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# Acceleration and fragmentation of CORINE land cover changes in the United Kingdom from 2006–2012 detected by Copernicus IMAGE2012 satellite data

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ABSTRACT

The CORINE land cover maps present the longest series of land cover maps with a consistent class labelling system and date back to 1985. This paper presents the results of the CORINE land cover mapping of the United Kingdom for 2012 and the corresponding land cover change map from 2006 to 2012. It compares the rates of change with those of the preceding land cover change map 2000–2006 and finds that land cover change has become smaller in scale, more diverse in types of change and affects more land cover polygons than in the past reporting period. Land cover change from 2006 to 2012 affected almost 60% more land cover polygons than from 2000 to 2006. A greater variety of 165 types of land cover change was detected from 2006 to 2012 than the 67 types of change from 2000 to 2006. The total land cover change area increased by over 21,000 ha or 11% but remained at around 1% of the total land area of the UK. Rotation forestry mostly of conifer forests was a dominant type of land cover change in both periods (53% of overall change from 2000 to 2006 and 54% from 2006 to 2012), followed by growth and replanting of conifer forest. From 2006 to 2012 the replanting rate decreased by almost 15,000 ha compared to 2000–2006 and a smaller decrease in planting of broadleaf and mixed forests was also observed. Urban land take continued from 2006 to 2012 in the UK, with over 16,000 ha of increase in artificial surfaces. The rate of change from other land cover types to artificial surfaces accelerated from 2006 to 2012. However, we urge caution when interpreting the rate of land take, as it includes wind farms in forested areas which leave the forest largely intact apart from an access road and the wind turbine sites. We also found that the inference from the land cover change matrices is dependent on the level of class aggregation (level 1, 2 or 3).

## 1. Introduction

In 1985 the European Union initiated the CORINE land cover monitoring programme on 'Coordination of information on the environment'. Now under the auspices of the European Environment Agency, CORINE is one of the world's first operational monitoring programmes using satellite data. At its core is an inventory of 44 land cover/land use classes. The CORINE land cover maps are available as cartographic products at a scale of 1:100,000 for most regions of Europe. CORINE is now the longest available land cover and land cover change database with a consistent class labelling system. When a new CORINE land cover map is produced, a corresponding change map covering a time period of around 6 years is also produced. In accordance with the technical guidelines, the status map has a minimum mapping unit (MMU) of 25 ha while the change map has an MMU of 5 ha, which allows the detection of smaller scale changes (Feranec et al., 2007a). A side effect of this difference in MMU is that the land cover change map is different from an overlay of the two land cover maps from time 1 and 2 (Feranec et al., 2007a). The reason for producing a separate land cover change map is to have a higher accuracy of the change statistics than would be achievable from a cross-tabulation of two land cover maps with 25 ha MMU.

An analysis of the CORINE land cover change map for the whole of Europe from 1990 to 2000 found that the main change processes were urbanisation (e.g. affecting 2.1% of the Netherlands), intensification of agriculture (Ireland 3.3%), extensification of agriculture (Czech Republic > 3.5%), afforestation (Portugal > 4%), deforestation (Portugal > 3.5%) and construction of water bodies (> 0.1% in the

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Netherlands and Slovakia), affecting a total area of 88,000 km$^2$ or 2.5% of total area (Feranec et al., 2007b). Based on CORINE land cover maps of 1990, 2000 and 2006, Gardi et al. (2015) estimated that agricultural land take in Europe took 752,973 ha out of production between 1990 and 2000 and a further 436,095 ha between 2000 and 2006, impacting on agricultural production potential equivalent to a loss of more than six million tonnes of wheat.

The UK has contributed to all European CORINE land cover maps, however, throughout the history of CORINE land cover map production in the UK, the national teams have adopted different approaches. These include:

- a semi-automated map generalization based on a 30 m resolution GB land cover map of 1990 produced from Landsat imagery and ancillary data sources (Brown et al., 2002; Fuller and Brown, 1996);
- a semi-automated generalisation of the segment-based UK Land Cover Map 2000 (Smith et al., 2005);
- a semi-automated generalisation of the object-based UK Land Cover Map 2007; and
- a visual interpretation following the CORINE technical guidelines (Büttner and Kosztra, 2017).

The progression in methods in the UK has followed developments in image and ancillary data availability and the increased processing power and capability of analysis system. CORINE land cover is the European flagship programme for long-term land monitoring and is now part of the Copernicus Land Monitoring Service (CLMS). As Copernicus has developed it has played a greater role in CORINE and for the production of the CORINE land cover map 2012, satellite image products from third parties were coordinated within the programme for the first time.

The CORINE land cover methodology described in the technical guidelines is generalised to encompass all European land cover/land use types at a high level. However, it has been criticised by some for having a 'Mediterranean bias' in the class nomenclature, a lack of clear rules to define some classes, the need for Level 4 subdivisions to avoid over-generalizations (pasture and peat bog) and a lack of mixed natural vegetation classes (Cruickshank and Tomlinson, 1996). The land cover change maps have been criticised for being particularly error-prone at local scale in Spain (Diaz-Pacheco and Gutiérrez, 2014). Because of the restrictions of the MMU, CORINE land cover data are inappropriate for small-scale features such as riverine ecosystems and omit large proportions of small landscape elements (Di Sabatino et al., 2013).

Unconventional methods for updating CORINE land cover maps have been explored, for example by using vegetation indices (Alexandridis et al., 2014; Ballabio et al., 2016), the use of Synthetic Aperture Radar (SAR) and Digital Elevation Model (DEM) data (Balzter et al., 2015) or by interpretation of digital aerial photography (Thomson et al., 2007) for historic land cover reconstruction (Gerard et al., 2010).

However, even given its limitations the applications of CORINE land cover data are manifold and include mapping soil organic carbon (Grüneberg et al., 2014; Pilaš et al., 2013; Schillaci et al., 2017) and other soil properties (Aksoy et al., 2016), mapping soil erosion risk (Reis et al., 2016; Yannelli et al., 2014), quantifying carbon storage in vegetation (Cruickshank et al., 2000), mapping drought risk (Ruda et al., 2017), explaining emergent macrophyte dynamics in lakes (Alahuhta et al., 2016), identifying anthropogenic impacts on lake phytoplankton blooms (Laplace-Treyture and Feret, 2016), disaggregating population statistics (Gallego et al., 2011), detecting land use impacts on soil salinity (Gorji et al., 2017), monitoring urban heat island effects (Giorgio et al., 2017; Majkowska et al., 2017), rapid assessments of habitat quality and biodiversity (Vogiatzakis et al., 2015), a farmland heterogeneity indicator (Weissteiner et al., 2016) and modelling bird migration (Leito et al., 2015) and forest bird species richness (Mag et al., 2011). Wildfire risks (Parente and Pereira, 2016; Pereira et al., 2014) and the impacts of the wildland-urban interface on the occurrence of mega-fires have been assessed on the basis of CORINE land cover data (Mancini et al., 2017; Modugno et al., 2016). CORINE data have also been used to map the prevalence of *fasciolasis* (liver fluke disease) in livestock (Novobilský et al., 2015).

De Meij et al. (2015) found that using CORINE land cover data and SRTM DEM data improved the model simulation of particulate matter (PM10) concentrations and CO, $SO_2$ and $NO_x$ concentrations in Northern Italy. At continental and catchment scales, CORINE land cover data have been used together with a soil surface agricultural nitrogen balance model to estimate surface nitrogen balances in Europe using agricultural statistics of nitrogen content for crops, forages, manure, fertiliser and atmospheric deposition as additional inputs (Campling et al., 2005).

CORINE land cover data have also been used to assess ecosystem services and the benefits they provide to people, for example by assigning value transfer functions for cultural ecosystem services (Brown et al., 2016), by quantifying flood regulation in a landscape (Nedkov and Burkhard, 2012) and by assessing trade-offs between bundles of 31 different ecosystem services (Depellegrin et al., 2016). The CORINE land cover change maps have been used to quantify the impacts of land cover change on ecosystem service provision (Cabral et al., 2016; Szumacher and Pabjanek, 2017). CORINE land cover maps have even been used to identify vulnerability of wetland ecosystem services and drivers of change (Ricaurte et al., 2017).

This paper describes how two of the CORINE land cover maps of the UK were produced and how the UK landscape has changed at the scale of the CORINE land cover MMU between 2006 and 2012. It examines whether an acceleration of land cover changes can be observed between the two time periods of 2000–2006 and 2006–2012 and whether the fragmentation of these changes is different.

## 2. Methods

### 2.1. CORINE land cover 2006

The approach to the production of CORINE land cover map 2006 for the UK employed a bottom-up system (Feranec et al., 2016) that was based on a semi-automated generalisation of the UK national Land Cover Map for 2007 (LCM2007). LCM2007 was the first UK land cover map with land parcels (the spatial framework) derived from national cartography by a generalisation process, thus dramatically improving spatial structure in relation to real world objects. The spatial framework was further refined by supplementing the land parcels with agricultural census data boundaries and image segments. LCM2007 contained almost 10 million land parcels. LCM2007 was produced from over seventy satellite images, mainly as summer-winter composite images which increase the contrast between different land cover types and so increase the accuracy of the classification. LCM2007 mapped 23 land cover classes, which combined to represent 17 terrestrial Broad Habitats (Jackson, 2000). LCM2007 had a MMU of 0.5 ha and a minimum feature width of 20 m with a rich set of metadata attributes on each land parcel to enable users to track the processing steps applied.

However, due to the large differences in MMU and the different nomenclatures between LCM2007 and the CORINE land cover map 2006, a simple thematic recoding and spatial generalisation were not possible. Another issue was that as LCM2007 was being produced in parallel with CORINE land cover 2006, on occasion preliminary input datasets from the LCM2007 production process were used in creating CORINE 2006.

The 'Full Production Run' to produce the CORINE land cover map 2006 and the CORINE land cover 2006 changes (2000–2006) datasets therefore consisted of:

- Acquisition and checking of the map, image and ancillary data inputs for use in the project.