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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.

Table 1
The three tier hierarchy of the 44 classes of the CORINE nomenclature.

Level 1		Level 2		Level 3	
1	Artificial surfaces	11	Urban fabric	111	Continuous urban fabric
				112	Discontinuous urban fabric
		12	Industrial, commercial and transport units	121	Industrial or commercial units
				122	Road and rail networks and associated land
				123	Port areas
				124	Airports
		13	Mine, dump and construction sites	131	Mineral extraction sites
				132	Dump sites
				133	Construction sites
		14	Artificial, non-agricultural vegetated areas	141	Green urban areas
				142	Sport and leisure facilities
2	Agricultural areas	21	Arable land	211	Non-irrigated arable land
				212	Permanently irrigated arable land
				213	Rice fields
		22	Permanent crops	221	Vineyards
				222	Fruit trees and berry plantations
				223	Olive groves
		23	Pastures	231	Pastures
		24	Heterogeneous agricultural areas	241	Annual crops associated with permanent crops
				242	Complex cultivation patterns
				243	Land principally occupied by agriculture with significant areas of natural vegetation
				244	Agro-forestry areas
3	Forests and semi-natural areas	31	Forests	311	Broad-leaved forest
				312	Coniferous forest
				313	Mixed forest
		32	Shrub and/or herbaceous vegetation associations	321	Natural grassland
				322	Moors and heathland
				323	Sclerophyllous vegetation
				324	Transitional woodland scrub
		33	Open spaces with little or no vegetation	331	Beaches, dunes and sand plains
				332	Bare rock
				333	Sparsely vegetated areas
				334	Burnt areas
				335	Glaciers and perpetual snow
4	Wetlands	41	Inland wetlands	411	Inland marshes
				412	Peat bogs
		42	Coastal wetlands	421	Salt marshes
				422	Salines
				423	Intertidal flats
5	Water bodies	51	Continental waters	511	Water courses
				512	Water bodies
		52	Marine waters	521	Coastal lagoons
				522	Estuaries
				523	Sea and ocean

- Update of the urban land use classes from CORINE 2000, land use layer update (LULU). As LCM2007 did not effectively address the land use classes present in CORINE land cover a separate update process was performed where the urban classes (level 1 class 1, see Table 1) from CORINE 2000 where compared to IMAGE2006, the satellite imagery supplied by the EEA to update CORINE for 2006 (Manakos and Braun, 2017). Any technical and actual changes were then incorporated into the LULU layer by visual interpretation and on-screen digitising.
- Automated generalisation of LCM2007. The first part of this task was to use a mapping table to populate the LCM2007 dataset with equivalent CORINE land cover class codes. This process was more complex than expected, since the LCM2007 dataset had a number of additional land cover class codes that do not exist in CORINE and the knowledge-based enhancements had not been applied, so some classes were found in places where common knowledge rendered them highly unlikely or impossible. The most complex part of this task was to perform the spatial generalisation of the recoded LCM2007 based on the CORINE land cover interpretation rules and a set of size dependent processes in an attempt to replicate generalisation of the visual interpretation process. Although highly successful in terms of the processes developed the actual implementation was hindered by errors (gaps, slivers and overlaps) in the input data, ambiguities in the CORINE land cover generalisation rules and the complexity of some actual landscapes relative to the CORINE land cover specifications.
- Integration of generalised LCM2007 and LULU. The final automated step in the CORINE land cover 2006 status layer production was the merging of the LULU layer produced earlier with the spatially and thematically generalised LCM2007. The LULU layer dominated to give a pseudo-CORINE land cover map 2006.
- Manual interpretation and quality checking. Due to the issues identified above there was a need for further manual interpretation and quality checking of the pseudo-CORINE land cover map 2006 against the IMAGE2006 data. Any necessary corrections were made using visual interpretation and on-screen digitising.
- Extraction of a change layer. With a completed CORINE land cover map 2006 it was possible to compare it to CORINE land cover 2000 to generate a set of potential change areas which were screened for size and shape to match the specification of the CORINE land cover change layer.
- Manual interpretation and quality check of changes. Further visual interpretation and onscreen digitising were required to finalise the CORINE land cover changes 2000–2006.

The CORINE land cover and land cover change layers for 2006 were then delivered to the EEA to be combined into the final pan-European product.

2.2. CORINE land cover 2012

As there was no equivalent UK land cover map in 2012, the UK CORINE land cover map 2012 (Cole et al., 2015) was produced following the technical guidelines set by the EEA using visual interpretation from satellite imagery (Büttner et al., 2011; Büttner and Kosztra, 2011, 2007). The standard "change mapping first approach" was applied meaning that changes were interpreted directly, based on a comparison of reference images. This produced three datasets:

1 A 25 ha MMU revised CORINE land cover map 2006 ($CLC2006_{revised}$)
2 The 2006–2012, 5 ha MMU CORINE land cover change layer ($CLC\text{-}Changes_{2006–2012}$)
3 The 25 ha MMU CORINE land cover map2012.

As was done for CLC2000 at the time of CLC2006 production, the existing CLC2006 was revised to correct for geometric and thematic interpretation mistakes and to avoid error propagation in to CORINE 2012.

All identified changes larger than 5 ha were delineated and a new 2012 land cover map created using the equation:

$$CLC2012 = CLC2006_{revised} + CLC\text{-}Changes_{2006–2012} \quad (1)$$

The technical specification of the change layer required parcels to

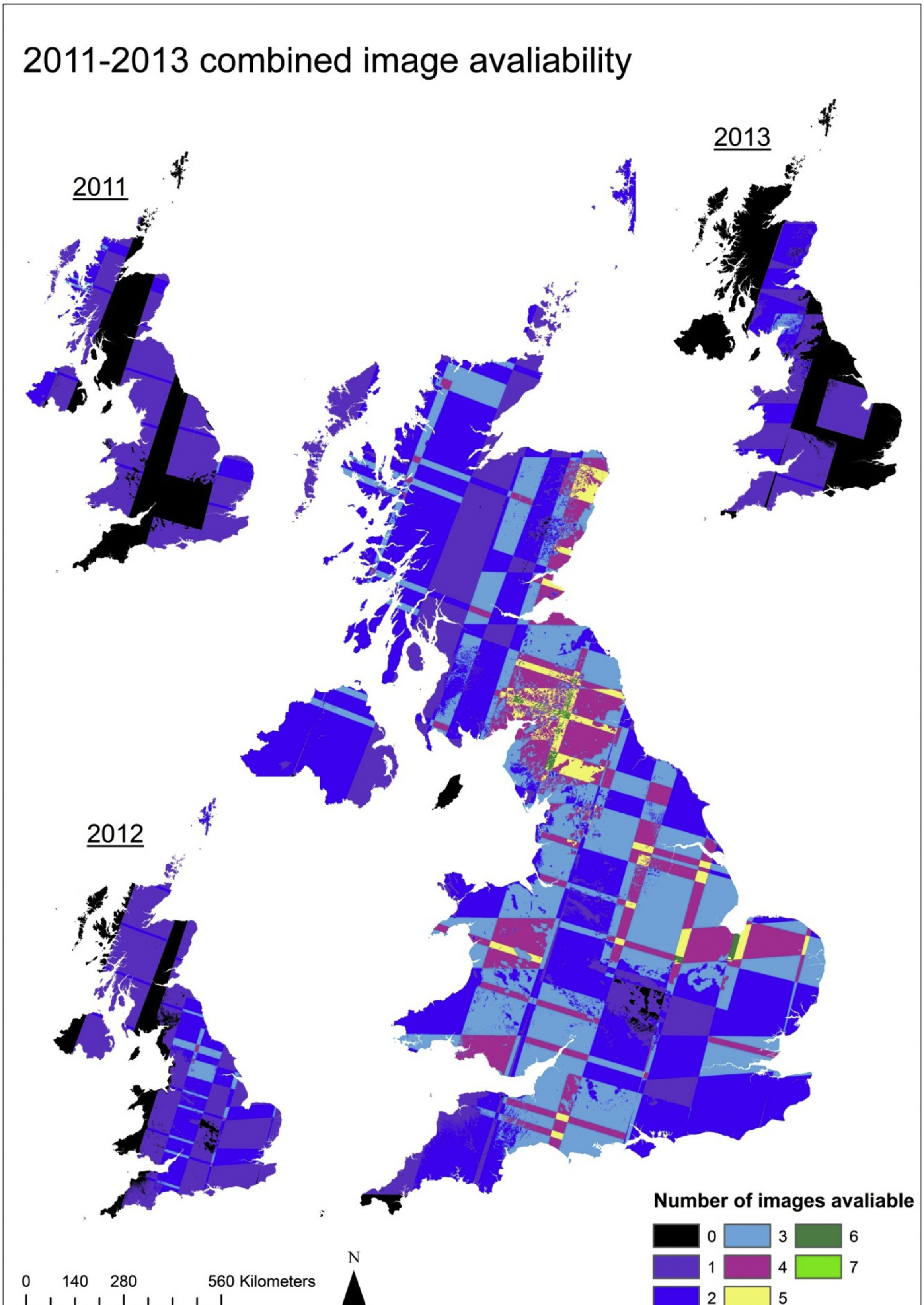

Fig. 1. Stacked footprints of all available images in IMAGE2012 coverage 1 product, with a cloud mask applied. Colours indicate the number of cloud-free coverages available.

be larger than 5 ha and wider than 100 m, change had to have occurred between 2006 and 2012 and needed to be detectable on satellite images. To fulfil the aim of producing a database of real land cover changes during the delineation, technical change parcels were also identified to support the creation of a realistic CORINE land cover 2012 database. Technical change is a way of accounting for differences in the MMUs of the status and change products allowing new land parcels with areas great than 25 ha to be delineated that previously would have been generalized out in the previous map but do not represent a change of land cover in reality.

The production process included quality checks for interpretation error, with each area reviewed and corrected by an independent interpreter as well as two external verifications by the CORINE Technical Team to check production by the UK team was of sufficient standard to guarantee a harmonised European CORINE land cover map product for 2012. Around 20% of the UK was checked for quality externally. Error checks for invalid geometries, multipart polygons, gaps, overlaps, size, shape and code errors were included at multiple stages. During the creation of the CORINE land cover 2012 status database the revised CORINE land cover map 2006 and the CORINE land cover change layer are intersected, neighbours are unified and small polygons are generalised according to a priority table of classes. The CORINE land cover nomenclature consists of 44 classes in a three level hierarchy (Table 1). The five main categories of land cover at level one are further broken down into 15 classes covering physical entities at level two, and the detailed 44 classes at level three. These categories have not changed since first implementation in 1986.

2.3. Data

Although the identification of land cover change was based on the interpretation of visually detectable land cover differences between satellite images acquired in 2006 and 2012, ancillary data was also used to aid this interpretation and ensure real land cover changes were mapped and not mere spectral changes of the same land cover type. All ancillary data were free open source and obtained online from commercial or government department websites. They included topographic maps, Google Earth imagery and information from national conservation bodies such as conservation designations, maps and databases.

The CLC2000 and CLC2006 projects in the UK adopted a bottom up policy using generalisation techniques to spatially and thematically transform the most appropriate national land cover products to the CLC specification. CLC2000 was produced by semi-automated generalisation of a rasterised versions of the Land Cover Map 2000 (LCM2000) and a back-dating exercise to 1990 to identify change, similar to the one proposed in the standard CLC methodology (Smith et al., 2005). CLC2006 was again produced by semi-automated generalisation (1Spatial, 2007), but this time using the vector-based Land Cover Map 2007 (LCM2007) (Morton et al., 2011) and a cross comparison with CLC2000 to identify changes. Northern Ireland was mapped using the standard method of change only update via computer assisted on-screen photo-interpretation of satellite images.

The satellite earth observation data available from the Copernicus programme formed three separate products; IMAGE2006, IMAGE2009 and IMAGE2012. Each set contained images for two separate time windows in spring and autumn, coverage 1 and 2. Unfortunately for the UK the data availability tended to be limited due to persistent cloud cover. The IMAGE2006 product had relatively good coverage, consisting of a mix of IRS-P6-LISSIII, SPOT-4 and SPOT-5 imagery. Coverage 1 imagery was collected between the beginning of April and the end of September, and coverage 2 between the beginning of October and April in 2005-2007. The IMAGE2009 product was only used to fill in any gaps when IMAGE2012 was not available or not very clear. IMAGE2012 consisted of IRS-P6-LISSIII images for coverage 1 only. Coverage 2 was provided by higher spatial resolution RapidEye data. The acquisition of the IMAGE2012 for the UK was hampered by large amounts of cloud cover and acquisition planning issues and therefore caused problems for the CORINE land cover 2012 production. The initial acquisition windows had to be extended to 1 March until the 30 October, resulting in a wide timeframe of seasonal acquisitions. As a result, coverage two data, collected in September and October in 2011 and 2012, potentially fell in the same acquisition window not allowing the minimum 6 week gap as specified in the requirements to allow for phenological change. Original image acquisition was acquired, between 2011 and 2012, however additional data was required over the UK to get a single coverage, collected in 2013. The distribution of usable data from all the combined acquisition years for IMAGE2012 coverage 1 data over the UK is shown in Fig. 1.

3. Results

3.1. Revisions to CORINE land cover 2006

Across all member states of the European Environment Agency, revisions to the previous CORINE map are always carried out as part of the production of the next CORINE map. This is to prevent any previous errors being carried forward to the new edition of the map. Significant revisions of the CORINE land cover map 2006 (1Spatial, 2007) were necessary because CORINE 2006 was generated from automated generalisation of LCM2007 (Morton et al., 2011) and not by the same visual interpretation approach as used in CORINE 2012. In the $CLC2006_{revision}$ layer the revisions that were made were predominantly in the natural vegetation classes, with large polygons of revision in the upland areas of Scotland, the Pennines and North Wales between the moors and heathland, grassland and sparsely vegetated areas corrected to peatlands, as well as a significant amount of moors and heathlands to natural grasslands. There were also significant amount of revision, between pasture and arable land, in both directions. The number of revisions must be seen in the context of the change in method from 2006 to 2012 in the UK from a mainly automated generalisation of the LCM2007 to a visual interpretation approach in CORINE 2012.

3.2. CORINE land cover map 2012

The UK CORINE land cover map 2012 is shown in Fig. 2 and currently forms the most up to date freely available national scale land cover dataset, including 39 of the 44 level three land cover classes from the nomenclature (Table 1). For analysis purposes, the 523 sea and ocean class is removed from the statistics to avoid skewing the terrestrial component of the map. The proportion of the area covered by each class aggregated to level 1 and level 2 are shown in Fig. 3 and 4.

The most dominant land cover type in the UK is agricultural land, occupying 56% of the country (Fig. 3). The division between 231, pasture, and 211, non-irrigated arable land is roughly equal with 28.4% and 26.8% respectively, with more pasture polygons and larger arable areas (Table 2). The spatial distribution of these classes across the country, has a clear east/west divide (Fig. 5) due to environmental conditions, although there is a mosaic of the two classes at a local scale.

The second most dominant class at level 1 is forest and semi-natural vegetation, representing 24.2% of the country. The natural vegetation classes 321–324 account for the largest part of this with 14.6% of the coverage (Table 2). Moors and heathlands (322) and natural grasslands (321) are dominant in this class, representing 13.2% together. The peatland class (412) covers another 9.3% of the country, indicating that together, these natural open moorland landscapes cover approximately one quarter of the country, mainly in the upland areas in Scotland, Wales and down the central Pennines (Fig. 5). The forestry classes, 31 represent 8.3% for the country and are distributed around the whole of the UK, with more coniferous forests in Scotland and the upland areas. The artificial surfaces represent another 8% of the country (Fig. 3) with the majority being urban settlements falling in class 112, discontinuous

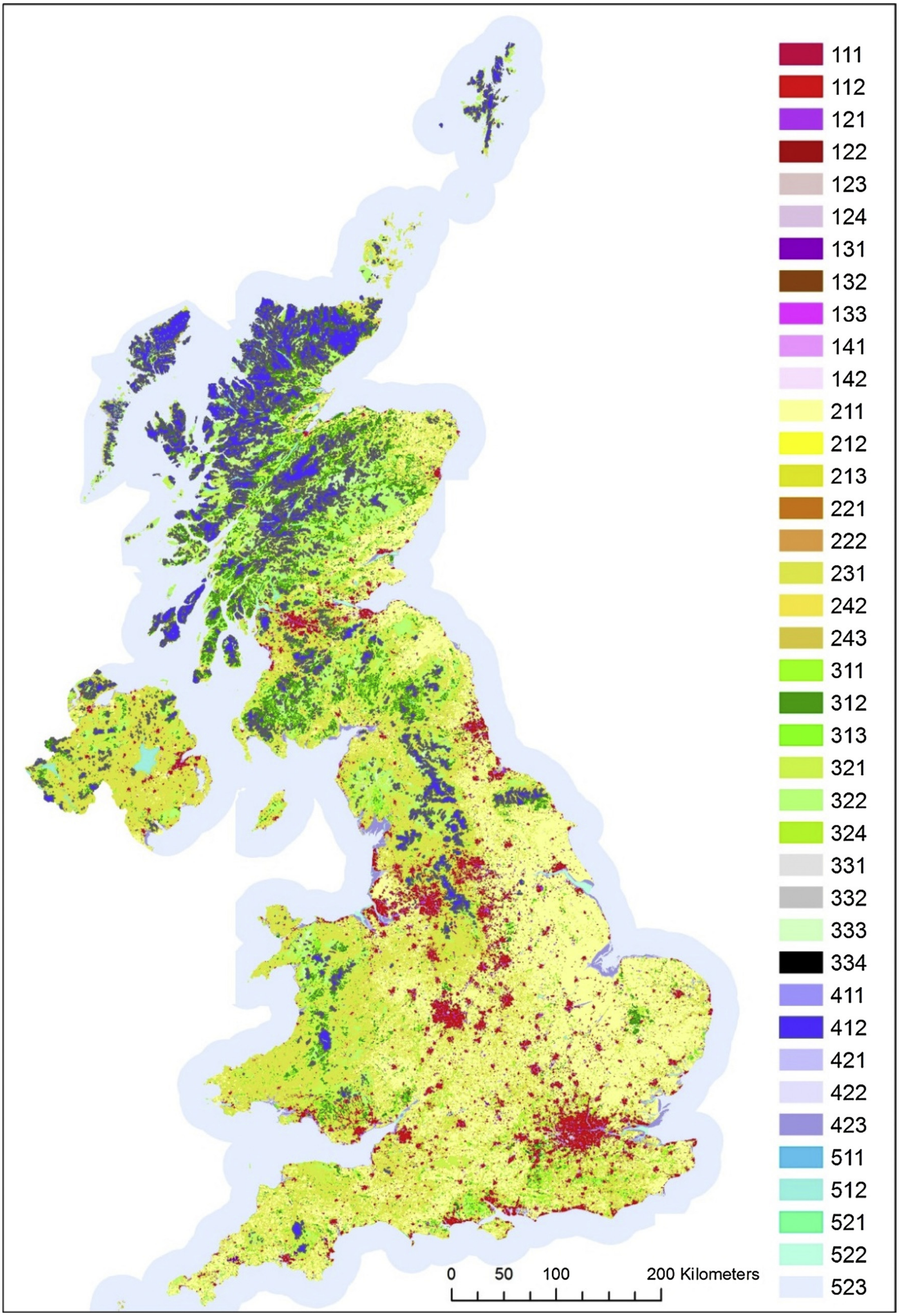

Fig. 2. CORINE land cover (CLC) 2012 map for the UK. See Table 1 for class descriptions.

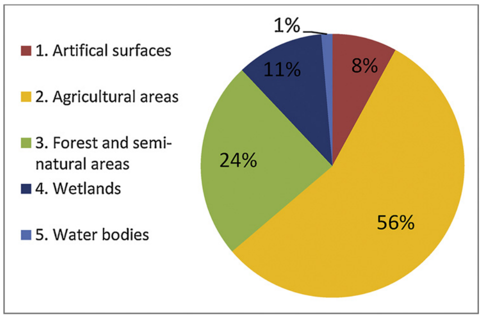

Fig. 3. Proportion of UK land area in each CORINE land cover level 1 class for 2012.

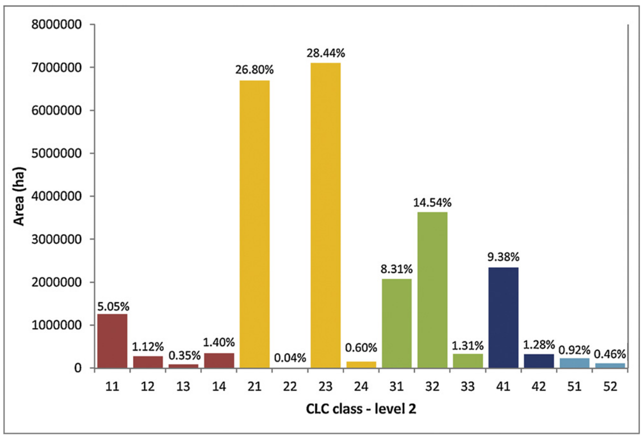

Fig. 4. Proportion of UK land area in each CORINE land cover level 2 class for 2012.

urban fabric.

3.3. CORINE land cover change from 2006 to 2012

9705 polygons of land cover change were detected in the UK between 2006 and 2012. This represents 165 different change types that cover an area of 225,238 ha of change at CORINE level 3, which corresponds to 1% of total land area of the UK. The spatial distribution of the changes is shown in the map in Fig. 6 and are distributed across the UK, but not equally. There is a higher concentration of changes in Scotland and Wales, predominantly following the areas of managed forest.

Table 3 shows the dominant land cover changes from 2006 to 2012 for the 15 CORINE land cover class transitions with the largest area of change. By far the most dominant CORINE land cover change is the clear cutting of coniferous forest (312–324) with over 54% of the total changes or greater than 122,500 ha. This is followed by growth or replanting of coniferous forest (324–312) with about 20% of the total changed area or 46,000 ha. It is noteworthy that clear cutting of coniferous forest (312–324) far exceeds replanting (324–312), however the slow regrowth of forestry is more difficult to map consistently. The next most dominant changes are associated with urbanisation (to classes 11 and 12) which is then followed by the conversion of land to mineral extraction (to 13).

The CORINE land cover level 3 change analysis shows some interesting issues but for most class transitions it is considered too detailed to visualise some of the primary land cover changes in the UK. Hence, the change analysis results were aggregated to CORINE land cover level 2 and 1. The results at level 2 are given in Table 4, which shows that the change from forests (class 31) to scrub and/or herbaceous vegetation associations (class 32) is 56% of the total changed area or 126,133 ha. This represents impacts of the clear-fell rotation forestry in Britain.

The CORINE land cover change analysis results aggregated at level 1 are given in Table 5 and show a rather different pattern. Changes of other CORINE land cover classes to artificial surfaces (class 1), urbanisation, appear dominant when aggregated to level 1. For example, 3.37% of the entire changed area equalling over 7500 ha turned from forest and semi-natural areas (class 3) to artificial surfaces (class 1) between 2006 and 2012, and nearly 6.46% or over 14,500 ha changed from agricultural areas (class 2) to artificial surfaces. Over 1000 ha (0.46% of total change area) were converted from wetlands (class 4) to artificial areas. Some 380 ha changed from class 2 (agricultural areas) to 3 (forest), and 540 ha from agricultural areas to wetlands (class 4).

Fig. 7 visualises the total area of gains and losses for each CORINE land cover class, aggregated at level 2 and 1 respectively. It shows how dominant the forestry changes and how minor the class 1 changes are in terms of areal extent. To view how much the classes changed in their respective size, Fig. 8 shows both the level 2 and 1 gains and losses as a percentage of each class area extent in the UK. It is apparent that the biggest relative gains were in artificial areas (class 1) and the biggest losses in agricultural areas (class 2) and forests (class 3). Class 1.2 (industrial, commercial and transport) has increased by 3% in the UK. There has been a 4% decrease in the forest class (3.1) in the UK.

3.4. Difference between changes from 2000 to 2006 compared to 2006 to 2012

The amount of land cover change identified from 2006 to 2012 was greater than between 2000–2006 (Tables 3 and 6). There was an increase of 57% in the number of change polygons mapped, from 6191 polygons in 2000–2006 to 9705 in 2006–2012. The number of types of change was dramatically greater with 165 types of change in comparison to the 67 types of change mapped in 2000–2006. The total area of change mapped increased by 21,854 ha, an increase of 11%. Despite this increase the area of change mapped across the UK remained at 1% of the total coverage of the country.

The increase in the amount of change polygons and the types of change in proportion to the total area suggest that more detail was mapped, smaller scale changes were identified and that the changes happening across the landscape are diversifying. It may be suggested that during the 2012 update there was better access to ancillary data, therefore it was possible to identify more of the subtler changes (e.g. access to better land use information from online Ordnance Survey maps and aerial photo coverages).

Table 6 shows the most important changes from 2000 to 2006. Like in 2006–2012 by far the most dominant change is clear cutting of coniferous forests, accounting for 53% of the change. The growth and replanting of coniferous forests is again the second most dominant change. Between 2000 and 2006 there was more tree replanting, accounting for 30% of the change mapped and covering an area of 60,897 ha, which is 14,890 ha greater than from 2006 to 2012. In addition to this another 2703 ha of coniferous forest was mapped as change directly from pasture. As well as this decrease in replanting of coniferous forests between 2006 and 2012 there was a decrease in growth or planting of broadleaf and mixed forests. A further three of the dominant types of change between 2000 and 2006 in Table 6 indicate forest growth, 324–311, 321–324 and 231–324. Collectively these changes affect 4181 ha. These types of land cover changes were not dominant in the time period from 2006 to 2012 (Table 3) where only 1094 ha of regrowth is reported (324–313).

These patterns can be seen in loss and gain charts for 2000–2006 in Fig. 9. At level 2 aggregation the difference in losses and gains for the forest classes 31 and 32 are much smaller (43,000 ha and 46,000 ha respectively) whereas these changes affected 83,000 ha and 76,000 ha in 2006–2012. What is striking about the results in 2000–2006 for the level 1 forestry classes is that the forest and semi-natural habitat (3) classes increase, whereas there is an overall decrease between 2006 and

Table 2
CORINE land cover statistics for the UK from three CLC maps (class 523 has been excluded).

CLC level1	CLC level3	Area (ha) 2000	Area (ha) 2006	Area (ha) 2012	Polygon count 2012	% area 2012	Mean area (ha) 2012
Artificial surfaces	111	28,750	32,506	32,594	300	0.13	108.65
	112	1,221,070	1,310,173	1,228,323	5611	4.92	218.91
	121	142,120	195,807	203,585	1984	0.81	102.61
	122	7,910	11,387	12,174	179	0.05	68.01
	123	13,290	14,436	14,495	103	0.06	140.73
	124	45,290	49,066	49,028	234	0.2	209.52
	131	54,440	69,076	71,682	966	0.29	74.21
	132	7,060	7,935	7,483	108	0.03	69.29
	133	4,920	8,181	7,734	142	0.03	54.47
	141	57,840	66,069	65,769	951	0.26	69.16
	142	232,220	281,431	283,577	3573	1.13	79.37
Agricultural areas	211	6,160,790	6,701,486	6,695,467	7928	26.8	844.53
	212		36	36	1		35.65
	213		114	114	3		37.86
	221			28	1		28.08
	222	17,620	9,205	9,190	63	0.04	145.87
	231	6,815,910	7,113,313	7,106,854	14052	28.44	505.75
	242	865,130	35,716	35,676	148	0.14	241.06
	243	565,350	114,450	114,283	929	0.46	123.02
Forest and semi-natural areas	311	657,460	535,107	536,200	6816	2.15	78.67
	312	1,286,890	1,346,556	1,267,824	5725	5.07	221.45
	313	51,280	273,559	272,369	3067	1.09	88.81
	321	1,987,210	1,438,521	1,440,645	5142	5.77	280.17
	322	2,923,640	1,850,237	1,853,285	4864	7.42	381.02
	324	193,360	275,199	339,925	3786	1.36	89.78
	331	29,720	48,786	48,674	364	0.19	133.72
	332	65,790	20,701	20,805	168	0.08	123.84
	333	348,860	257,239	257,228	1029	1.03	249.98
	334		1,517	1,714	29	0.01	59.11
Wetlands	411	15,150	14,242	14,575	112	0.06	130.14
	412	532,520	2,329,011	2,328,112	2284	9.32	1019.31
	421	41,720	46,067	46,089	256	0.18	180.03
	422		68	68	1		67.68
	423	203,730	274,419	274,597	627	1.1	437.95
Water bodies	511	5,300	4,601	4,601	40	0.02	115.02
	512	220,580	225,542	226,498	1512	0.91	149.8
	521	730	757	757	5		151.45
	522	98,270	113,051	112,998	91	0.45	1241.73

2012. This result needs to be viewed with caution as the class 324, where the majority of this gain is happening, is a mixed class called ‘transitional woodland-scrub’. This class included felled areas as well as young regrowth and so included both deforestation and reforestation.

The growth in artificial surfaces in 2006–2012 is a continuing trend and can be seen in the 2000–2006 results as well. In fact the area of growth is very similar between the two change datasets. The one big difference is, however, where the developments are located geographically. In 2000–2006 the main gains of 8121 ha were in class 11 (Urban fabric) with secondary gains of 4127 ha in class 12 (Industrial commercial and transport). This division was reversed in 2006–2012 with the majority of the gain of 8544 ha being in class 12 and secondary gains of 4278 ha in class 11. It should also be noted that the rate of conversion of land to class 142 (Sport and leisure facilities), mainly golf courses at this scale, continues to decline in 2012 from previous CORINE land cover maps. One other major difference in the pattern of change is that less agricultural land has been lost in 2006–2012 than previously, particularly in class 23 (pasture).

4. Discussion

4.1. Interpretation of results

Whilst the statistics presented above summarise the landscape and then large-scale land cover changes in the UK from 2000 to 2012, they should be interpreted with the necessary caution and an awareness of the limitations of the CORINE change detection methodology. There is sensitivity within the results to “technical changes” introduced by growth of the area of a land cover polygon beyond the minimum mapping unit, scale of change in the landscape, issues surrounding the class definitions in the nomenclature and the applicability to the landscape of the United Kingdom.

4.2. Different results depending on aggregation level

The change has been presented at two levels of aggregation, level 2 and level 1. The complete level 3 change is not presented here in full, but the analysis shows some interesting features. The results in the section above show this, the emphasis on the reported patterns of change is altered between level 2 where forestry change dominates and level one where increase in the artificial surfaces is the main reported result. By aggregating at this coarse thematic level, the more subtle changes within the broad level 1 classes are lost. For example, all the forest management related changes are not visible anymore when the clear-fell forestry is all combined within class 3. It is worth noting that 82% of the total changed area is composed of internal changes within class 3.

4.3. Forest and semi-natural areas

Inspection of the patterns in more detail within this level 1 class, Forest and Semi-natural areas, allows us to see the largest areas of

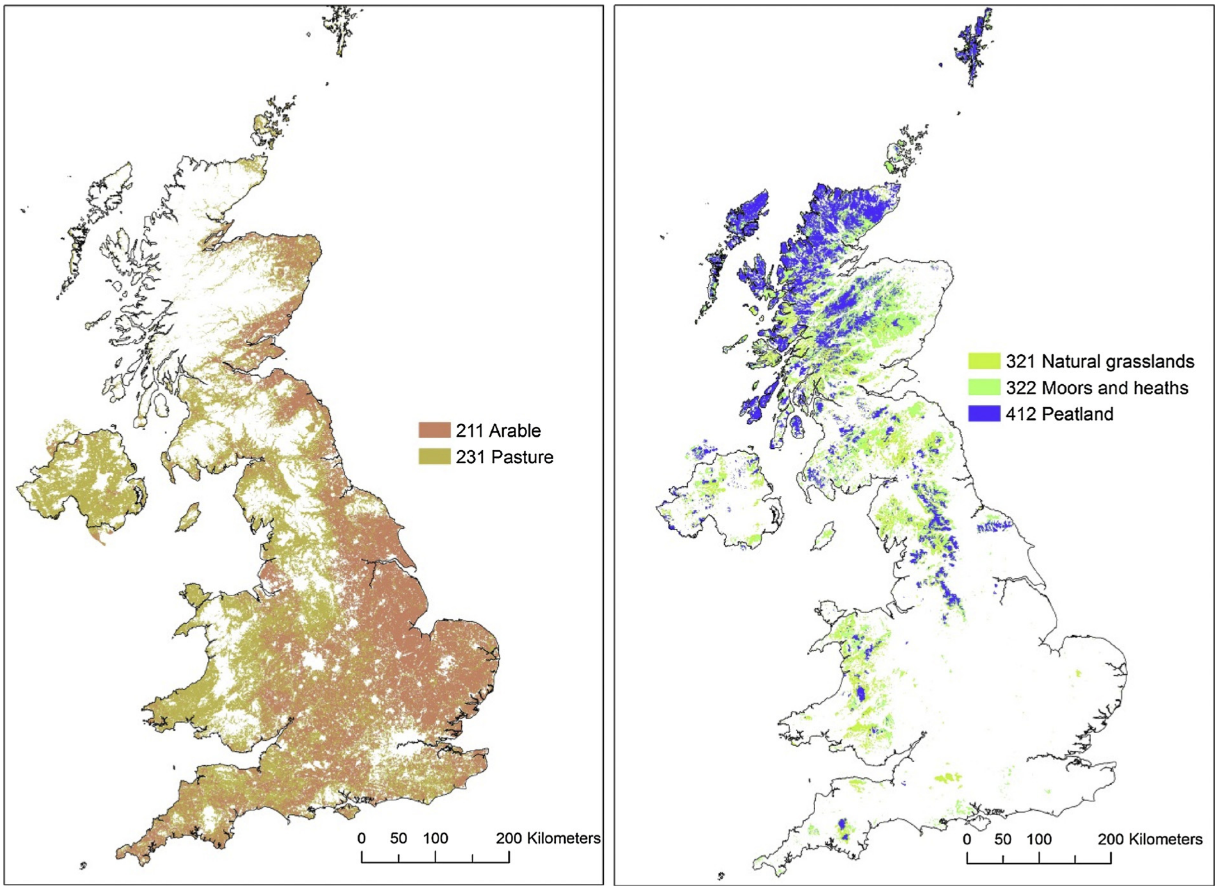

Fig. 5. Spatial distribution of the dominant CORINE level 3 land cover classes in the UK for 2012.

mapped change in the UK. The majority of the change is between class 312, Coniferous forest, and 324, Transitional woodland scrub. The Transitional woodland scrub falls within a different level 2 class, 32, Shrub and/or herbaceous vegetation associations. It is this change that accounts for 56% of the total change area in the level 2 analysis (Table 4). However, if we look at the definition of this class in the nomenclature "Transitional bushy and herbaceous vegetation with occasional scattered trees. Can represent woodland degradation, forest regeneration/recolonisation "(European Environment Agency, 2012, p. 57) it is seen that this class includes clearcut forestry and forestry regrowth, is less than 5 m high, has less than 30% coverage, natural development of forest formations, transitional processes, regeneration and degeneration, afforestation on non-forest areas. In practice in the UK this class is representative of cleared forestry areas, either freshly cut or regenerating, as part of a production process. Technically natural shrub encroachment and forest development can be included in this class but it is dominated by managed forest felling and stock rotation. Interestingly, in the mapped change between 2006 and 2012 there has been a net loss of all the three forestry classes 311, broadleaved forest, by 202 ha, 312, coniferous forest, by 80,208 ha and 313, mixed forest, by 2184 ha. Within the 32 shrub and herbaceous vegetation classes, 321, Natural grassland, and 322, Moors and Heathlands, decreased by 660 ha and 2097 ha respectively but the overall level 2 class increased collectively due to the increase in 324, transitional woodland scrub. This gain of 79,000 ha is not, however, as large as the losses in forestry, suggesting we have an overall decline in forested areas in the UK between 2006 and 2012.

If we compare this to the published statistics on forest management from the Forestry Commission, the government department responsible for state-owned woodlands in the UK, we can see some clear differences not only in quantity but more significantly in pattern. The total area of woodland in the UK in 2012 is estimated to be 3.1 million ha representing 13% of the land area, in the UK forest statistics (Forestry Commission, 2012). The total wooded area in the CORINE 2012 database, level 2 class 31, is 2.08 million ha representing 8.3% of the total land area. This variation in area can mainly be attributed to the difference in definition of wooded area. Woodland is defined in UK forestry statistics as "land under stands of trees with a canopy cover of at least 20% (25% in Northern Ireland), or having the potential to achieve this. The definition relates to land use, rather than land cover, so integral open space and felled areas that are awaiting restocking are included as woodland" (Forestry Commission, 2012, p. 9). The CORINE land cover nomenclature for 31 (Forests) is "Areas occupied by forests and woodlands with a vegetation pattern composed of native or exotic coniferous and/or broad-leaved trees and which can be used for the production of timber or other forest products. The forest trees are under normal climatic conditions higher than 5 m with a canopy closure of 30% at least. In case of young plantation, the minimum cut-off-point is 500 subjects by ha." (European Environment Agency, 2012). To make it more comparable it could be considered that class 324 is included in the CORINE land cover 2012 statistics. This brings the total to 2.4 million ha covering 9.7% total area. As discussed above the 324 class is a complex class, applicable to a wide range of types of succession, replanting, clear felling, natural development and transitional processes.

The total area of woodland reported in the national statistics had risen from 3.03 million ha in 2006 to 3.11 million ha in 2012 – an 80,000 ha increase. This is in line with the annual new planting, creation of new areas of woodland on land not previously wooded including natural colonisation, and restocking figures for the period. 60,800 ha were planted and 111,300 ha restocked between 2006 and 2012. This overall increase in wooded areas, even when felling and production is taken into account, is a direct contrast to the results found in the

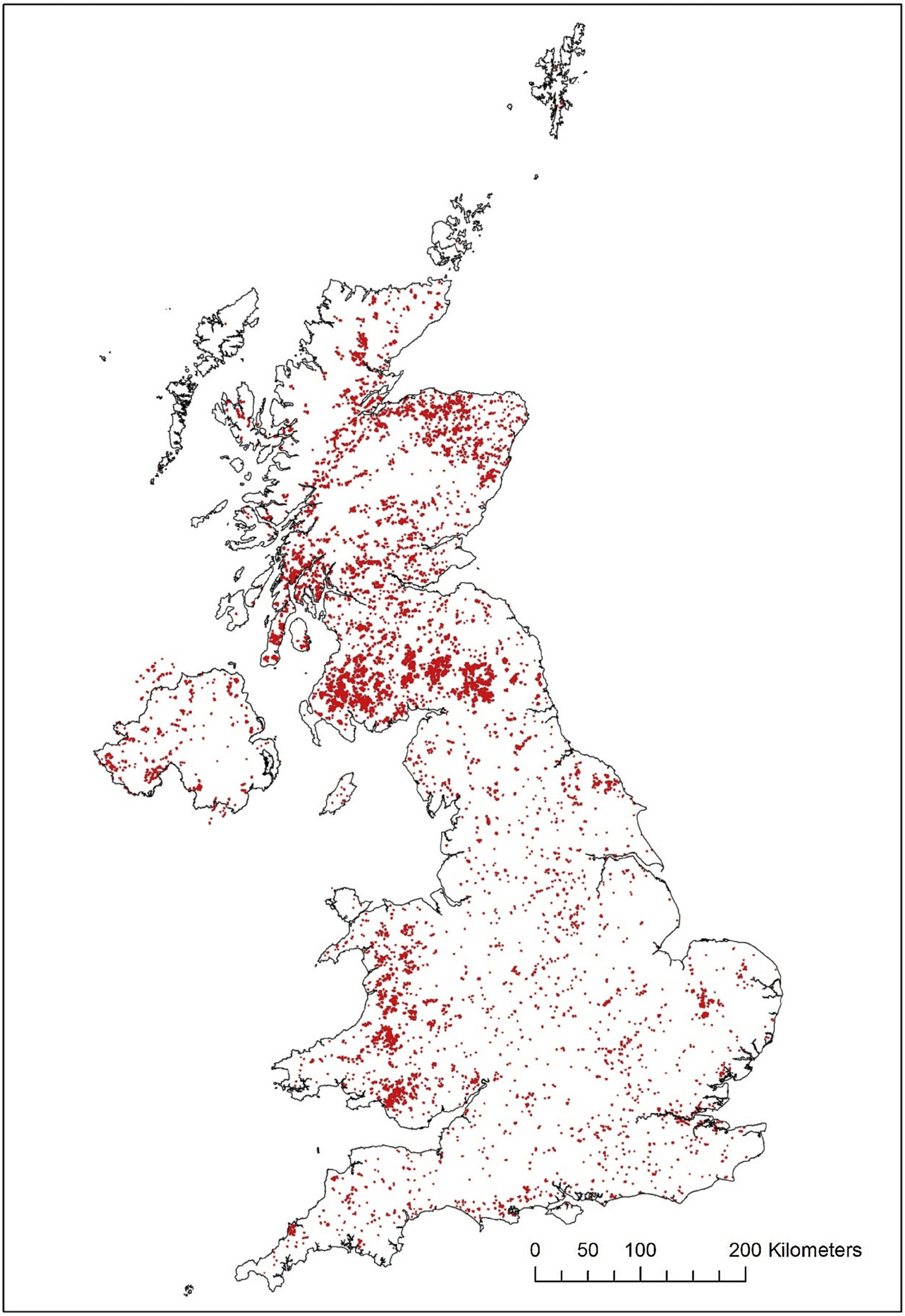

Fig. 6. Map of CORINE land cover changes between 2006 and 2012 for the UK.

CORINE land cover maps. There is an overall decrease of 3594 ha of the forest classes even if we take into account the conversion to class 324, Transitional woodland/shrub. There are a number of possible reasons for this disparity in the trend, firstly the class definitions are considerably different. Even when adapting the CORINE land cover results, by re-aggregating to include the 324 class to align them as closely as possible they are still not consistent. The hard rules with which they are defined differ, e.g. 20% cover vs. 30% cover, as well as

Table 3
Dominant CORINE land cover changes between 2006 and 2012 for the UK in terms of total area of change.

Change code	Change description	No. of poly.	Area (ha)	Area, % of total change
312-324	Clear cutting of coniferous forest	4806	122501.72	54.39%
324-312	Growth/replanting of coniferous forest	1558	46007.48	20.43%
324-324	Technical change – transitional woodland-shrub	705	6911.37	3.07%
211-131	Arable land to mineral extraction sites	165	3442.48	1.53%
313-324	Clear cutting of mixed forests	255	3189.61	1.42%
133-112	Completion of construction sites to urban areas.	125	2881.36	1.28%
312-121	Coniferous forests lost to industrial development	65	2861.96	1.27%
211-133	Arable land converted to construction sites	131	2624.56	1.17%
231-131	Pasture land to mineral extraction sites	114	2213.82	0.98%
231-133	Pasture land converted to construction sites	139	2088.32	0.93%
131-231	Mineral extraction sites converted to pasture land	60	1833.12	0.81%
231-211	Pasture land converted to arable land (intensification of agriculture)	73	1424.39	0.63%
324-313	Growth/replanting of mixed forests	48	1094.47	0.49%
312-312	Technical change – coniferous forest	133	1068.79	0.47%
133-121	Completion of construction sites to industrial and commercial developments	40	1058.15	0.47%

the boundaries of what is included, the national forestry statistics include “areas with the potential to achieve” a certain level of cover. This is hardly surprising when considering that the purpose of the data is different, the collection methods are different, and the scale of recording is different. Comber et al. (2005) highlight how with the integration of ‘information’ into ‘data’ without fully understanding the meaning and semantics the simplest concepts like the definition of forest can become problematic. They give the example of the different conceptualisations of forest from around the world and the resulting wide range of definitions. As acknowledged in the description of total area of woodland the national forest statistics use land use rather than land cover, another disparity and area to muddy the water in the conceptualisation of the nomenclature.

One of the main factors for the difference in results will be the scale of data collection. The national forestry statistics are partially based on the national forest inventory map and field survey as well as administrative records, all of which will be a finer resolution than the MMU of 25 ha for the CORINE land cover 2012 map and the 5 ha MMU for the 2006–2012 change map. The fivefold increase in resolution of the change map in comparison to the stock map is crucial in picking up a large amount of change across the landscape. Inevitably, there will be smaller parcels of change that the CORINE land cover maps are not identifying. However, the benefits of a European-wide product have to be balanced with the coarser spatial resolution mapping this allows. The scale at which we analyse and present the change in the results is also important. As discussed above the level of aggregation of the classes in the nomenclature hierarchy make an impact, but also the

Table 5
CORINE land cover change matrix 2006–2012 aggregated at level 1, showing the percentage of total area change.

		2006 CORINE land cover Level 1					Total (gains)
		1	2	3	4	5	
2012 CORINE Level 1	1	3.91%	6.46%	3.37%	0.46%	0.05%	14.26%
	2	1.45%	0.85%	0.01%			2.31%
	3	0.52%	0.17%	81.91%	0.01%	0.02%	82.63%
	4		0.24%		0.01%		0.24%
	5	0.32%	0.18%	0.02%		0.04%	0.56%
	Total (losses)	6.21%	7.89%	85.31%	0.48%	0.10%	100.00%

scales of the changes too. If we look at area of change polygons alone forestry is so dominant it outstrips all the other changes happening.

4.4. Artificial changes

By looking at change in the percentage of the total area of this class, the increase in class 1, artificial surfaces, appears as the biggest change, 16,384 ha between 2006 and 2012. This is an important increase, despite being a comparatively small total area to the forestry classes, as relative to the area covered by impermeable surfaces represents a 1% increase in this class, the only level 1 class to have an increase. The increased rate of change between the 2000–2006 change map and the 2006–2012 change map is also a cause for concern. The aggregated

Table 4
CORINE land cover change matrix for the UK from 2006 to 2012 aggregated at level 2, showing the percentage of total area change.

		2006 CORINE land cover Level 2															Total (gains)
		11	12	13	14	21	22	23	24	31	32	33	41	42	51	52	
2012 CORINE land cover Level 2	11	0.03%		1.34%	0.03%	0.27%		0.31%	0.01%	0.05%							2.03%
	12	0.01%	0.25%	0.76%	0.07%	0.41%		0.34%		1.30%	1.01%		0.24%	0.00%		0.01%	4.41%
	13	0.09%	0.27%	0.29%	0.14%	2.71%		1.94%	0.04%	0.40%	0.56%		0.22%		0.01%	0.03%	6.70%
	14		0.08%	0.47%	0.09%	0.21%		0.22%		0.01%		0.05%			0.00%		1.12%
	23		0.0%	1.07%	0.03%	0.13%		0.03%									1.26%
	21			0.35%		0.02%	0.01%	0.63%			0.01%						1.03%
	32			0.48%		0.02%		0.15%		56.09%	3.31%	0.31%	0.01%		0.01%		60.38%
	33			0.04%							0.45%	0.05%			0.00%		0.54%
	51			0.32%		0.12%		0.06%			0.02%				0.04%		0.56%
	22					0.01%		0.01%									0.02%
	41					0.03%		0.12%					0.01%				0.15%
	42					0.09%		0.00%									0.09%
	31							0.01%		0.53%	21.16%						21.70%
	24								0.00%								0.00%
Total (losses)		0.13%	0.61%	5.12%	0.35%	4.01%	0.01%	3.82%	0.06%	58.4%	26.5%	0.41%	0.48%	0.00%	0.07%	0.04%	100.00%

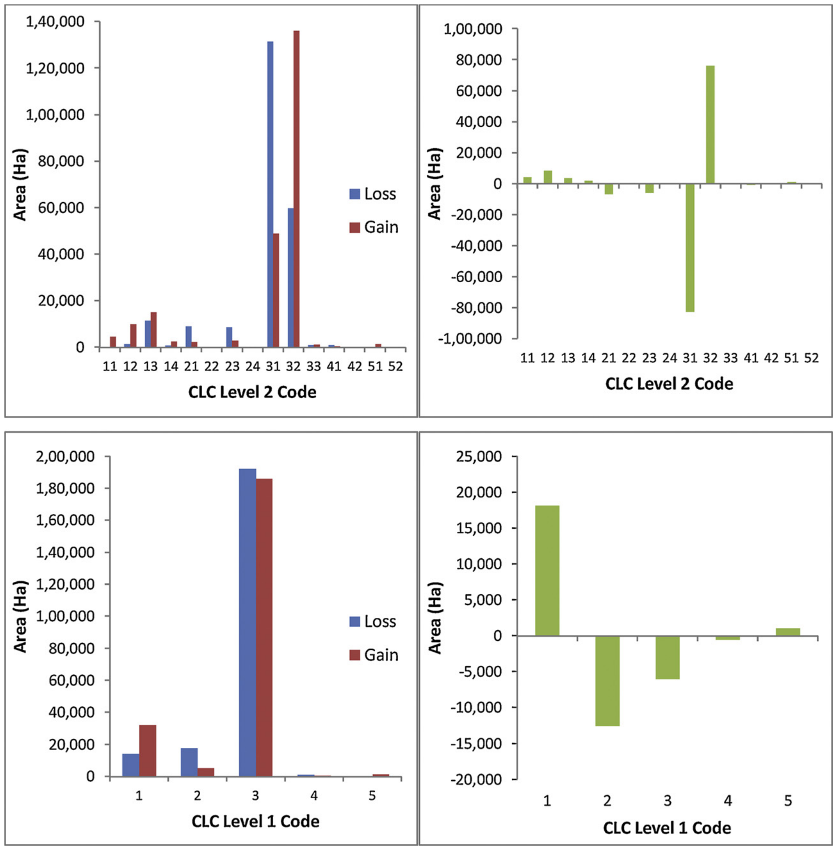

Fig. 7. Total area of gains and losses per CORINE land cover class for the UK aggregated at level 2 and 1 (left). Total area of overall change (difference) per class aggregated to level 2 and level 1 (right) for 2006–2012.

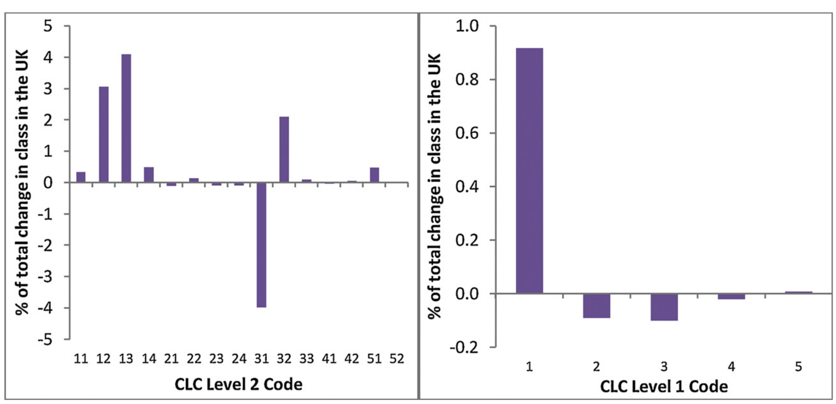

Fig. 8. Level 2 and 1 gains and losses of CORINE land cover classes by percentage of existing area in the UK for 2006–2012.

class 1 (artificial surfaces) only increased by 0.21% in 2000–2006. Looking further within this class at the level 2 and 3 subclasses we can see where this expansion in artificial surfaces is occurring. Class 12 (Industrial, commercial and transport units) has the largest overall gain of 8544 ha, with class 11 (Urban fabric) increasing by 4279 ha and smaller gains for class 13 (Mine, dump and construction sites) and 14 (Artificial, non-agricultural vegetated areas).

The largest individual level 3 subclass to increase the most is class 121 (Industrial or commercial units), at nearly double the amount of any of the other classes, with a 7696 ha gain. This is followed by a 4172 ha gain in class 112 (Discontinuous urban fabric). This latter class describes most residential areas in the UK and urban development that is not as dense as city centres. Housing areas are increasing but just not to the same extent as industrial estates. This could be because the scale of developments in residential areas is often too small for the 5 ha MMU, only large developments are above this cut-off. The transition from class 133 (Construction sites) to another classes is greatest in the class 112 (Discontinuous urban fabric), showing new residential developments. Construction sites increased overall, so more are being created than completed, backing up the overall increase in development. Finally the other notable increase of 3151 ha occurred for class 131 (Mineral extraction sites), which is potentially due to quarrying to support the increase in construction.

These results can be interpreted in the context of other European countries where on the whole urban sprawl is becoming an increasingly urgent problem. The UK is fairly low on the list of European countries when looking at the annual urban land take per country as a percentage of 2006 artificial land. However, it ranks in the top section of the list, in 8th position, when looking at the annual urban land take as a percentage of total urban land take in Europe (European Environment Agency,

Table 6
Dominant CORINE land cover changes in the UK between 2000 and 2006 by area of change.

Change code	Change description	No. of poly.	Area (ha)	Area, % of change
312-324	Clear cutting of coniferous forest	3045	107328.09	52.77%
324-312	Growth/replanting of coniferous forest	1290	60897.39	29.94%
211-112	Arable land converted to urban area	173	2846.86	1.40%
231-312	Pasture converted to coniferous forest	98	2703.18	1.33%
231-112	Pasture converted to urban area	187	2592.09	1.27%
231-142	Pasture converted to sports and leisure facilities	48	2319.20	1.14%
211-131	Arable land converted to mineral extraction sites	59	1732.64	0.85%
231-131	Pasture converted to mineral extraction sites	71	1619.45	0.80%
231-121	Pasture converted to industrial or commercial buildings	87	1598.76	0.79%
324-311	Growth/ replanting of broadleaf forest	50	1560.79	0.77%
321-324	Growth or planting of woodland/scrub on natural grasslands	37	1499.19	0.74%
133-112	Completion of construction sites to urban areas	57	1481.70	0.73%
211-121	Arable land converted to industrial or commercial buildings	69	1285.76	0.63%
231-324	Growth or planting of woodland/scrub on pasture land	40	1121.33	0.55%
231-133	Pasture converted to construction sites	34	991.30	0.49%

2017). The area covered by artificial surfaces in the UK in 2006 is already high, so a smaller percentage increase has a large effect. Across Europe the rate of land take is slowing from all the 3 CORINE assessment periods, 1990–2000, 2000–2006, and 2006–2012 (European Environment Agency, 2017), however this does not seem to be the case in the UK. Urban sprawl is generally a gradual process with cumulative ecological, economic and social effects, including loss of farmland, loss of soil function, reduction in habitats and increase in landscape fragmentation, higher greenhouse gas emissions, infrastructure costs and the degradation of various ecosystem services (European Environment Agency, 2016). Using the High Resolution Layer (HRL) degree of imperviousness, produced by the Copernicus Land Monitoring Service, is a finer spatial resolution product compared to the CORINE land cover map with a 20 m pixel and is updated every three years. A report on urban sprawl in Europe quantified the extent of the problem using a 'weighted urban proliferation' (WUP) and the second largest high sprawl values in Europe is identified as the UK between London and the Midlands (European Environment Agency, 2016). At country level the

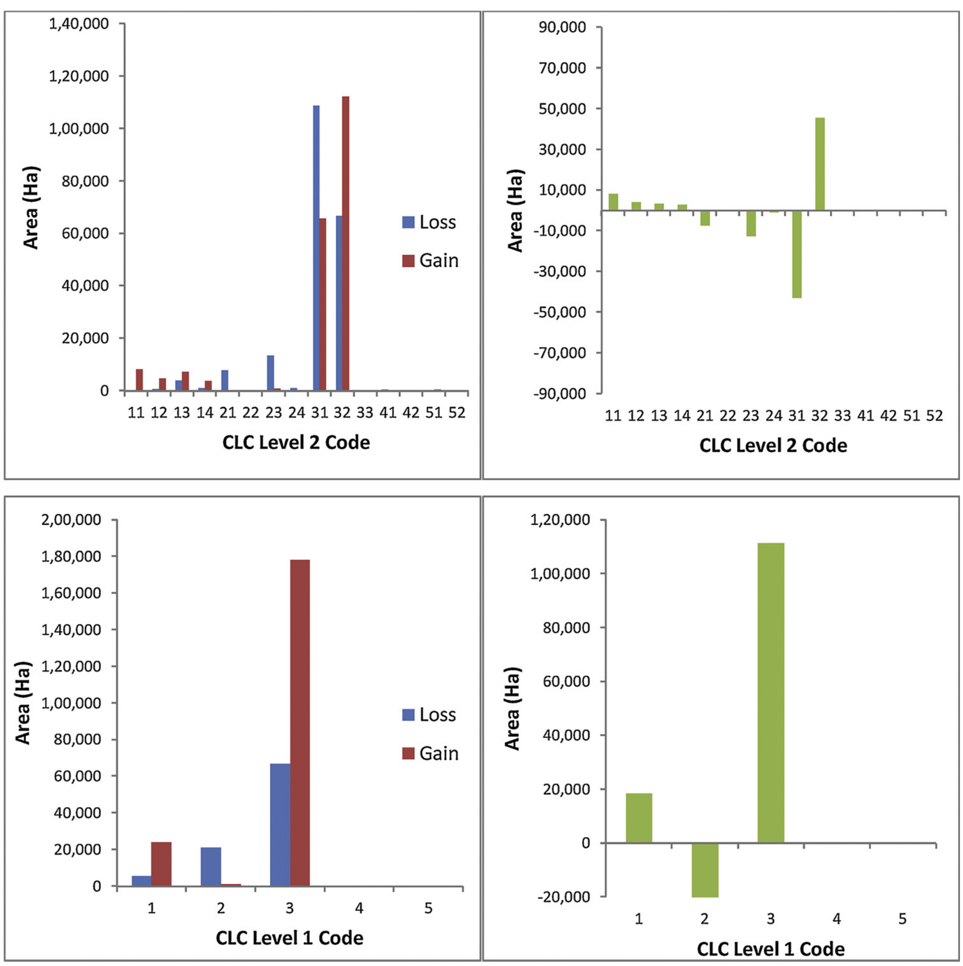

Fig. 9. Total area of gains and losses per CORINE land cover class in the UK aggregated at level 2 and 1 (left). Total area of overall change (difference) per class aggregated at level 2 and level 1 (right) for 2000–2006.

WUP increased in the UK from 3.07 in 2006 to 3.18 in 2009 with the built-up areas increasing from 17,774 km^2 to 18,217 km^2 in the same period. In this context we can see the significance of the overall gain mapped in the UK CORINE land cover change layer 2006–2012 in class 1 (Artificial surfaces).

The large gains in the class 121, Industrial or commercial units, are transitions from a large range of other land cover classes, but the largest transformation, with 2862 ha, is from class 312, Coniferous forest. The transition from coniferous forest to industry may seem quite unusual, but all but one polygon of this transformation relates to the erection of wind turbines in upland areas, mainly in Scotland. Erecting wind turbines in forested areas usually does not completely destroy the forest cover but access roads to the turbines are usually built through the forest. The entire area of mixed trees, roads and turbines is classed as 121 (Industrial) because its main land use is considered to be energy production from now on. Forestry is becoming a secondary land use.

This is also true of the transformations to 121 from 321, Natural grassland, 322, Moors and heaths, 324, Transitional woodland shrub, and 412, Peatlands, which together make up another 2758 ha of industrial development. This group of natural landscape classes provides the most likely locations to locate new wind farm developments, but we have also seen wind farm and solar panel development within the agricultural classes of 211 and 231, transitioning to 121. Certainly, over two thirds of the 'industrialisation' of the UK landscape, i.e. transition to class 121 is in fact development of wind farms. The nature of these developments is that not all the area is in fact turned into artificial surfaces, often a lot of the original land cover is intact with the wind turbines, a footing and a service road the only development on the ground. Hence the rapid rise of industrial development should be viewed with some caution.

4.5. Nomenclature

The CORINE nomenclature was developed in 1985, it was designed to be fit for purpose across the whole of Europe, inclusive of the whole variety of landscapes present in what is quite a wideit was designed to be fit for purpose across the whole of Europe, inclusive of the whole variety of landscapes present in what is quite a wide-ranging set of climatic zones, altitudes, geology and human development. The 44 classes have not changed since its implementation in the first CORINE land cover map between 1986 and 1998, however the definitions of the classes have improved (European Environment Agency, 2012).

The EEA is addressing the known issues with CORINE nomenclature by supporting the EIONET Action Group on Land monitoring in Europe (EAGLE) Group. The aim of the group is to elaborate a future oriented conceptual solution that would be in support of a European information capacity for land monitoring built on existing or future national data sources (Arnold et al., 2015). The EAGLE concept (Arnold et al., 2015) can be a useful framework for the integration of land cover/land use (LC/LU) information from various data sets in one single data model. It is applicable on both national and EU level and is a vehicle for comparison and semantic translation between different LC/LU nomenclatures, and facilitates data exchange. It is open to be implemented as a LC/LU data collection standard for national land monitoring initiatives and can be a coherent common data framework for several single Copernicus products (CORINE land cover, HRLs, Urban Atlas). The EAGLE is currently developing the conceptual framework and technical specifications for a new set of products, which will become the 2nd generation CORINE maps with improved spatial and thematic performance.

As noted earlier not all CORINE land cover classes are present in the UK as they are defined to represent the full depth and breadth of landscape types across Europe. Some of those that are present may not suited to the UK landscape or the existing definitions used in their monitoring to date. For instance, CORINE separates grassland in pasture and natural land based on land management, whereas UK agencies use management and soil type to separate four broad grassland habitats. The classes in the different nomenclatures cannot be aligned unambiguously creating a tension between UK and European products. Similarly, UK peatbogs are classified by the depth of peat set to 50 cm while the CORINE rules refer to 30 cm and both can be confounded by the presence of a variety of surface expressions.

4.6. Change in mapping methods

The mapping method employed in the 2012 update of the CORINE land cover map was different to the approach taken in 2006 as in 2012 there was no national land cover product in the UK on which to base a bottom-up approach. The resulting change products must be seen in the context of the methods used to produce the original CORINE land cover map 2006 and those used for the revision of CORINE 2006 during the CORINE 2012 production. Prior to the CORINE 2012 production, the philosophy in the UK had been to base CORINE on a generalisation of the most current version of the national land cover product. The LCM2007 had a smaller MMU, adopted a spatial framework aligned to national cartography and used a habitat / floristically based classification scheme, so conversion to CORINE format was always challenging both spatially and thematically. When checking the CORINE land cover 2006 during its production, the emphasis was placed on maintaining the link to the national land cover product rather than doing a fully re-interpretation based on visual analysis of the images. Consequently, the original CORINE land cover map 2006 would have had considerably differences from a standard CORINE land cover map interpretation and could have also perpetuated any errors present in the LCM2007. The revision of CORINE land cover map 2006 during the CORINE 2012 production used the visual interpretation methods of the standard CORINE approach and would therefore never produce identical results. The alterations required to revise CORINE 2006 are associated with semi-natural upland habitat, often related to the presence or absence of peat, crop rotation and pastures and dynamic environments such as the intertidal. The revised CORINE land cover map 2006 is undoubtedly more in line with the CORINE requirements, but has distanced itself from the national land cover product of that time.

This change in method between the two iterations of the CORINE land cover map production was required. At the time of production of the CORINE land cover map 2012 there was no update to the national land cover map, LCM2007 was still the most up to date, so generalisation was not a viable option. Bringing the CORINE land cover map production and subsequent map in line with the technical specifications outlined by the EEA has improved the final product, as the amount of revisions required shows the automated method in 2006 provided results that were not as closely matched to the required specification. The level of interpretation required in the classification and implementation of the nomenclature unique to this product meant the automated method used in 2006 did not give the required results.

The change in method may have also had an impact upon the increase of the amount of change identified between 2006 and 2012. One reason for the greater amount of change recorded and the diversity of types of change recorded could be that the change mapping was done in a greater detail in 2012.

5. Conclusion

The rate of CORINE land cover change from 2006 to 2012 was greater than from 2000 to 2006 with a 57% increase in the number of change polygons. A greater variety of types of land cover change was mapped from 2006 to 2012 than from 2000 to 2006, with 165 types of change rather than the previous 67 types of change. The total land area affected by land cover change increased by 21,854 ha or 11%, but the overall area of change remained at around 1% of the total land area of the UK.

The most prevalent type of land cover change from 2000 to 2006 and from 2006 to 2012 was clear cutting of coniferous forest (53% and

54% of overall change during these time periods), followed by growth and replanting of coniferous forest. From 2006 to 2012 the rate of forest replanting slowed down with 14,890 ha less replanted area compared to 2000–2006. A decrease in growth or planting of broadleaf and mixed forests was also observed.

Urban land take remains an important land cover change in the UK from 2006 to 2012. CORINE land cover class 1, Artificial surfaces, was the biggest type of change and grew by 16,384 ha between 2006 and 2012. The rate of change from other land cover types to Artificial surfaces grew from 2000 to 2006 to 2006–2012. However, the rate of change needs to be interpreted carefully, as many areas of this type are wind and solar 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).

This work forms a sound basis for the future analysis of land cover land use change once the currently on-going update of CORINE land cover map 2018 is completed in late 2018.

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References

Aksoy, E., Yigini, Y., Montanarella, L., 2016. Combining soil databases for topsoil organic carbon mapping in Europe. PLoS One 11. http://dx.doi.org/10.1371/journal.pone.0152098.

Alahuhta, J., Luukinoja, J., Tukiainen, H., Hjort, J., 2016. Importance of spatial scale in structuring emergent lake vegetation across environmental gradients and scales: GIS-based approach. Ecol. Indic. 60, 1164–1172. http://dx.doi.org/10.1016/j.ecolind.2015.08.045.

Alexandridis, T.K., Oikonomakis, N., Gitas, I.Z., Eskridge, K.M., Silleos, N.G., 2014. The performance of vegetation indices for operational monitoring of CORINE vegetation types. Int. J. Remote Sens. 35, 3268–3285. http://dx.doi.org/10.1080/01431161.2014.902548.

Arnold, S., Smith, G., Hazeu, G., Kosztra, B., Perger, C., Banko, G., Soukup, T., Strand, G.H., Valcarcel Sanz, N., Bock, M., 2015. The EAGLE concept: a paradigm shift in land monitoring. In: Ahlqvist, O., Varanka, D., Fritz, S., Janowicz, K. (Eds.), Land Use and Land Cover Semantics. Principles, Best Practices, and Prospects. CRC Press, pp. 107–144 Print ISBN: 978-1-4822-3739-9. eBook ISBN: 978-1-4822-3740-5.

Ballabio, C., Panagos, P., Monatanarella, L., 2016. Mapping topsoil physical properties at European scale using the LUCAS database. Geoderma 261, 110–123. http://dx.doi.org/10.1016/j.geoderma.2015.07.006.

Balzter, H., Cole, B., Thiel, C., Schmullius, C., 2015. Mapping CORINE land cover from Sentinel-1A SAR and SRTM digital elevation model data using random forests. Remote Sens. 7, 14876–14898. http://dx.doi.org/10.3390/rs71114876.

Brown, N., Gerard, F., Fuller, R., 2002. Mapping of land use classes within the CORINE land cover map of Great Britain. Cartogr. J. 39, 5–14.

Brown, G., Pullar, D., Hausner, V.H., 2016. An empirical evaluation of spatial value transfer methods for identifying cultural ecosystem services. Ecol. Indic. 69, 1–11. http://dx.doi.org/10.1016/j.ecolind.2016.03.053.

Büttner, G., Kosztra, B., 2007. CLC2006 Technical Guidelines. European Environment Agency, Technical Report.

Büttner, G., Kosztra, B., 2011. CLC 2012. Addendum to CLC2006 Technical Guidelines. EEA/ETC SIA Working document.

Büttner, G., Kosztra, B., 2017. CLC2018 Technical Guidelines.

Büttner, G., Maucha, G., Kosztra, B., 2011. European Validation of Land Cover Changes in CLC2006 Project.

Cabral, P., Feger, C., Levrel, H., Chambolle, M., Basque, D., 2016. Assessing the impact of land-cover changes on ecosystem services: a first step toward integrative planning in Bordeaux, France. Ecosyst. Serv. 22, 318–327. http://dx.doi.org/10.1016/j.ecoser.2016.08.005.

Campling, P., Terres, J.M., Vande Walle, S., Van Orshoven, J., Crouzet, P., 2005. Estimation of nitrogen balances from agriculture for EU-15: spatialisation of estimates to river basins using the CORINE land cover. Phys. Chem. Earth 30, 25–34. http://dx.doi.org/10.1016/j.pce.2004.08.014.

Cole, B., King, S., Ogutu, B., Palmer, D., Smith, G., Balzter, H., 2015. Corine Land Cover 2012 for the UK, Jersey and Guernsey. NERC Environmental Information Data Centre, Shapefiles. http://dx.doi.org/10.5285/32533dd6-7c1b-43e1-b892-e80d61a5ea1d.

Comber, A., Fisher, P., Wadsworth, R., 2005. What is land cover? Environ. Plann. B Plann. Des. 32, 199–209.

Cruickshank, M.M., Tomlinson, R.W., 1996. Application of CORINE land cover methodology to the U.K. – some issues raised from Northern Ireland. Glob. Ecol. Biogeogr. Lett. 5, 235–248.

Cruickshank, M.M., Tomlinson, R.W., Trew, S., 2000. Application of CORINE land-cover mapping to estimate carbon stored in the vegetation of Ireland. J. Environ. Manage. 58, 269–287. http://dx.doi.org/10.1006/jema.2000.0330.

De Meij, A., Bossioli, E., Penard, C., Vinuesa, J.F., Price, I., 2015. The effect of SRTM and corine land cover data on calculated gas and PM10 concentrations in WRF-chem. Atmos. Environ. 101, 177–193. http://dx.doi.org/10.1016/j.atmosenv.2014.11.033.

Depellegrin, D., Pereira, P., Misiunė, I., Egarter-Vigl, L., 2016. Mapping ecosystem services potential in Lithuania. Int. J. Sustain. Dev. World Ecol. 23, 441–455. http://dx.doi.org/10.1080/13504509.2016.1146176.

Di Sabatino, A., Coscieme, L., Vignini, P., Cicolani, B., 2013. Scale and ecological dependence of ecosystem services evaluation: spatial extension and economic value of freshwater ecosystems in Italy. Ecol. Indic. 32, 259–263. http://dx.doi.org/10.1016/j.ecolind.2013.03.034.

Diaz-Pacheco, J., Gutiérrez, J., 2014. Exploring the limitations of CORINE land cover for monitoring urban land-use dynamics in metropolitan areas. J. Land Use Sci. 9, 243–259. http://dx.doi.org/10.1080/1747423X.2012.761736.

European Environment Agency, 2012. CORINE Land Cover Nomenclature Illustrated Guide.

European Environment Agency, 2016. Urban Sprawl in Europe.

European Environment Agency, 2017. Land Take. Indicator Assessment, Data and Maps.

Feranec, J., Hazeu, G., Christensen, S., Jaffrain, G., 2007a. Corine land cover change detection in Europe (case studies of the Netherlands and Slovakia). Land Use Policy 24, 234–247. http://dx.doi.org/10.1016/j.landusepol.2006.02.002.

Feranec, J., Hazeu, G., Jaffrain, G., Cebecauer, T., 2007b. Cartographic aspects of land cover change detection (over- and underestimation in the I&CORINE land cover 2000 project). Cartogr. J. 44, 44–54. http://dx.doi.org/10.1179/000870407X173869.

Feranec, J., Soukup, T., Hazeu, G., Jaffrain, G., 2016. European Landscape Dynamics: CORINE Land Cover Data. CRC Press, Boca Raton 337 Pages, ISBN 9781482244663.

Forestry Commission, 2012. Forestry Statistics 2012.

Fuller, R., Brown, N., 1996. A CORINE map of Great Britain by automated means. Techniques for automatic generalization of the land cover map of Great Britain. Int. J. Geogr. Inform. Syst. 10, 937–953.

Gallego, F.J., Batista, F., Rocha, C., Mubareka, S., 2011. Disaggregating population density of the European Union with CORINE land cover. Int. J. Geogr. Inform. Sci. 25, 2051–2069. http://dx.doi.org/10.1080/13658816.2011.583653.

Gardi, C., Panagos, P., Van Liedekerke, M., Bosco, C., De Brogniez, D., 2015. Land take and food security: assessment of land take on the agricultural production in Europe. J. Environ. Plann. Manage. 58, 898–912. http://dx.doi.org/10.1080/09640568.2014.899490.

Gerard, F., Petit, S., Smith, G., Thomson, A., Brown, N., Manchester, S., Wadsworth, R., Bugar, G., Halada, L., Bezak, P., Boltiziar, M., De Badts, E., Halabuk, A., Mojses, M., Petrovic, F., Gregor, M., Hazeu, G., Mücher, C.A., Wachowicz, M., Huitu, H., Tuominen, S., Köhler, R., Olschofsky, K., Ziese, H., Kolar, J., Sustera, J., Luque, S., Pino, J., Pons, X., Roda, F., Roscher, M., Feranec, J., 2010. Land cover change in Europe between 1950 and 2000 determined employing aerial photography. Prog. Phys. Geogr. 34 (2), 183–205.

Giorgio, G.A., Ragosta, M., Telesca, V., 2017. Climate variability and industrial-suburban heat environment in a Mediterranean area. Sustainability (Switz.) 9. http://dx.doi.org/10.3390/su9050775.

Gorji, T., Sertel, E., Tanik, A., 2017. Monitoring soil salinity via remote sensing technology under data scarce conditions: a case study from Turkey. Ecol. Indic. 74, 384–391. http://dx.doi.org/10.1016/j.ecolind.2016.11.043.

Grüneberg, E., Ziche, D., Wellbrock, N., 2014. Organic carbon stocks and sequestration rates of forest soils in Germany. Glob. Change Biol. 20, 2644–2662. http://dx.doi.org/10.1111/gcb.12558.

Jackson, D., 2000. Guidance on the Interpretation of the Biodiversity Broad Habitat Classification (Terrestrial and Freshwater Types): Definitions and the Relationship With Other Habitat Classifications. Joint Nature Conservation Committee.

Laplace-Treyture, C., Feret, T., 2016. Performance of the phytoplankton index for lakes (IPLAC): a multimetric phytoplankton index to assess the ecological status of water bodies in France. Ecol. Indic. 69, 686–698. http://dx.doi.org/10.1016/j.ecolind.2016.05.025.

Leito, A., Bunce, R.G.H., Külvik, M., Ojaste, I., Raet, J., Villoslada, M., Leivits, M., Kull, A., Kuusemets, V., Kull, T., Metzger, M.J., Sepp, K., 2015. The potential impacts of changes in ecological networks, land use and climate on the Eurasian crane population in Estonia. Landsc. Ecol. 30, 887–904. http://dx.doi.org/10.1007/s10980-015-0161-0.

Mag, Z., Szép, T., Nagy, K., Standovár, T., 2011. Modelling forest bird community richness using CORINE land cover data: a study at the landscape scale in Hungary. Commun. Ecol. 12, 241–248. http://dx.doi.org/10.1556/ComEc.12.2011.2.13.

Majkowska, A., Kolendowicz, L., Półrolniczak, M., Hauke, J., Czernecki, B., 2017. The urban heat island in the city of Poznań as derived from Landsat 5 TM. Theor. Appl. Climatol. 128, 769–783. http://dx.doi.org/10.1007/s00704-016-1737-6.

Manakos, I., Braun, M. (Eds.), 2017. Land Use and Land Cover Mapping in Europe. Practices & Trends. Series: Remote Sensing and Digital Image Processing. Springer, pp. 282–296 ISBN: 978-94-007-7968-6/3.

Mancini, L.D., Barbati, A., Corona, P., 2017. Geospatial analysis of woodland fire occurrence & recurrence in Italy. Ann. Silvicult. Res. 41, 41–47. http://dx.doi.org/10.12899/asr-1376.

Modugno, S., Balzter, H., Cole, B., Borrelli, P., 2016. Mapping regional patterns of large

forest fires in wildland-urban interface areas in Europe. J. Environ. Manage. 172, 112–126. http://dx.doi.org/10.1016/j.jenvman.2016.02.013.
Morton, D., Rowland, C., Wood, C., Meek, L., Marston, C., Smith, G., Wadsworth, R., Simpson, I.C., 2011. Final Report for LCM2007 – The New UK Land Cover Map. Countryside Survey Technical Report No 11/07 NERC/Centre for Ecology & Hydrology 112 pp.
Nedkov, S., Burkhard, B., 2012. Flood regulating ecosystem services – mapping supply and demand, in the Etropole municipality, Bulgaria. Ecol. Indic. 21, 67–79. http://dx.doi.org/10.1016/j.ecolind.2011.06.022.
Novobilský, A., Novák, J., Björkman, C., Höglund, J., 2015. Impact of meteorological and environmental factors on the spatial distribution of Fasciola hepatica in beef cattle herds in Sweden. BMC Vet. Res. 11, 128. http://dx.doi.org/10.1186/s12917-015-0447-0.
Parente, J., Pereira, M.G., 2016. Structural fire risk: the case of Portugal. Sci. Total Environ. 573, 883–893. http://dx.doi.org/10.1016/j.scitotenv.2016.08.164.
Pereira, M.G., Aranha, J., Amraoui, M., 2014. Land cover fire proneness in Europe. For. Syst. 23, 598–610. http://dx.doi.org/10.5424/fs/2014233-06115.
Pilaš, I., Kušan, V., Medved, I., Medak, J., Bakšić, N., Marjanović, H., 2013. Estimation of soil organic carbon stocks and stock changes in Croatia (1980–2006) – use of national soil database and the Corine Land Cover. Period. Biol. 115, 339–347.
Reis, M., Akay, A.E., Savaci, G., 2016. Erosion risk mapping using CORINE methodology for Goz watershed in Kahramanmaras region, Turkey. J. Agric. Sci. Technol. 18, 695–704.
Ricaurte, L.F., Olaya-Rodríguez, M.H., Cepeda-Valencia, J., Lara, D., Arroyave-Suárez, J., Max Finlayson, C., Palomo, I., 2017. Future impacts of drivers of change on wetland ecosystem services in Colombia. Glob. Environ. Change 44, 158–169. http://dx.doi.org/10.1016/j.gloenvcha.2017.04.001.
Ruda, A., Kolejka, J., Batelková, K., 2017. Geocomputation and spatial modelling for geographical drought risk assessment: a case study of the Hustopeče Area, Czech Republic. Pure Appl. Geophys. 174, 661–678. http://dx.doi.org/10.1007/s00024-016-1296-x.
1Spatial, 2007. CORINE Land Cover Map Feasibility Study Final Project Report for Centre of Ecology and Hydrology. Unpublished 1 Spatial report to CEH and Defra. .
Schillaci, C., Lombardo, L., Saia, S., Fantappiè, M., Märker, M., Acutis, M., 2017. Modelling the topsoil carbon stock of agricultural lands with the stochastic gradient treeboost in a semi-arid Mediterranean region. Geoderma 286, 35–45. http://dx.doi.org/10.1016/j.geoderma.2016.10.019.
Smith, G.M., Brown, N.J., Thomson, A.G., 2005. CORINE Land Cover 2000: Semi-Automated Updating of CORINE Land Cover in the UK. Phase II: Map Production in the UK, Final Report. Unpublished CEH report to DG-Regio. .
Szumacher, I., Pabjanek, P., 2017. Temporal changes in ecosystem services in European cities in the continental biogeographical region in the period from 1990–2012. Sustainability (Switz.) 9. http://dx.doi.org/10.3390/su9040665.
Thomson, A.G., Manchester, S.J., Swetnam, R.D., Smith, G.M., Wadsworth, R.A., Petit, S., Gerard, F.F., 2007. The use of digital aerial photography and CORINE-derived methodology for monitoring recent and historic changes in land cover near UK Natura 2000 sites for the BIOPRESS project. Int. J. Remote Sens. 28, 5397–5426. http://dx.doi.org/10.1080/01431160601105868.
Vogiatzakis, I.N., Stirpe, M.T., Rickebusch, S., Metzger, M.J., Xu, G., Rounsevell, M.D.A., Bommarco, R., Potts, S.G., 2015. Rapid assessment of historic, current and future habitat quality for biodiversity around UK Natura 2000 sites. Environ. Conserv. 42, 31–40. http://dx.doi.org/10.1017/S0376892914000137.
Weissteiner, C.J., García-Feced, C., Paracchini, M.L., 2016. A new view on EU agricultural landscapes: quantifying patchiness to assess farmland heterogeneity. Ecol. Indic. 61, 317–327. http://dx.doi.org/10.1016/j.ecolind.2015.09.032.
Yannelli, F.A., Tabeni, S., Mastrantonio, L.E., Vezzani, N., 2014. Assessing degradation of abandoned farmlands for conservation of the monte desert biome in Argentina. Environ. Manage. 53, 231–239. http://dx.doi.org/10.1007/s00267-013-0176-8.