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Dealing with the uncertainty of technical changes in the CORINE Land Cover dataset: The Portuguese approach

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ABSTRACT

Land Use and Land Cover (LULC) datasets are widely used across disciplines, with many users demanding more and better information. Understanding the uncertainties and errors associated to the main LULC datasets is a required step to facilitate their correct use, as well as to identify what could be improved in the future production of these products. CORINE Land Cover is probably the most well-known and used LULC dataset in Europe, especially valuable for the rich time-series that it provides. Despite being produced through a change mapping first approach, which tries to avoid technical errors and uncertainties in the temporal analysis of LULC changes, the Copernicus Land Monitoring Service distributes status layers of CORINE (CSL), which are not valid for change analysis because of their associated errors and uncertainties. The CORINE layers of changes (CHA) remove a lot of these issues, but do not meet the needs of many users. In Portugal, the national authority in charge of producing CORINE, the DGT, has implemented a backdating approach to produce consistent CSL layers that allow change analysis with low levels of uncertainty. Throughout this paper, we evaluate the changes that can be analyzed through all available CORINE layers in Portugal: Copernicus CSL layers; the national DGT CSL layers; and CHA layers. To this end, we aim to assess what type of changes can be studied through each type of layer, their associated sources of uncertainty and the relevance and utility of the Portuguese backdating approach to produce a consistent time-series of LULC maps. The results prove how the Portuguese CORINE layers distributed by the Copernicus Land Monitoring Service contain important sources of uncertainty, which however have been removed through the national backdating methodology. This methodology can be therefore exported for the production of CORINE in other European countries.

1. Introduction

Nowadays, Land Use and Land Cover (LULC) datasets are crucial for many different fields of research and applications, including the development of indicators to monitor the accomplishment of global agendas, the setup of climate change models or the study of ecosystem services (Bontemps et al., 2012; Brown, 2013; Diogo and Koomen, 2016; Giri, 2016). They inform about the Earth's biophysical cover (land cover) and the way these covers are used by humans (land use) (García-Álvarez et al., 2022; Giri, 2016). These datasets can be usually classified as general LULC datasets, which provide information on the different land uses or covers that make up the land surface, and thematic LULC datasets, which map specific uses or covers (e.g. datasets of impervious surfaces or cropland areas) (García-Álvarez and Nanu, 2022). General LULC datasets are used in most of the cases, as they provide a general characterization of all uses or covers on the earth. This allows for assessing land changes, analyzing the impact of any human or natural process on the environment or using this information as a driver to explain any other process or phenomenon.

CORINE Land Cover, hereinafter referred to as "CORINE", is one of the most relevant general LULC datasets in the European context available today (Bielecka and Jenerowicz, 2019; Camacho Olmedo

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et al., 2022). This is due to (i) its spatial detail (Minimum Mapping Unit of 25 ha and 5 ha for mapped changes); (ii) semantic detail (44 different land use categories); (iii) spatial coverage (39 European countries in the last update); and (iv) temporal coverage (1990–2018) (Falťan et al., 2020; García-Álvarez and Nanu, 2022). The last one, with a LULC map produced every 6 years on average, is one of the most valued features of this dataset. There are not many available historical time series of general LULC maps in the European context and, when existing, they are usually produced at coarse resolutions (Grekousis et al., 2015; García-Álvarez and Nanu, 2022).

The production of historical time series of general LULC maps that are coherent through the different years and do not bring large sources of uncertainty into the temporal analysis of LULC dynamics is one of the key challenges of the LULC mapping practice (Bontemps et al., 2012; Grekousis et al., 2015). The production method of MODIS Land Cover, the first global LULC dataset providing a time series of LULC maps (2001–2020 at 500 m), has been recently updated to deal with this issue. However, many uncertainties still arise when studying LULC changes from this dataset because of technical issues (Sulla-Menashe et al., 2019). The Annual Land Cover Product produced for Europe at 30 m for the period 2000–2019 also shows sources of uncertainty for LULC change analysis. Nonetheless, they have not been assessed and characterized in detail yet (Witjes et al., 2022). The Land Cover-Climate Change Initiative of the European Space Agency has specifically focused on the production of a time series of LULC maps that is consistent through time and allows to study LULC change with certainty (Bontemps et al., 2012; ESA, 2017). Although providing data for a long timeframe (1992–2018), its spatial resolution is low (300 m) and only changes that meet a series of criteria are mapped: changes among six wide categories, which persist over 2 years and meet a 1 km Minimum Mapping Unit (ESA, 2017).

CORINE is produced through a change mapping first approach (Büttner, 2014; European Environment Agency, 2021), which aims to ensure the temporal consistency of the CORINE time series. Through this approach, changes are independently mapped for each period and then, the CORINE Status Layer (CSL) is progressively updated based on those mapped changes (Fig. 1). In addition, in each update, previous CSL layers are also updated to account for the detected errors and inconsistencies. In the end, two layers are generated as part of the CORINE project: the layers of LULC changes (CHA) and the Status Layers (CSL) for each mapped year (Fig. 1). Whereas CHA layers aim to reflect real changes on the ground, without any technical change, the study of LULC changes from CSL layers may bring important sources of uncertainty. However, CHA layers are also affected by some errors and uncertainties, such as errors in de delineation of changing polygons, photointerpretation mistakes or uncertainties in the application of the CORINE nomenclature (Maucha et al., 2011). In addition, many users persist in making use of CSL layers for their multi-temporal analyses, including the study of LULC change (Fernández Nogueira, 2021; Gemitzi et al., 2021; Rusu et al., 2020). Although sometimes this is because of unawareness of the characteristics of the product and the existence of CHA layers, in other cases users demand status layers to carry out their multi-temporal analyses (Cantarino Martí and Goerlich Gisbert, 2013; Goerlich and Cantarino, 2013; Kucsicsa et al., 2019).

The production of CORINE is carried out at the national level. Each national team produces CORINE through a national-specific workflow that, however, meets the requirements and standards of the European Environmental Agency, the coordinating institution (European

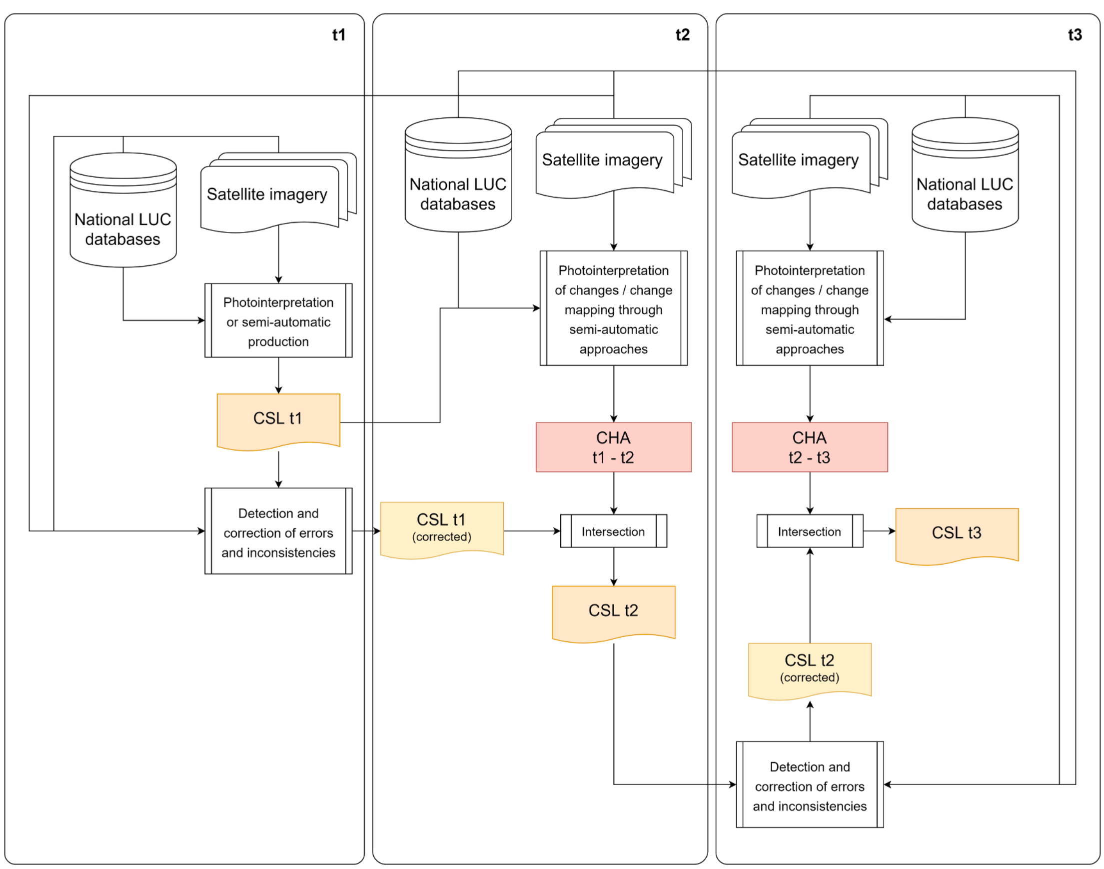

Fig. 1. CORINE production methodology following the mapping first approach. Depending on the country, CORINE Status Layers (CSL) and CORINE layers of changes (CHA) are obtained either through photointerpretation of satellite imagery or through semi-automatic approaches. In red, CHA layers. In yellow, CSL layers without corrections. In orange, CSL layers after the corrections carried out in the last update. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Environment Agency, 2021). In some countries, the production methodologies of CORINE have changed throughout the years, which has meant important changes in the mapped uses or covers and, consequently, disagreements between CSL layers (European Environment Agency, 2021; García-Álvarez and Camacho Olmedo, 2017; Martínez-Fernández et al., 2019). Changes mapped through CHA layers may have also been affected by these technical changes. This could be due to variances in the interpretation of certain categories before and after the alteration of the production method or due to the delineation of change areas that do not adhere to a consistent logical pattern compared to previous areas of change (García-Álvarez and Camacho Olmedo, 2022). However, this issue has not been explored in depth yet.

In Portugal, the production of CORINE has changed since the 2018 edition (Fig. 2). Now, CORINE is produced through a semi-automatic approach based on a combination of both photointerpretation and the information provided by a fine-scale (1 ha MMU, 1:25,000) national LULC database: *Carta de Uso e Ocupação do Solo* (European Environment Agency, 2021). The Portuguese Directorate-General for Territory (DGT), in charge of producing CORINE Portugal, produces its own CORINE Status Layers (CSL) by backdating the latest CSL layers to the past (Fig. 2) (Caetano and Marcelino, 2017). This product, which aims to provide consistency to the study of LULC change with CORINE in Portugal, is complementary to the layers supplemented by the Copernicus Land Monitoring Service, hereinafter referred to as "Copernicus". Copernicus provides non-backdated CSL layers and CHA layers. This Portuguese approach can be considered a reference to manage the uncertainty of LULC changes in the CORINE database.

Because of the relevance of CORINE to provide a consistent time series of LULC information, the study of the existent inconsistencies and uncertainties on this data should be object of further revision. Accordingly, given the Portuguese CORINE production changes since the 2018 and the low validation scores of the Portuguese CHA layers in global validation exercises (Moiret et al., 2021; Sannier et al., 2017), this paper aims to evaluate the DGT Portuguese approach to backdate the CORINE Status Layers as a methodology of reference to obtain consistent and time-coherent LULC datasets. The main objectives are to evaluate (i) the LULC changes that can be studied through traditional CORINE Status Layers (CSL) (distributed by Copernicus); (ii) the LULC changes that can be studied from the Portuguese CSL layers; (iii) the LULC changes that can be studied from the CORINE layers of changes (CHA) distributed by Copernicus; and lastly, (iv) to provide insight into the characteristics and limitations of the Portuguese CORINE for producing a coherent and consistent time series, which could be exported globally to all CORINE participating countries.

2. Materials and methods

We have analyzed the changes that can be studied by utilizing the various types of CORINE layers available in vector format for Portugal: the CORINE Status Layers for the reference years 1990, 2000, 2006, 2012 and 2018 distributed by Copernicus (CSL Copernicus); the CSL layers for the same years produced by the Portuguese DGT (CSL DGT); and the CORINE layers of changes (CHA) for the reference periods 1990–2000, 2000–2006, 2006–2012 and 2012–2018, also distributed by Copernicus (Fig. 3).

CSL layers show the land uses and covers of Portugal for each mapped year of reference (Fig. 3). Whereas the CSL Copernicus layers map both mainland Portugal and the Portuguese islands, CSL DGT layers

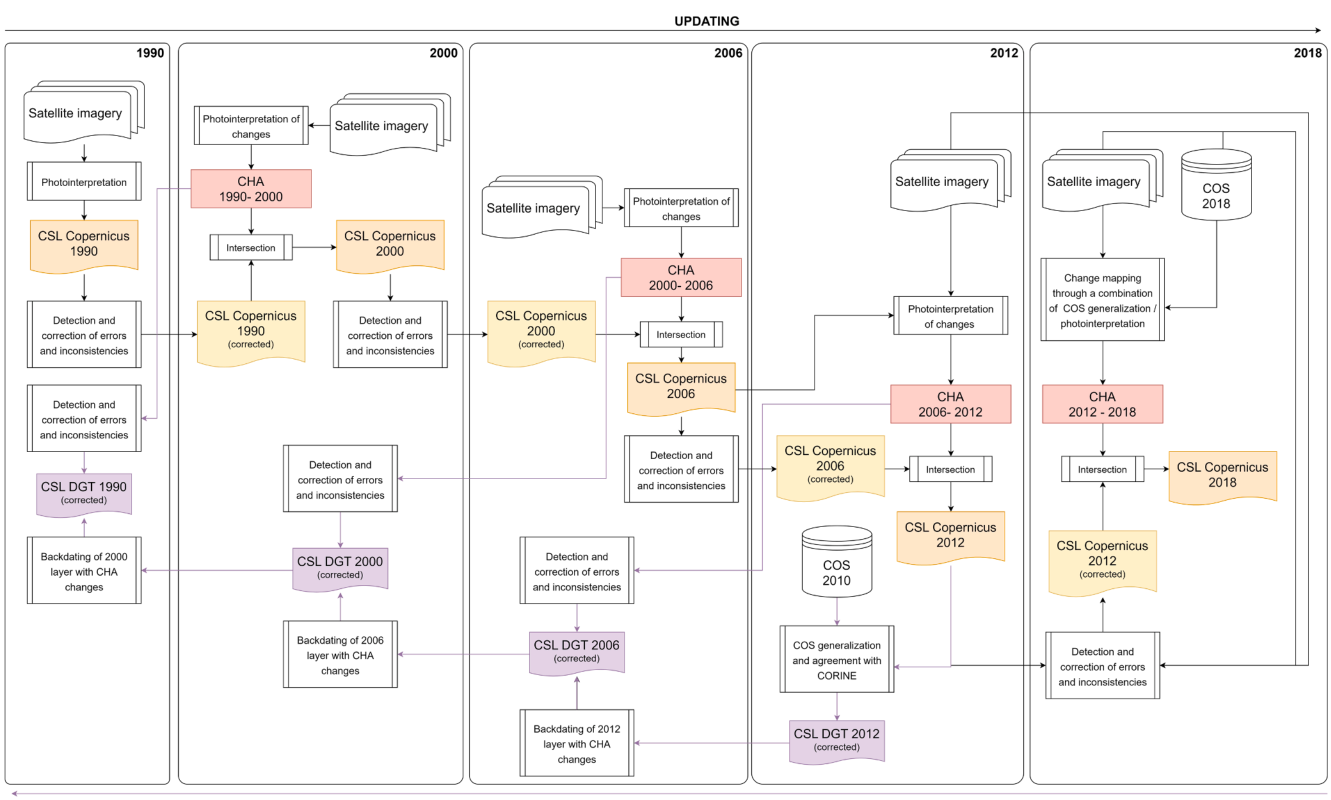

Fig. 2. CORINE production methodology in Portugal. Above, the CORINE production methodology implemented by the DGT (Portuguese Directorate-General for Territory) to produce the CORINE Status Layers (CSL) and CORINE layers of changes (CHA) distributed by Copernicus (updating approach). Below, the CORINE production methodology implemented by the DGT to produce the national time-coherent CSL layers (backdating approach). In red, distributed CHA layers. In yellow, distributed CSL Copernicus layers without corrections. In orange, distributed CSL Copernicus layers after the corrections carried out in the last update. In purple, distributed CSL DGT layers obtained through the Portuguese backdating approach. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

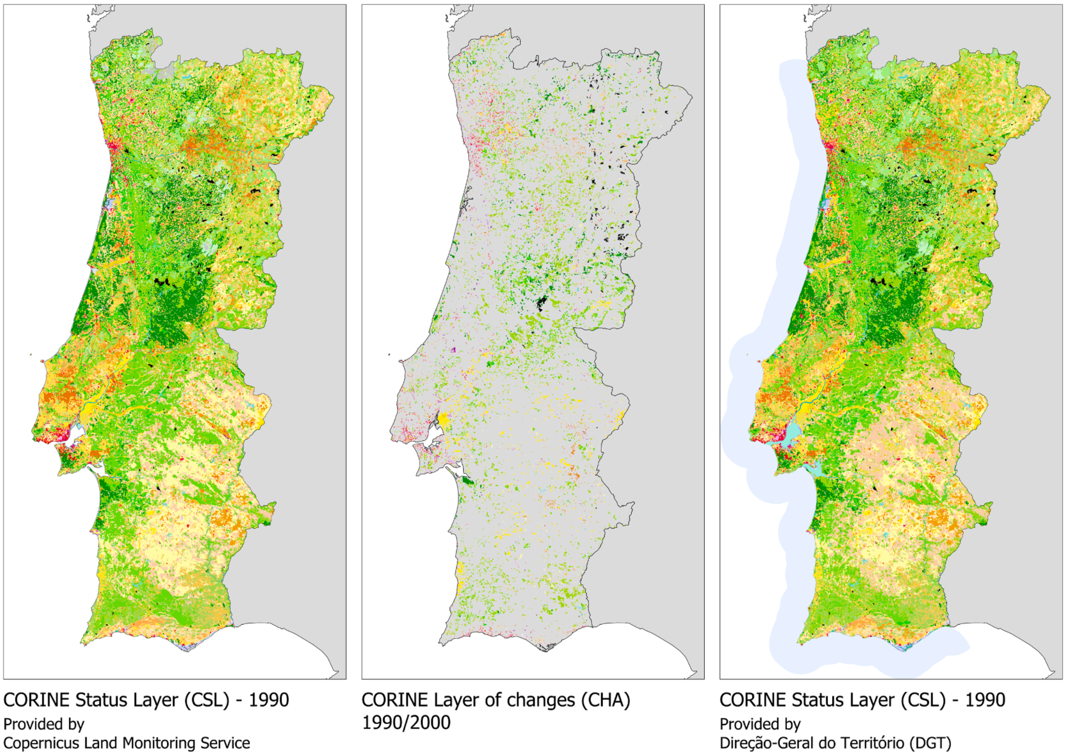

Fig. 3. Graphic overview of the three types of CORINE layers analyzed. Sources: CORINE Land Cover (Copernicus Land Monitoring Service, DGT). Readers can find a full and detailed version of these maps as supplementary material in the online version of this paper.

only map mainland Portugal. Land uses and covers are mapped in both cases according to the same mapping rules: Minimum Mapping Unit (MMU) of 25 ha and Minimum Mapping Width of 100 m (Caetano and Marcelino, 2017). CHA layers only show the LULC changes for each mapped period with a MMU of 5 ha (Fig. 3). They cover both mainland Portugal and its islands.

Copernicus distributes CSL and CHA layers covering Europe for all available years and periods (https://land.Copernicus.eu/pan-european/corine-land-cover). For this analysis, we have clipped those layers for the Portuguese territories. The Portuguese DGT distributes its CSL DGT layers at the National Spatial Data Infrastructure (https://snig.dgterritorio.gov.pt/). Readers should note that the CSL DGT 2018 layer has not yet been produced and, therefore, the DGT provides the CSL Copernicus layer for comparison purposes. Accordingly, this layer may contain potential uncertainties and errors when compared with the other CSL DGT layers, as it has not been produced following the Portuguese backdating method.

The methodological workflow of this study is summarized in Fig. 4. CHA layers already show LULC changes and, therefore, have not been object of any transformation. We calculated the area of the transitions between the categories at the most detailed level of the classification legend, along with their proportions concerning all changes within each period. Additionally, we calculated three metrics: area of the smallest polygon, area of the largest polygon and mean area of all polygons ("Analysis of CHA layers" in Fig. 4).

CSL Copernicus and DGT layers were overlaid in pairs to obtain the LULC changes for each CORINE period: 1990–2000, 2000–2006, 2006–2012 and 2012–2018. Once the layers were overlaid in pairs, we removed all polygons that remained invariant. Then, we calculated the area and proportions of the transitions of change for each layer and period, as well as the three metrics that we mentioned before ("Analysis of changes" in Fig. 4).

To check the agreement between CHA and CSL changes, we overlaid for each period (1990–2000, 2000–2006, 2006–2012, 2012–2018) CHA and CSL changes (CHA – CSL Copernicus; CHA - CSL DGT). We then categorized the overlaid polygons in four categories: (i) agreement (both layers show change, and the changing categories are the same); (ii) change without agreement (both layers show change, but from and/or to different categories); (iii) change only in CHA layer and; (iv) change only in CSL layer. Finally, for each of the four defined categories, we calculated the percentage that the (dis)agreement represented regarding all the mapped changes ("Analysis of CHA – CSL agreement" in Fig. 4).

CSL and CHA layers were also individually analyzed. For each CSL layer (Copernicus and DGT), we calculated (i) the area in hectares that each CORINE category represented in each year; (ii) the percentage of that area regarding all mapped uses/covers; and (iii) the percentage of annual change for each category and period ("Analysis of CSL layers" in Fig. 4).

For CHA layers, we analyzed the coherence or logical consistency of changes between CHA layers across different time-periods ("Analysis of CHA layers" in Fig. 4). To determine this, we considered a change to be coherent or logic between the CHA layer of one period (t_1) and the CHA layer of the subsequent period (t_2) when the destination category of a transition in t_1 matched the category origin of the transition in t_2. If this condition was not met, we considered the change to be incoherent or illogic. We calculated the area of non-coherent polygons for all periods to determine the percentage it represented in relation to (i) the total changes in CHA layers, and (ii) the total areas in CHA layers that changed in at least two different periods. It is important to note that change coherence analysis can only be conducted when there is a change in at least two periods, as it requires comparing the destination category of one period to the origin category of the transition in the next period.

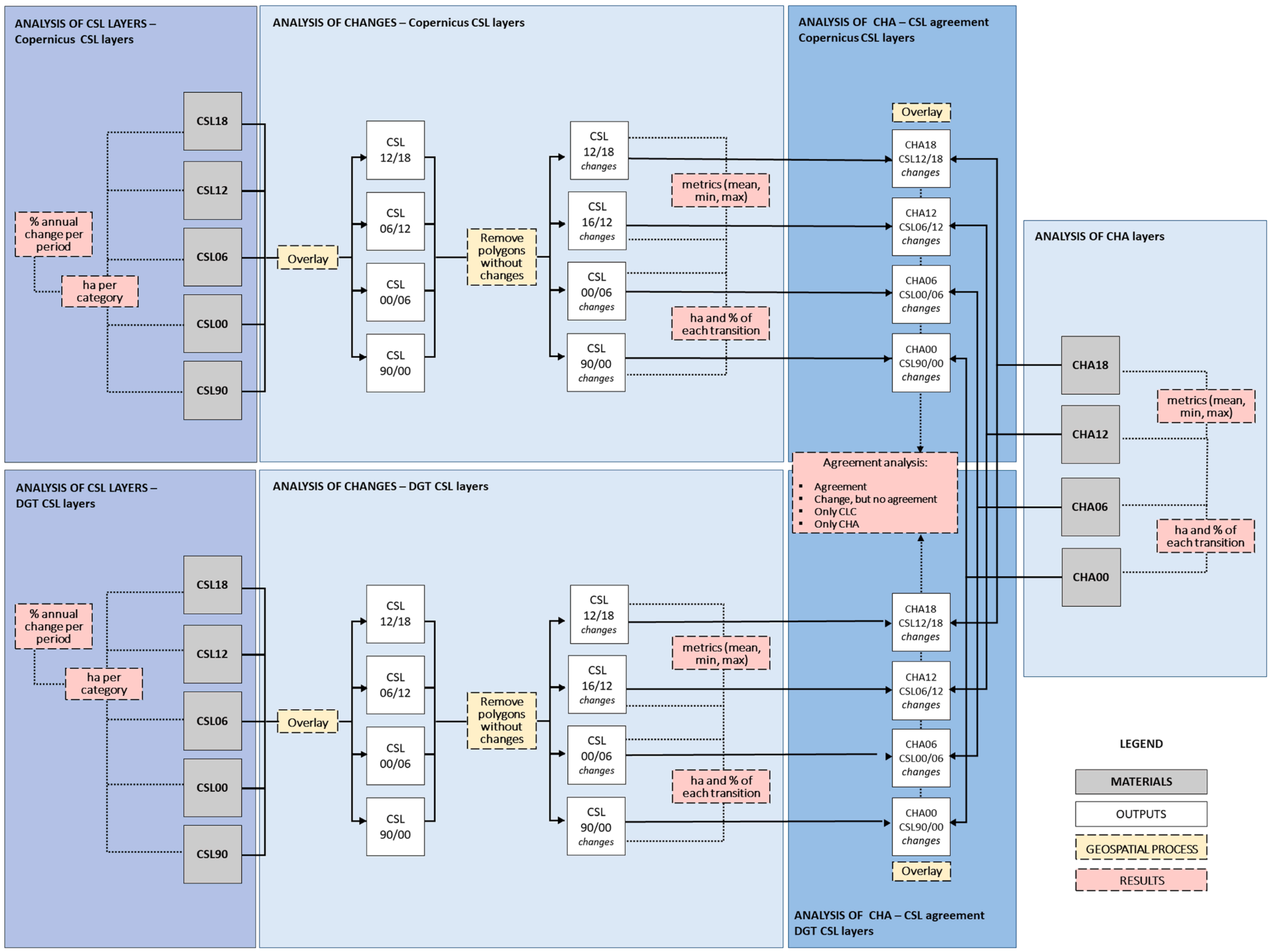

Fig. 4. Conceptual chart of the methods followed to analyze the CORINE layers available for Portugal.

Table 1
Annual percentage of change and proportion of the Portuguese mapped area in the two types of CORINE Status Layers (CSL Copernicus, CSL DGT) for a selection of CORINE categories that exhibit the most contrasted trends between layers (highlighted in orange cells). The complete version of this table, which includes all CORINE categories, is available as supplementary material in the online version of this paper.

	Percentage of annual change								Percentage that each category represents regarding the country									
	CSL Copernicus				CSL DGT				CSL Copernicus					CSL DGT				
	90-00	00-06	06-12	12-18	90-00	00-06	06-12	12-18	90	00	06	12	18	90	00	06	12	18
Continuous urban fabric	0.0%	0.2%	32.2%	0.0%	1.0%	0.3%	0.1%	0.1%	0.1%	0.1%	0.1%	0.4%	0.4%	0.3%	0.3%	0.3%	0.3%	0.3%
Discontinuous urban fabric	4.5%	2.3%	-1.5%	0.1%	1.7%	1.0%	0.1%	0.4%	1.5%	2.4%	2.7%	2.5%	2.5%	1.4%	1.7%	1.8%	1.8%	1.9%
Green urban areas	2.0%	7.9%	1.5%	-0.2%	1.5%	1.6%	0.1%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Non-irrigated arable land	-0.9%	-2.0%	-3.4%	-0.8%	-0.6%	-0.8%	-0.8%	-1.1%	12.8%	11.2%	9.8%	7.8%	7.5%	7.9%	7.2%	6.9%	6.6%	6.0%
Pastures	-0.7%	6.5%	18.5%	-0.4%	-0.2%	0.1%	-0.2%	0.6%	1.2%	1.1%	1.5%	3.2%	3.1%	2.1%	2.0%	2.0%	2.0%	2.0%
Annual crops associated with permanent crops	-0.7%	-3.2%	-3.0%	0.0%	-0.6%	-0.2%	0.0%	-0.7%	4.9%	4.4%	3.6%	2.9%	2.9%	2.8%	2.6%	2.6%	2.5%	2.4%
Agro-forestry areas	0.8%	0.0%	3.8%	0.0%	0.0%	-0.2%	-0.1%	0.2%	6.2%	6.8%	6.8%	8.4%	8.4%	7.1%	7.1%	7.0%	7.0%	7.0%
Broad-leaved forest	-0.1%	-2.3%	-1.5%	-1.6%	0.5%	-2.1%	1.3%	-1.5%	12.9%	12.7%	10.9%	9.9%	9.0%	7.8%	8.4%	7.3%	7.9%	7.1%
Natural grasslands	-0.6%	-6.6%	-7.6%	0.0%	-1.2%	-1.5%	0.3%	-0.9%	2.4%	2.2%	1.3%	0.7%	0.7%	0.5%	0.4%	0.4%	0.4%	0.4%
Moors and heathland	-1.4%	2.6%	6.5%	-0.2%	-0.1%	0.5%	0.2%	0.2%	4.3%	3.5%	4.0%	5.5%	5.5%	4.2%	4.1%	4.3%	4.3%	4.3%
Bare rocks	-3.2%	-14.0%	-2.3%	0.0%	-0.2%	-0.2%	0.0%	0.1%	0.5%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Sparsely vegetated areas	2.0%	-2.6%	-7.2%	0.0%	0.1%	-0.1%	0.0%	1.0%	0.9%	1.1%	1.0%	0.5%	0.5%	0.4%	0.4%	0.4%	0.4%	0.4%
Peat bogs	-0.1%	0.0%	-1.9%	0.0%					0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%

3. Results

3.1. The status of the Portuguese LULC in CSL layers

In the CSL DGT layers, CORINE LULC categories represent in all reference years a similar proportion of the Portuguese landscape (Table 1), as expected in any European low-dynamic landscape. "Broad-leaved forest" is the only category that shows a meaningful change of proportion in the period 1990–2018, which can be attributed to the high dynamism of this category, very affected by fires, logging and other human or natural-inducted processes.

In CSL Copernicus layers, there are very meaningful differences in the proportions that some categories represent in the Portuguese landscape over the years. Most of these changes happen between 2006 and 2012 (Table 1). The continuous urban fabric represented only 0.1 % of the Portuguese landscape in 2006, whereas it represents four times more area in 2012 (0.4 %) (Table 1). The discontinuous urban fabric represents less area of the Portuguese territory in 2012 (2.5 %) than in 2006 (2.7 %). Pastures double their area between 2006 and 2012, whereas sparsely vegetated areas and natural grasslands lose half of their area in that period (Table 1). Some of these trends seem unlogic, such as the compaction of the Portuguese urban area.

The proportions that each category represents in each layer and year are significantly different in CSL Copernicus and CSL DGT layers. The ocean band, which is only included in the CSL DGT layers, represents up to 19 % of all total Portuguese surface in these layers, whereas it only represents 0.1 % of the Portuguese landscape in CSL Copernicus layers (see supplementary material). Peat bogs, although not very relevant in terms of area, are mapped in CSL Copernicus layers (0.1 % of total area), but not in CSL DGT layers (Table 1).

The annual percentage of changes per category shows for both types of layers a similar behavior to that the one pointed out before. In CSL Copernicus layers, some categories abruptly show in 2012 contrasting rates of change to the ones observed in the previous and next periods. For example, the continuous urban fabric grows 32.2 % per year between 2006 and 2012 according to CSL Copernicus layers, whereas this rate is only 0.1 % in CSL DGT layers. This is a more similar rate of change to the one observed in CSL Copernicus layers between 2000 and 2006 (0.2 %) and between 2012 and 2018 (0.0 %) (Table 1).

In the period 2012–2018, the annual rate of change of green urban areas is negative in the Copernicus layers (−0.2 %) and positive in the DGT layers (0.4 %). For the 2000–2006 period, a few categories also show contrasting rates of change between Copernicus and DGT layers: pastures (6.5 % vs 0.1 %), annual crops associated with permanent crops (−3.2 % vs −0.2 %), natural grasslands (−6.6 % vs −1.5 %) bare rocks (−14 % vs −0.2 %), and sparsely vegetated areas (−2.6 % vs −0.1 %) (Table 1). Notwithstanding, in none of these cases the rates of change show opposite dynamics (growth vs losses). In the 1990–2000 and 2012–2018 periods, the differences are less significant.

Table 3
Minimum (MIN), maximum (MAX), and mean (MEAN) size in hectares of changing patches in CORINE layers of changes (CHA), CORINE Status Layers distributed by Copernicus (CSL Copernicus) and CORINE Status Layers distributed by the Portuguese DGT (CSL DGT).

MEAN	90–00	00–06	06–12	12–18
CSL Copernicus	6.9	4.2	12.9	7.2
CSL DGT	46.6	50.8	55.4	26.1
CHA	34.3	23.2	22.8	16.8
MIN	**90–00**	**00–06**	**06–12**	**12–18**
CSL Copernicus	0.0	0.0	0.0	0.0
CSL DGT	0.1	0.1	0.7	0.0
CHA	1.0	0.3	0.1	0.1
MAX	**90–00**	**00–06**	**06–12**	**12–18**
CSL Copernicus	32452.4	305.9	845.6	8180.4
CSL DGT	5546.1	38301.0	6637.9	8180.4
CHA	8361.7	31969.4	5359.9	7965.2

3.2. The LULC changes in CSL and CHA layers

3.2.1. The agreement between LULC changes in CSL and CHA layers

CSL Copernicus layers show very different information to CHA layers in the periods 2000–2006 and 2006–2012 (Table 1). For these periods, only 30 % or less of the mapped change in CSL Copernicus layers agree with the information in CHA layers (Table 2). On the contrary, around 60–70 % of the areas mapped as change in CSL Copernicus layers are not included in the CHA layers. 2012–2018 is the only period for which the agreement between CSL Copernicus and CHA layers is high (78 %). The last CSL Copernicus has been obtained from the revision of the previous CSL layer and the superposition of the new CHA layer, which ensures the agreement between CSL Copernicus and CHA layers until a new revision of the CSL layer is carried out.

CSL DGT layers show better agreement with CHA layers, usually above 70 %, except for the last period: 2012–2018 (Table 2). The lower agreement for that period (53.2 %) can be explained by the lack of processing of that layer by the DGT. The CSL DGT 2018 layer has been not obtained through the Portuguese backdating method and, therefore, shows important disagreements with the other CSL DGT layers.

3.2.2. The pattern of the LULC changes in CSL and CHA layers

The mean area of the changes mapped by CSL DGT layers is bigger than the mean area of the changes mapped by CHA layers (Table 3), which can be explained by of the bigger Minimum Mapping Unit of CSL layers. The opposite is true for the CSL Copernicus layers, which could be attributed to the presence of errors and technical changes in these layers. A visual inspection of the changes mapped by each type of layer helps us to perceive this issue (Fig. 5).

The size of the biggest polygon of change is the same in CSL Copernicus and DGT layers in the last period and very similar (slightly bigger) to the size of the biggest polygon in the CHA layer of that period. This makes sense because of the bigger Minimum Mapping Unit of CSL

Table 2
Agreement between LULC changes in CORINE Status Layers (CSL Copernicus, CSL DGT) and CORINE layers of changes (CHA).

	CSL Copernicus - CHA				CSL DGT – CHA			
	90-00	00-06	06-12	12-18	90-00	00-06	06-12	12-18
Agreement	55.3%	30.5%	25.8%	**78.0%**	71.0%	70.1%	76.9%	**53.2%**
Change differently mapped in each layer	2.7%	3.7%	2.1%	5.2%	12.5%	9.8%	5.3%	5.3%
Only change in CHA layer	1.7%	2.7%	2.5%	9.3%	9.7%	10.1%	9.2%	9.1%
Only change in the CSL layer	40.4%	63.1%	69.6%	**7.5%**	6.7%	10.0%	8.6%	**32.4%**

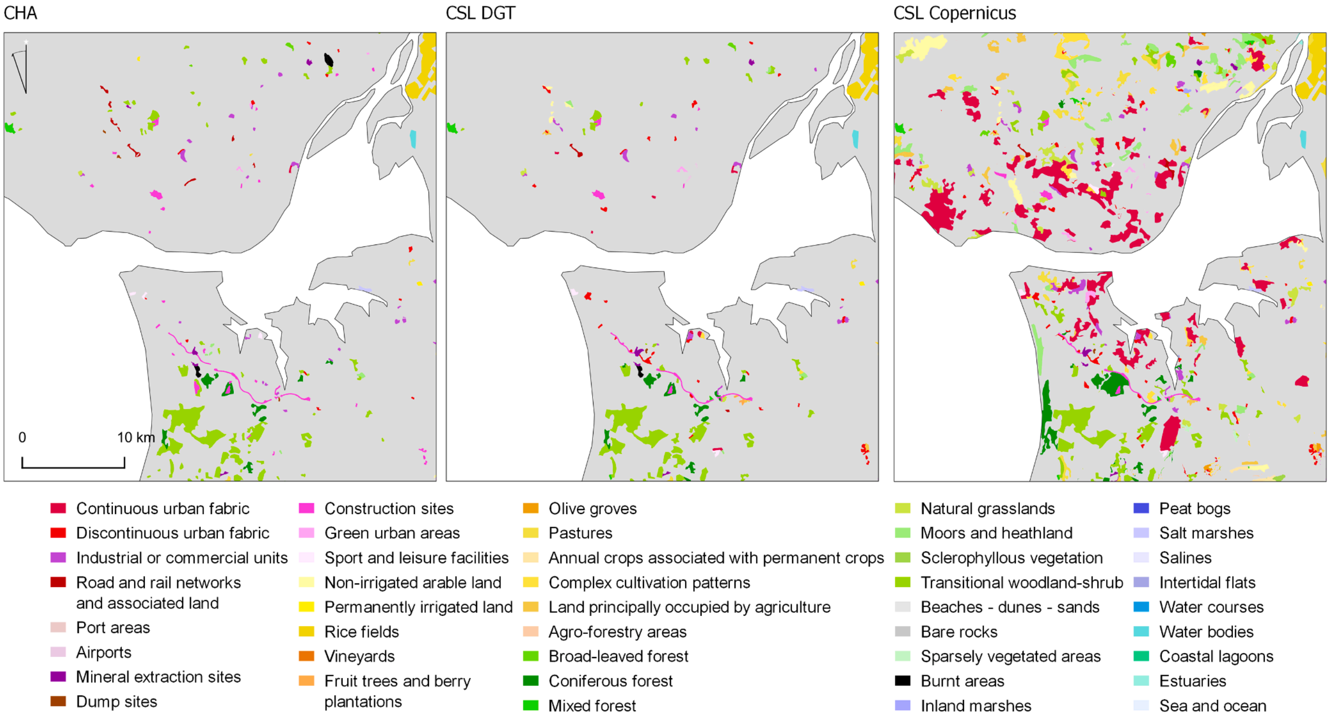

Fig. 5. Comparison of LULC changes for the period 2006–2012 in the three layers compared: CORINE layers of changes (CHA); CORINE Status Layers distributed by the Portuguese DGT (CSL DGT); and CORINE Status Layers distributed by Copernicus (CSL Copernicus). The legend shows the categories to which the transition takes place. That is, continuous urban fabric means areas that were a different category in 2006 and transitioned to continuous urban fabric in 2012.

Table 4
Transitions of change between CORINE categories that account in either CORINE Status Layers distributed by Copernicus (CSL Cop) or CORINE Status Layers distributed by the Portuguese DGT (CSL DGT) for more than 2 % of the mapped change in each period and layer. CSL Cop, CSL DGT and CHA columns indicate the proportion of each transition relative to the total quantity of changes in the respective layer. DIF Cop and DIF DGT columns indicate the difference, in percentage, of the area mapped as change for each transition between CORINE Status Layers (Copernicus/DGT) and CORINE layers of changes (CHA). DIF Cop displays the area difference of the changes mapped by CSL Copernicus concerning CHA layers. DIF DGT shows the area difference of the changes mapped by CSL DGT concerning CHA layers. In either DIF Cop or DIF DGT, a positive percentage of 20 % means that the corresponding CSL layers map 20 % more quantity of change that the CHA layer. Readers can find the full information for all layers, periods and transitions of change as supplementary material in the online version of this paper.

		90-00					00-06					06-12					12-18				
Category t1	Category t2	CSL Cop	CSL DGT	CHA	DIF Cop	DIF DGT	CSL Cop	CSL DGT	CHA	DIF Cop	DIF DGT	CSL Cop	CSL DGT	CHA	DIF Cop	DIF DGT	CSL Cop	CSL DGT	CHA	DIF Cop	DIF DGT
Coniferous forest	Transitional woodland-shrub	9,2%	12,6%	15,0%	1%	-23%	10,5%	23,6%	25,6%	7%	-8%	3,2%	8,6%	9,1%	11%	-6%	12,9%	10,2%	14,5%	-14%	-6%
Transitional woodland-shrub	Broad-leaved forest	6,9%	10,0%	10,7%	6%	-10%	3,3%	6,6%	7,5%	14%	-14%	9,0%	26,0%	26,6%	8%	-3%	10,0%	8,3%	10,5%	-8%	5%
Transitional woodland-shrub	Coniferous forest	5,4%	7,5%	7,8%	13%	-7%	2,3%	3,7%	4,4%	29%	-17%	2,0%	5,5%	5,7%	12%	-3%	2,2%	1,9%	2,3%	-5%	12%
Broad-leaved forest	Transitional woodland-shrub	5,5%	6,2%	6,8%	25%	-14%	9,4%	19,3%	20,5%	18%	-6%	5,4%	14,1%	14,5%	17%	-3%	23,1%	18,0%	24,2%	-7%	0%
Mixed forest	Transitional woodland-shrub	3,8%	4,9%	5,9%	5%	-24%	5,0%	9,4%	9,8%	26%	-4%	2,0%	5,6%	6,1%	5%	-11%	7,7%	6,1%	8,0%	-5%	2%
Transitional woodland-shrub	Mixed forest	3,0%	4,2%	4,2%	17%	-2%	1,9%	2,2%	1,6%	67%	25%	2,3%	6,9%	6,1%	18%	11%	1,0%	1,0%	0,8%	20%	41%
Non-irrigated arable land	Permanently irrigated land	3,4%	3,8%	4,1%	27%	-10%	0,8%	0,7%	0,7%	66%	-5%	1,2%	1,2%	1,2%	70%	-4%	2,9%	2,5%	2,9%	-2%	13%
Sclerophyllous vegetation	Transitional woodland-shrub	2,3%	2,7%	2,4%	37%	10%	1,3%	1,3%	1,4%	60%	-8%	0,9%	0,2%	0,2%	93%	12%	0,5%	0,5%	0,5%	-9%	11%
Burnt areas	Transitional woodland-shrub	1,3%	1,8%	2,2%	-3%	-24%	1,0%	2,3%	3,3%	-23%	-44%	1,3%	4,0%	4,7%	-15%	-19%	2,0%	1,2%	2,1%	-7%	-23%
Moors and heathland	Transitional woodland-shrub	2,5%	1,7%	2,1%	48%	-27%	2,5%	0,6%	0,5%	92%	7%	1,6%	0,3%	0,2%	96%	32%	0,7%	1,2%	0,6%	6%	61%
Non-irrigated arable land	Transitional woodland-shrub	1,9%	1,5%	1,4%	56%	6%	2,3%	2,9%	3,3%	45%	-14%	0,5%	0,9%	0,9%	38%	-5%	0,5%	0,6%	0,6%	-23%	32%
Transitional woodland-shrub	Burnt areas	0,8%	1,4%	1,3%	-1%	5%	0,6%	1,4%	1,5%	5%	-7%	0,5%	1,3%	1,7%	-1%	-32%	4,5%	3,2%	4,4%	0%	-1%
Non-irrigated arable land	Pastures	0,3%	0,3%	0,2%	57%	19%	1,1%	0,1%	0,0%	100%	89%	6,9%	0,1%	0,1%	100%	-12%	0,3%	1,6%	0,3%	-14%	84%
Broad-leaved forest	Agro-forestry areas	4,3%	0,4%	0,2%	98%	49%	1,4%	0,5%	0,7%	82%	-30%	10,4%	0,0%	0,0%	100%	-57%	0,2%	0,4%	0,2%	-2%	64%
Mixed forest	Burnt areas	0,1%	0,2%	0,2%	1%	0%	0,2%	0,5%	0,5%	-3%	-6%	0,1%	0,3%	0,4%	-9%	-76%	2,1%	1,5%	2,1%	1%	1%
Non-irrigated arable land	Olive groves	0,2%	0,2%	0,1%	43%	35%	0,6%	0,5%	0,4%	78%	23%	1,7%	5,2%	5,3%	5%	-3%	2,8%	2,1%	2,8%	-2%	0%
Broad-leaved forest	Burnt areas	0,1%	0,1%	0,1%	-15%	-12%	0,3%	0,9%	0,8%	4%	4%	0,1%	0,2%	0,4%	-9%	-173%	2,4%	1,7%	2,4%	-2%	-1%
Natural grasslands	Moors and heathland	0,2%	0,0%	0,0%	99%	86%	2,6%	0,0%	0,0%	100%	6%	3,1%	0,0%	0,0%	100%	-1412%	0,0%	0,2%	0,0%	3%	89%
Transitional woodland-shrub	Moors and heathland	0,6%	0,3%		100%	100%	1,6%	0,2%		100%	100%	4,5%	0,3%	0,0%	100%	97%	0,3%	0,7%	0,2%	46%	83%
Agro-forestry areas	Pastures	0,0%	0,0%		100%	100%	0,2%	0,0%		100%	100%	2,1%	0,0%		100%	100%	0,0%	0,1%	0,0%	17%	67%
Sparsely vegetated areas	Moors and heathland	0,1%	0,0%		100%	100%	1,2%	0,0%	0,0%	100%	-2236%	2,5%	0,0%	0,0%	100%	-98%	0,0%	0,1%		100%	100%
Moors and heathland	Sclerophyllous vegetation	3,0%	0,0%		100%	100%	0,1%	0,0%		100%	100%	0,3%			100%			0,1%			100%
	Total	54,6%	59,8%	64,5%			50,2%	76,6%	82,5%			61,8%	80,6%	83,2%			76,1%	63,1%	79,3%		

layers, which means more mapping generalization than in CHA layers. However, for the periods 2000–2006 and 2006–2012, although a similar trend can be appreciated in the case of CSL DGT layers, for CSL Copernicus layers the metric is very different. For the period 2006–2012, the biggest polygon is 63 times smaller in CSL Copernicus than in CHA layers. For the period 2000–2006, the biggest polygon is 1045 times smaller (Table 3). In 1990–2000, the pattern is exactly the opposite: the biggest polygon in CSL Copernicus is almost 4 times the size of the biggest polygon of CHA.

3.2.3. An analysis of the LULC changes at the transition level

Table 4 summarizes the main transitions of change that have been identified in the different CORINE layers. The 22 transitions listed in Table 4 collectively account for over half of the mapped changes across all periods and layers, covering more than 80 % of the total mapped changes in several layers for different periods.

Natural vegetation categories, and especially, forest categories, are involved in most of the major transitions of change. Transitional woodland-shrub, a category which is not very well defined, is the one that shows the most dynamism over the different years and in all types of

Table 5
The area involved in each transition for each type of layer and period on a standard scale, where 1 is equal to the mean area of changes in the CHA layers over the four mapped periods. For the Coniferous forest to Transitional woodland-shrub transition, 0.7* means that the area that underwent this transition in the period 1990–2000 in these layers is 30 % lower than the mean area that underwent this transition over the period 1990–2018 in CHA layers.

Category t1	Category t2	90-00			00-06			06-12			12-18		
		CSL Cop	CSL DGT	CHA	CSL DGT	CSL DGT	CHA	CSL Cop	CSL DGT	CHA	CSL Cop	CSL DGT	CHA
Coniferous forest	Transitional woodland-shrub	0,7*	0,5	0,7	2,3	1,9	2,1	0,5	0,5	0,5	0,8	0,8	0,9
Transitional woodland-shrub	Broad-leaved forest	0,7	0,6	0,6	0,9	0,7	0,8	2,0	1,8	1,8	0,8	0,9	0,8
Transitional woodland-shrub	Coniferous forest	1,4	1,2	1,2	1,8	1,1	1,3	1,2	1,0	1,1	0,5	0,6	0,5
Broad-leaved forest	Transitional woodland-shrub	0,4	0,3	0,3	2,0	1,5	1,6	0,9	0,7	0,7	1,3	1,4	1,4
Mixed forest	Transitional woodland-shrub	0,6	0,5	0,6	2,4	1,7	1,8	0,8	0,7	0,7	1,0	1,1	1,1
Transitional woodland-shrub	Mixed forest	1,3	1,1	1,1	2,4	1,0	0,8	2,3	2,1	1,9	0,3	0,5	0,3
Non-irrigated arable land	Permanently irrigated land	2,2	1,4	1,6	1,5	0,5	0,5	1,8	0,5	0,6	1,5	1,7	1,5
Sclerophyllous vegetation	Transitional woodland-shrub	2,5	1,7	1,6	4,1	1,5	1,6	2,2	0,2	0,2	0,4	0,5	0,5
Burnt areas	Transitional woodland-shrub	0,0	4,0	0,0	0,0	9,5	0,0	0,0	10,9	0,0	0,0	5,1	0,0
Moors and heathland	Transitional woodland-shrub	4,4	1,8	2,3	13,3	1,1	1,1	6,8	0,4	0,3	0,9	2,3	0,9
Non-irrigated arable land	Transitional woodland-shrub	1,3	0,6	0,6	4,7	2,2	2,6	0,8	0,5	0,5	0,3	0,5	0,3
Transitional woodland-shrub	Burnt areas	0,4	0,4	0,4	1,0	0,9	0,9	0,7	0,5	0,7	2,0	1,9	1,9
Non-irrigated arable land	Pastures	2,2	1,2	1,0	24,6	1,0	0,1	125,2	0,5	0,6	1,8	13,3	2,1
Broad-leaved forest	Agro-forestry areas	15,3	0,7	0,4	14,9	2,0	2,6	85,8	0,1	0,1	0,5	1,5	0,6
Mixed forest	Burnt areas	0,2	0,2	0,2	0,9	0,8	0,9	0,4	0,3	0,5	2,5	2,5	2,5
Non-irrigated arable land	Olive groves	0,1	0,1	0,1	1,0	0,3	0,2	2,4	2,2	2,3	1,4	1,4	1,4
Broad-leaved forest	Burnt areas	0,1	0,1	0,1	1,2	1,2	1,1	0,3	0,1	0,4	2,4	2,4	2,4
Natural grasslands	Moors and heathland	11,7	1,0	0,1	437,8	0,3	0,2	419,6	0,1	1,2	1,6	13,9	1,6
Transitional woodland-shrub	Moors and heathland	8,5	2,1	0,0	61,6	3,3	0,0	143,4	3,1	0,1	3,4	10,8	1,8
Agro-forestry areas	Pastures	0,0	1,8	0,0	46,0	3,4	0,0	406,0	0,6	0,0	2,6	6,6	2,2
Sparsely vegetated areas	Moors and heathland	15,0	0,4	0,0	840,5	0,0	0,5	1383,1	1,6	3,1	0,3	16,5	0,0
Moors and heathland	Sclerophyllous vegetation	12736,2	4,0	0,0	949,9	3,5	0,0	2650,0	0,0	0,0	0,0	494,6	0,0

layers. Usually, 40 % or more of all mapped change in all CORINE layers is driven by changes from or to this category (Table 4).

Proportions of changes in CSL DGT and CHA layers are very similar in 1990–2000, 2000–2006 and 2006–2012. In the last period (2012–2018), CSL Copernicus layers resemble better the information provided by CHA layers.

In all periods before 2012, the most relevant transitions analyzed in Table 4 show smaller proportions in CSL Copernicus layers than in CSL DGT and CHA layers. However, the area involved in those transitions is very similar for both types of layers. In the transition from coniferous forest to transitional woodland-shrub, the difference in area from both CSL Copernicus and CSL DGT layers concerning CHA layers is always below 25 % (Table 4). Furthermore, the quantities of change remain very similar in all layers for the four periods (Table 5). Accordingly, those differences in the proportions that the most relevant transitions represent regarding all mapped change in CSL Copernicus, as compared to CSL DGT and CHA layers, can be attributed to the important area that minor transitions not mapped in CSL DGT and CHA layers represent in CSL Copernicus layers. These minor transitions may include technical changes and errors that are not captured in CSL DGT and CHA layers.

The less relevant transitions in terms of size are the ones that show more differences regarding the quantity of changing area among layers and periods. The last five transitions included in Table 4 are sometimes not even mapped in CHA layers. The difference in area of these transitions is usually huge between CHA and CSL Copernicus layers, and important but small between CHA and CSL DGT layers (Table 5), with the only exception of the 2012–2018 period, which agrees with the trends studied before. Whereas the small difference between CHA and CSL DGT layers could be attributed to map generalization, in the case of CSL Copernicus layers, it can only be explained by the presence of technical or spurious changes.

Finally, most of the transitions show abrupt trend changes over the different mapped periods. In CHA and CSL DGT layers, the transition from coniferous forest to transitional woodland-shrub in the 2000–2006 period and the transition from transitional woodland-shrub to the broad-leaved forest in the period 2006–2012 represent a much bigger proportion of the total change mapped by those layers than in the previous and the next periods (Table 4). The area of change involved in these transitions is also bigger for these periods (Table 5).

Some transitions are only significant in some specific periods and layers. The transitions to burnt areas are specifically relevant in 2012–2018 for all layers (Table 4), being small in all other periods and layers (Table 5). The moors and heathland to sclerophyllous vegetation transition mean 3 % of all mapped change in 1990–2000 in CSL Copernicus layers, but 0.3 % or less in all other layers and periods (Table 4). The same is true for the agro-forestry areas to pastures transition in the 2006–2012 period.

3.2.4. *The coherence of LULC changes in CHA layers*

The analysis of change coherence between the CHA layers of the four mapped periods reveals how 16.1 % of the areas that change in more than one period do not show a coherent transition timeline. This means that, if an area changed from one category to another in a period, in the next period there was a new transition from a different category than the one to which the transition took place in the previous period.

CSL layers always show a coherent transition timeline, as changes are obtained through the crosstabulation of the CSL layers for the different years of reference. This means that the transition from 1990 to 2000 and the transition from 2000 to 2006 are produced based on the same 2000 layer, which ensures the coherence between the two layers of changes obtained.

4. Discussion

CORINE is a European LULC database of reference that, given the change first mapping approach it follows, should provide a consistent time series of LULC maps, allowing the study of LULC change for any European country with certainty. However, LUC change can be studied in CORINE from different layers, each one providing different results with different levels of uncertainty.

CHA are the official layers of changes distributed by Copernicus, which however contain some sources of uncertainty. These are analyzed in detail in Section 4.1. Studying LULC change from CSL layers may bring important sources of uncertainty, which have been partially corrected by the DGT in Portugal through a specific national edition of the CSL layers. This is addressed in detail in Section 4.2.

4.1. The CHA layers as the reference to study LULC change from CORINE

The CHA layers are the product of the CORINE project specifically developed for studying LULC change (European Environment Agency, 2021). They should display real changes on the ground, without any technical or spurious change caused by factors such as photointerpretation errors or changes of methodology. However, we have found inconsistencies between the changes included in CHA layers for different periods, which agrees with the conclusions of García-Álvarez and Camacho Olmedo (2022) for the Spanish CORINE and Maucha et al. (2011) for previous global editions of CORINE.

Our analysis was limited to checking the coherence of those changing areas that changed in at least two different periods. Validating changes only happening in one period could therefore unveil new sources of uncertainty. For Portugal, the global validation exercises of CHA layers carried out by the European Environment Agency revealed how the mapped LULC changes in Portugal at the most detailed level of the classification legend achieved one of the lowest validation scores of all CORINE participating countries (Moiret et al., 2021; Sannier et al., 2017). This could be attributed to different causes, such as (i) the complexity of Mediterranean landscapes and their higher dynamism; (ii) the changes in the production methodology of CORINE; and (iii) the uncertainties associated to the interpretation and mapping of mixed categories.

The reports of the European Environment Agency showed how one of the most challenging areas to accurately map was the was the Mediterranean biogeographical region (Moiret et al., 2021). Thus, areas of heterogenous landscapes, which a higher mixture of land uses and land covers, are ones of the most difficult to map with certainty, specially at medium and higher levels of spatial detail (Pérez-Hoyos et al., 2012; Waser and Schwarz, 2006).

On the other hand, our analysis has proved how in the last Portuguese CHA layer, transitions that were insignificant in previous periods (e.g transitions involving the burnt area category), accounted for a relevant proportion of the mapped change in the 2012–2018 period, after the change of production method. Similar issues have been found in the Spanish CHA layers prior and after the 2012 methodological production change (García Álvarez and Camacho Olmedo, 2023).

Since 2012, the LULC changes in Portugal are mapped following a semi-automatic approach based on photointerpretation and the information provided by the fine-scale national LULC database: *Carta de Uso e Ocupação do Solo* (COS) (European Environment Agency, 2021). As the categories of COS are not the same as the categories of CORINE and the mapping criteria of each class can differ among the classes (Caetano and Marcelino, 2017), change mapping before and after the implementation of this semi-automatic approach could deliver different results. Then, although some consistency is achieved between the different CHA layers, these may reflect LULC changes that are based on varying landscape conceptualizations. In this regard, Büttner (2014) points out how complex can be the generalization and interpretation of some categories through automatic or semi-automatic methods, such as in the Portuguese case, compared to the easier task that this means for a photointerpreter.

Finally, the analysis carried out by Maucha et al. (2011) revealed how most of the detected inconsistencies in global CORINE CHA layers were related to the mapping and interpretation of mixed categories. They are usually associated with higher levels of uncertainty because of the flexible meanings associated to these classes, which can be differently interpreted by several photointerpreters or through complementary generalization methods (European Environment Agency, 2021; García-Álvarez and Camacho Olmedo, 2017).

In Portugal, our analysis has proved how the main transitions of change in CHA and CSL layers are driven by the dynamism of mixed classes. Transitional woodland-shrub was the category involved in most of the change mapped by the different CORINE layers. The definition of this category is quite imprecise. In addition, no category corresponds to transitional woodland-shrub in the national dataset COS (DGT, 2018, 2019). However, this served as the primary source for mapping CORINE changes through a semi-automatic approach in the latest update of the Portuguese CORINE.

Whereas some CORINE participating countries call for splitting these mixed categories into a more detailed and well-defined series of LULC categories, that could be mapped with higher certainty (European Environment Agency, 2021), other experts claim that, at scales like the one at which CORINE is produced (1:100.000), land uses and covers can not be mapped with certainty at high levels of thematic detail, such as the most detailed level of the CORINE legend (Barreira González et al., 2012). Therefore, the solution to the problem of the mixed categories is not clear.

A specific and in-depth validation exercise of the Portuguese CHA layers could provide new insights, which would help to correct some of the issues of the database. In this regard, there is a general need to assess in detail the uncertainties of CHA layers and the potential issues associated with LULC change mapping at the national level. Although there are general analyses for most of the CHA layers, the first one for 1990–2000 has not been object of any validation yet,[1] and the analysis of the CHA layer for the period 2000–2006 does not provide any insight at the national level (Büttner et al., 2012). In addition, the methodology developed by Maucha et al. (2011) to eliminate the incoherencies and contradictions between CHA layers may be considered a first step to increasing the certainty and consistency of the database.

4.2. The Portuguese approach to study LULC change from CSL layers

Although many users still make use of CSL layers to study LULC change or for studies with a multi-temporal component (Fernández Nogueira, 2021; Hewitt and Escobar, 2011; Văculişteanu et al., 2023), the European Environment Agency and the Copernicus Land Monitoring Service discourage their use for this purpose and, instead, recommend the use of CHA layers. These, however, do not usually meet the needs and requirements of those users. Thus, studying LULC change with certainty from CSL layers is a required need of many users, as also recognized by the European Environment Agency when developing the CORINE accounting Layers (European Environment Agency, 2021).

The backdating approach to the CSL layers implemented by the Directorate-General for Territory (DGT) in Portugal answers that problem. Our analysis has proved how CSL DGT layers up to 2012 are consistent through time and provide similar results for LULC change analysis than CHA layers, with similar areas and proportions of change. Their main limitations are associated with the cartographic generalization because of their lower Minimum Mapping Unit (MMU) and the potential uncertainties associated with CHA layers. The MMU imposes significant map generalization, limiting the ability to capture small-scale changes. This explains some of the disagreements that we have observed between the changes in CSL DGT and CHA layers. Notwithstanding, when backdating the revised CSL layers, the DGT validated the CHA layers, thereby addressing some of their errors and uncertainties (Caetano and Marcelino, 2017). This may make the study of LULC change from CSL DGT layers even more certain compared to using CHA layers.

The CSL Copernicus layers show many inconsistencies and disagreements with CHA layers for all periods before 2012. The size, proportions and pattern of LULC changes are very different in CHA and CSL layers. These differences can only be explained by technical and spurious changes coming from mapping errors and changes in the production methodology. Accordingly, CSL Copernicus layers show many transitions that are not mapped in CHA layers. In CSL Copernicus layers before 2012, changes are all over the territory and made up of long and small patches, usually in the borders between categories. The analysis of the Portuguese CSL Copernicus layers for different years has also proved

[1] https://land.Copernicus.eu/pan-european/corine-land-cover.

how the landscape conceptualization varied between the different editions and, specifically, between 2006 and 2012.

The big differences of CSL Copernicus layers between 2006 and 2012 can be attributed to the 2012 revision carried out by the DGT to ensure the agreement and coherence between the CORINE Status layer (CSL) for 2012 and the national fine-scale dataset for 2010 (COS) (Caetano and Marcelino, 2017). This revision affected 10 % of the mapped area in CSL (European Environment Agency, 2021). It explains why the agreement between CHA and CSL Copernicus layers is the lowest for this period. The detected disagreements and inconsistencies for the periods 1990–2000 and 2000–2006 should be associated with similar causes, although no documentation is available about changes in the Portuguese CORINE production methodology for those years.

The last released CORINE user manual already warns about this issue and points out methodological changes in the CORINE production methodology for different countries, which could mean similar disagreements and inconsistencies (European Environment Agency, 2021). The studies of García-Álvarez and Camacho Olmedo (2017) and Martínez-Fernández et al. (2019) have analyzed this problem in detail for the Spanish CORINE, where the methodological change of 2012 meant a very different landscape conceptualization of the country. For these countries, the production of a new series of CSL layers following the DGT backdating approach could give an answer to those users that require a consistent time series of CSL layers.

When using CSL Copernicus layers, only the two last time points are consistent through time and provide a LULC change analysis with a low level of uncertainty, as also proved by García-Álvarez and Camacho Olmedo (2022) for all CORINE participating countries. This is because the last CSL layer is obtained through the combination of the CHA layer with the revised version of the previous CSL layer. Both layers, the layer of changes and the revision of the previous CSL layer, are obtained simultaneously, which ensures their coherence and agreement (Büttner, 2014). The agreement between CSL Copernicus and CHA layers for 2012–2018 is similar to the usual agreement between CSL DGT layers and CHA layers for all periods before 2012, which again proves the adequacy of the backdating approach for obtaining a consistent and coherent CSL time series of maps.

Copernicus has produced, as expert products, the CORINE accounting Layers, which follow a similar backdating approach to the one implemented in Portugal by the DGT. In this case, the update is carried out from the last updated CSL layers (i.e. 2018). However, these are layers in raster format at 100 m spatial resolution that, therefore, are not comparable to the usual deliverables of the CORINE project. In addition, they show some inconsistencies because of polygons that do not meet the Minimum Mapping Unit and non-coherent transitions imported from CHA layers (European Environment Agency, 2021). The development of a similar product in vector format at the same scale as traditional CORINE layers, which also accounts for the issues that have been pointed out, could answer this issue. Meanwhile, the validation of these layers and their comparison with other CORINE layers available in vector format could deliver interesting and informative results to the audience.

The Copernicus Land Monitoring Service should provide to the users with information about the availability of national corrected CSL layers, like the ones of Portugal, which account for the errors and uncertainties of the standard CSL layers distributed on their website. In this regard, many European users are not aware of the availability of these layers and their characteristics. At the national level, the Portuguese DGT should also provide more information on all other layers available for CORINE and their problems and limitations.

The CSL DGT layer of 2018 shows some disagreements and inconsistencies with the rest of the time series, which hampers the full analysis of LULC changes for the period 1990–2018 with low levels of uncertainty. In this regard, the DGT backdating exercise was carried out after the revision of CSL 2012 to ensure their coherence with COS 2010 (Caetano and Marcelino, 2017). To meet the needs and requirements of all users of CORINE and ensure the utility of the DGT layers, the backdating exercise should be repeated each time a new edition of CORINE is produced. At the moment, the different projections of CSL Copernicus and CSL DGT layers even hamper the comparison of CSL Copernicus 2018 with the rest of CSL DGT layers, as this is not a perfect overlap between polygons, which ends in many technical changes in the borders between categories.

5. Conclusions

The CORINE Status Layers (CSL) distributed through the Copernicus Land Monitoring Service contain significant sources of uncertainty that hinder their effective use for monitoring Land Use and Land Cover (LULC) change. When studying LULC change with these layers, users will find a lot of errors and technical changes, which may be attributed to alterations in the production method of the Portuguese CORINE.

The CORINE layers of changes (CHA) distributed by Copernicus serve as a reliable reference for studying LULC change, avoiding many of the issues associated with the CSL Copernicus layers. However, CHA layers still exhibit some inconsistencies and uncertainties that require further scrutiny and revision.

The Portuguese Directorate-General for Territory (DGT) has generated a specific revised version of the CSL layers through a backdating method that ensures their consistency and coherence through time, removing those changes that can be labelled as technical or spurious. The production of these Portuguese CSL layers also involved revising the CHA layers to address potential uncertainties. Accordingly, studying LULC change using these CSL DGT layers may yield more precise results compared to using CHA layers.

The Portuguese experience can be considered a reference for producing a coherent and consistent time series of CSL layers at the same scale and with the same technical characteristics than standard CSL layers. This experience could be exported globally to all CORINE participating countries. However, it is crucial to standardize the backdating methodology and apply it each time a new CORINE edition is generated. At the moment, the Portuguese DGT has not produced the CSL 2018 layer using this backdating method, limiting the availability of a full and certain series of CORINE CSL layers. In addition, more information on this specific product from both the Copernicus Land Monitoring Service and the Portuguese DGT should be provided. One of the current limitations associated with CORINE products comes from the lack of comprehensive information on the different layers that comprise the database and their sources of uncertainty.

CRediT authorship contribution statement

David García-Álvarez: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Cláudia M. Viana:** Conceptualization, Writing – review & editing. **Eduardo Gomes:** Writing – review & editing. **Filipe Marcelino:** Resources. **Mário Caetano:** Writing – review & editing. **Jorge Rocha:** Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Two of the authors of the paper, Filipe Marcelino and Mário Caetano, work for the Portuguese Directorate-General for Territory. This is the institution in charge of producing CORINE Land Cover (CLC) for Portugal.

However, their contribution has not influenced the objectivity of the analysis. In this regard, they have contributed to the analysis made by the rest of the authors by providing his expertise and in-depth knowledge of the analyzed product. The analysis and discussion was independently made by the other authors, but discussed and enriched by the knowledge and experience of Filipe Marcelino and Mário Caetano.

As the editor and readers may note, the conclusions of the analysis are objective and critically analyze the Portuguese method to backdate CORINE CLC, as well as its distribution to the audience.

Data availability

The data is openly available in the Copernicus Land Monitoring Service and in the website of the Portuguese Direção-Geral do Território

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jag.2023.103389.

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