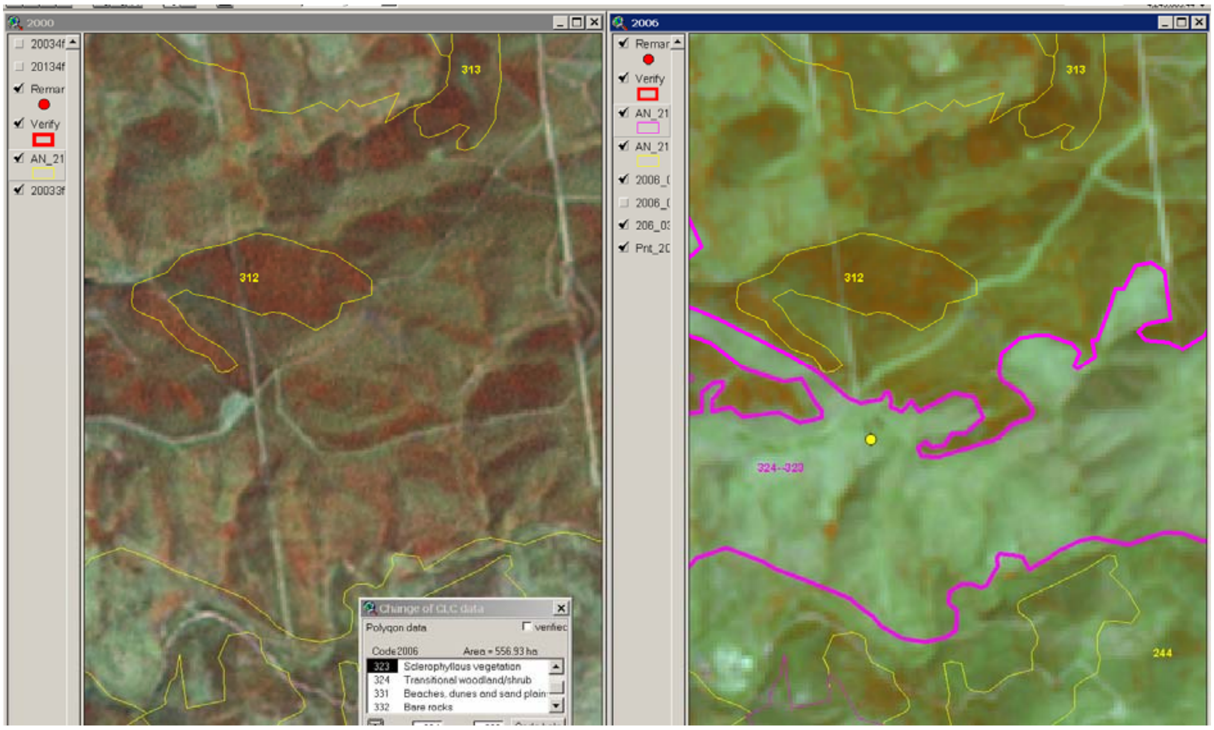

Figure 14: Transitional woodland (forest plantation, 324) has become sclerophyllous vegetation, most likely because of earlier fire damage (324-323). A decrease in the biomass is visible comparing the satellite images. When examining the area using in-situ data, we learn that in 2000 (left) the area was a forestation area with fairly young trees (rows of plantation visible). By 2006 (right) much of the biomass disappeared and the lines of plantation are no longer visible. Forest plantation (324) has been destroyed by wildfire then natural vegetation (323) occupied its place during the regeneration process. There are 65 polygons of this change type covering 0.13 % of all changes in CLC-Change$_{2000\text{-}2006}$ Europe database.

Table 5. Frequent mistakes of mapping the "Degradation of forests and shrubs by fire" change process.

Frequent mistakes:	**How to avoid the mistake**
Omitted changes	Characteristic black / dark green colour of freshly burnt vegetation is very easy to recognize. Revising the interpretation area in scale 1:40.000 is good way of finding these patches. By checking the code statistics we can find out whether forest fires are typical of the given area; if 334 code occurs in the parent stock layer, we can expect this process to be present in the area.
False change due to burnt area not recognized, forest burn is misinterpreted as clearcutting	Beside colour (black/dark green), shape of forest loss might help to identify forest fires. Fire scars have irregular shape, while forest clearcuts are often regular, with defined boundaries.
Old fire scars misinterpreted as 334	Code 334 should be used only until dark colour is visible. After that the next step of regeneration process (e.g. 333, 321, 323, 324) should be mapped.

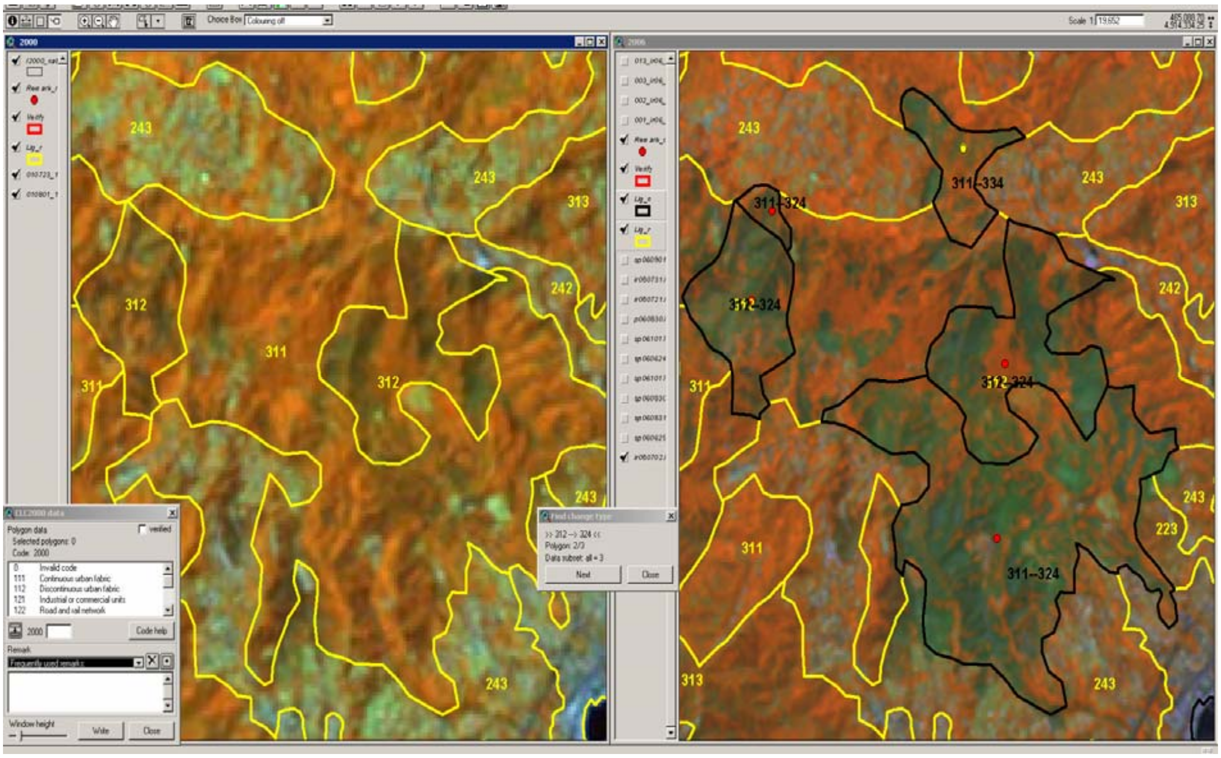

Figure 15: Mistake: forest burn misinterpreted as clearcut. Loss of forest is normally assumed to be of human origin, i.e. clearcutting. Here interpreter failed to recognize the characteristic dark green colour of burnt forest in 2006 (right) and misinterpreted the area as transitional woodland and shrub (324). The right process is 311-334 and not 311-324.

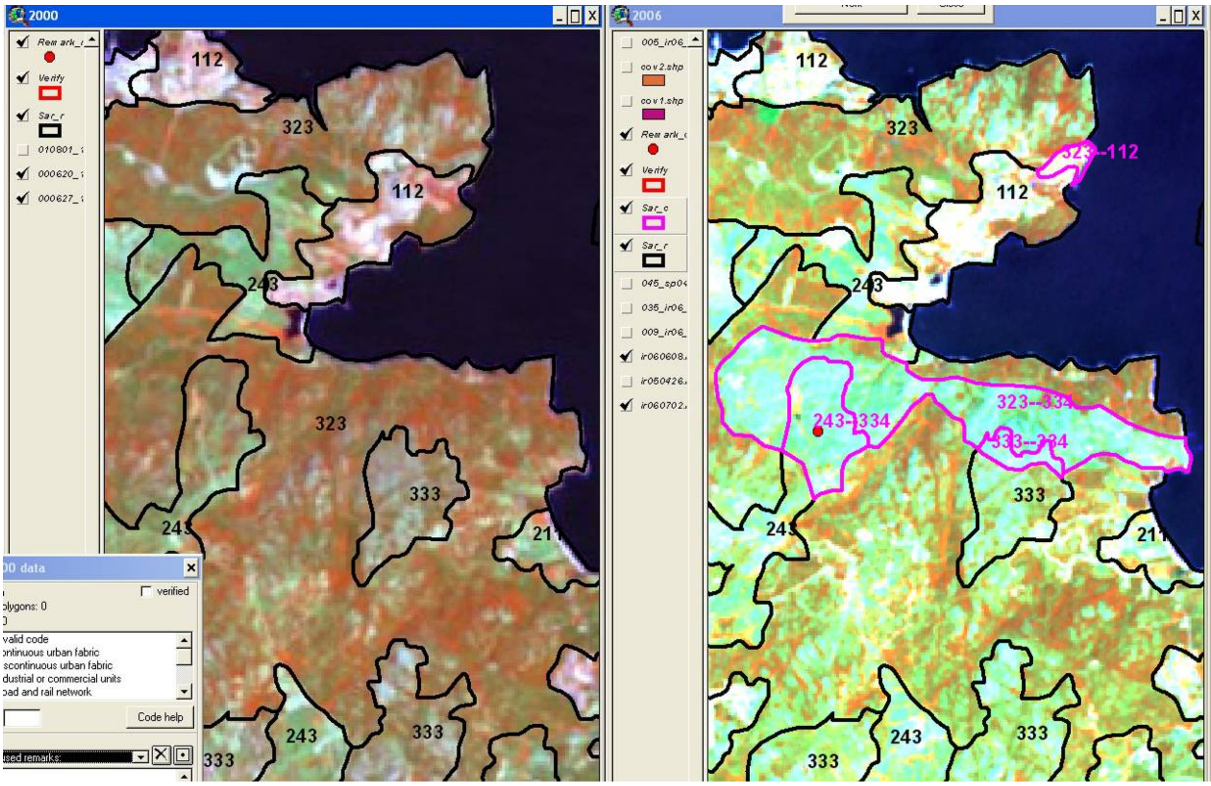

Figure 16: Mistake in mapping burnt sclerophyllous vegetation. 334 should be used until dark colour is visible. Here we see light colour of the ground in 2006 (right), which is the consequence of soil erosion after fire removed protective vegetation cover (323). Thus the process to be mapped is Mediterranean shrub changed to sparsely vegetated area (323-333) and not shrub being burnt (323-334).

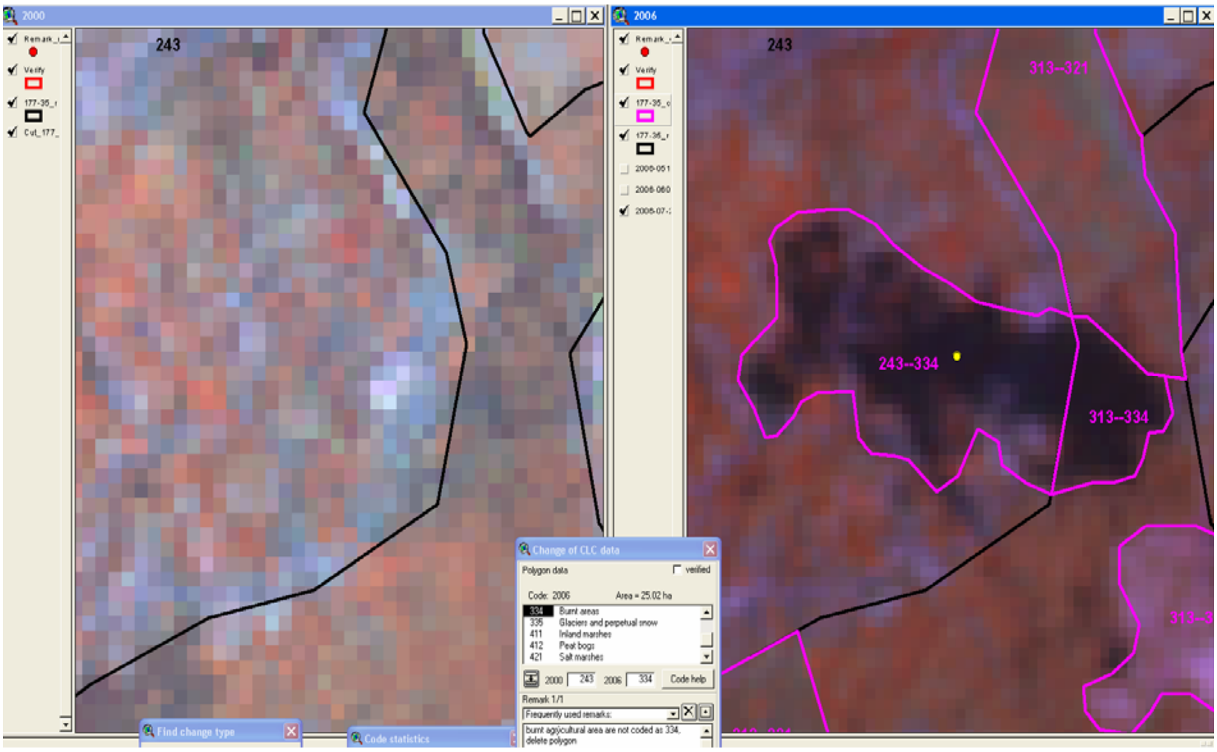

Figure 17: Mistake: burnt agricultural area erroneously mapped as 334. On the 2000 image (left) a heterogeneous agricultural area is visible, correctly mapped as 243. Black patches on 2006 image (right) indicate fire scars. The fire affected both the agricultural area and the neighbouring forest (313). Burnt forest is correctly mapped as 313-334, but following the rules described in the nomenclature, burnt agriculture polygon (243-334) should have been deleted. 334 class should be used only for fire-affected natural vegetation (forest, shrub, sparse vegetation). These changes are very easy to find during control process by revising all 2xx-334 changes from the change code statistics.

3.2. Discussed technical issues

A separate chapter of the Manual is dedicated to the discussion of technical issues that are not associated to a single change type, but considered being of general importance.

- Changes within complex agricultural classes (i.e. 242, 243)
- Impossible, rare and forbidden changes (i.e. geographically, botanically or logically impossible change processes)
- Linear features and complex changes (i.e. mapping of roads and changes made up of several elementary changes)
- Automatic use of in-situ information (i.e. filtering out impossible changes and false changes; age of source data). Example of such mistake is shown on Figure 18.
- Relation between Change and Stock layer polygons (i.e. matching geometry of polygon outlines)
- Technical change (i.e. use supplementary, so called ‘technical changes’ that help avoiding mistakes in the new stock layer)
- Typing errors

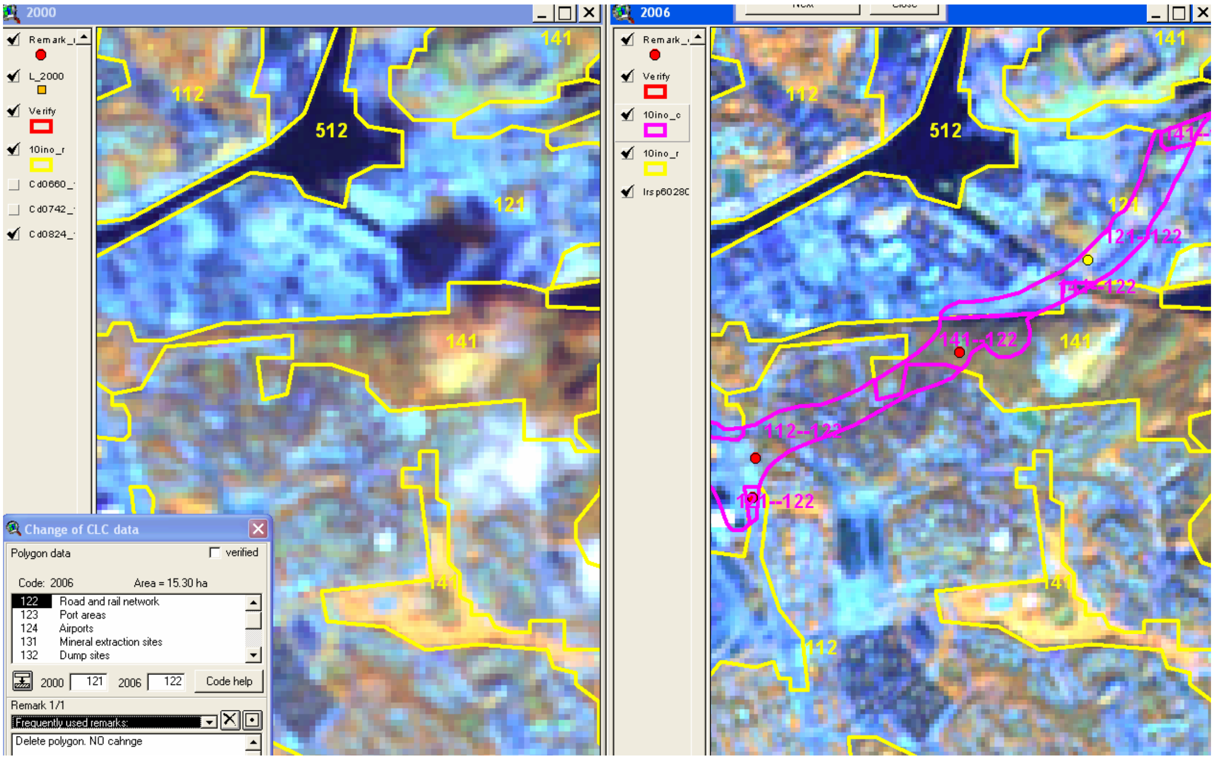

Figure 18: Mistake: wrong change due to improper use of cartographic database. IMAGE2000 (left) and IMAGE2006 (right) show a large urban area. We do not see any difference on the images (except the small cloud and shadow on IMAGE2000), while a new road (112/141-122) was mapped Changes were derived by comparing the topographic databases of 2000 and 2006. Analysing the situation revealed that a tunnel has been constructed between the two dates, which naturally has no visible consequence on the surface. All derived change polygons are false and have to be deleted. Changes derived from differencing in-situ data should be checked by an expert.

4. Conclusions

CLC is the largest European land monitoring project (implemented in 38 countries with 5.8 M km2 in CLC2006), having long heritage (3 completed inventories, the 4th one is on the start under GMES Initial Operations), a well-documented nomenclature and implementation guidelines and a well-established user community. CLC is the number one LC/LU dataset for the EEA used in reporting, indicator development and environmental assessment.

The structure of European land monitoring is however in transition. Besides a number of ongoing inventories (CORINE Land Cover, LUCAS, High-Resolution Layers) aiming to provide the land information required by users, various national land monitoring activities aim and are able to complete and often substitute European inventories. High-resolution Layers (HRL) to be produced by GIO [12] can provide snap-shots of Europe with low thematic, but high geometric resolution, while might also serve as input data to CLC change mapping. The number of countries planning to compile European CLC data by combining higher-resolution national data is likely to increase. They are foreseen to supplement or substitute traditional CAPI method with semi-automated technologies based on national data in the CLC2012 inventory.

The Manual of CLC changes has been compiled by authors based on experience and examples from using the CAPI method. Major user community of the manual is therefore seen as interpreters and project coordinators using CAPI method, as well as users, who intend to more deeply understand the processes indicated by CLC change code pairs. Indeed, authors are convinced that the Manual of changes will serve as valuable guidelines for those teams designing CLC production with semi-automated methodologies. For them major use of consulting the document is a better understanding of mapping which processes should be addressed by their methods and also a better recognition of potential mistakes in order to avoid them. The majority of countries to participate at the next CLC inventory are still foreseen to use traditional methods. Even in countries aiming to produce CLC by semi-automated methods, mapping of changes still requires significant human involvement, including manual photointerpretation or visual control of potential change areas.

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Annex 1. The standard CORINE Land Cover nomenclature.

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-agricultural 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