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A high-resolution habitat map for England (LCM 3m): product documentation

Christopher Marston, Clare Rowland, John Redhead, Lucy Ridding, Rebecca Rowe, Russell Stevens, Josep Serra Gallego, Emily Williams, Emily Upcott, Zephyr Orsler, Zeke Marshall, Margaret Bolton, Aneurin O'Neil, Mark Tabor, Richard Pywell

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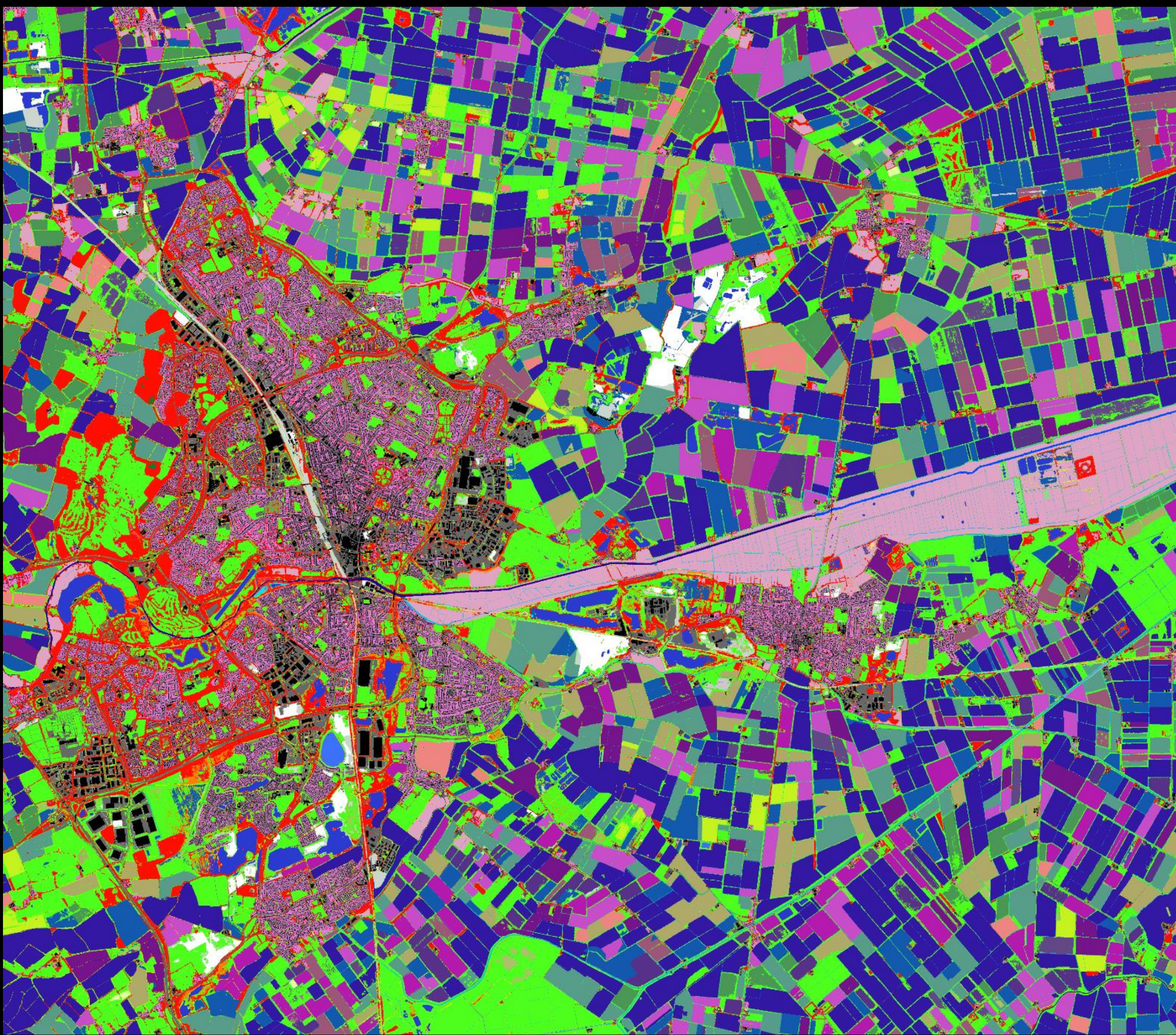

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1. Introduction

The UK Centre for Ecology & Hydrology (UKCEH) has a long history of national land cover mapping using Earth observation data, from the 25 m resolution Land Cover Map 1990 through to the annual production of 10 m resolution Land Cover Maps from LCM2020 onwards. These datasets provide a consistent evidence base for monitoring environmental change across the UK and support a wide range of scientific, policy and operational applications (Marston et al., 2023).

While 10 m resolution land cover products are well suited to national-scale environmental monitoring, their ability to detect and characterise small or fragmented landscape features is inherently constrained by pixel size. In heterogeneous environments, where multiple land cover types may occur within a single pixel, classification uncertainty can increase because of mixed spectral signals. The increasing availability of high-resolution satellite imagery offers an opportunity to overcome these limitations and improve the representation of ecologically important landscape features.

This report describes the production of ‘A high-resolution habitat map for England (LCM 3m)’, hereafter referred to as LCM 3m, a new national-scale 3 m resolution Land Cover Map for England. The map was generated using a modified version of the UKCEH Land Cover Mapping processing chain, combining a 12-month time series of analysis-ready PlanetScope monthly basemap imagery with contextual geospatial datasets and extensive training data to classify land cover into 72 categories, broadly aligned with the UK Habitat Classification framework (UKHab).

The use of multi-temporal imagery, as applied here, enables seasonal and phenological patterns to be quantified, improving discrimination between vegetation communities and other land cover types. Furthermore, the 3 m spatial resolution allows the identification and characterisation of finer-scale landscape features, including hedgerows, individual trees, shrubs and field margins, which are often poorly represented in coarser-resolution national mapping products. The thematic detail of the classification is further enhanced through integration of independent datasets, including Ordnance Survey MasterMap, which provides additional information on land cover classes such as buildings, sealed surfaces and gardens.

Together, these advances represent a significant enhancement in the capability to monitor England’s landscapes, providing a robust and detailed evidence base for environmental assessment, habitat monitoring and policy evaluation. This document describes the datasets, processing workflow and classification methodology used to produce the LCM 3m, and presents the results of the classification together with an assessment of its accuracy and performance.

2. Methods

The production workflow for the LCM 3m is split into four stages; 1) collating the classification training data; 2) refining this training data; 3) the classification process, and; 4) post-classification knowledge-based enhancements. Figure 1 shows the key stages in the LCM 3m production workflow.

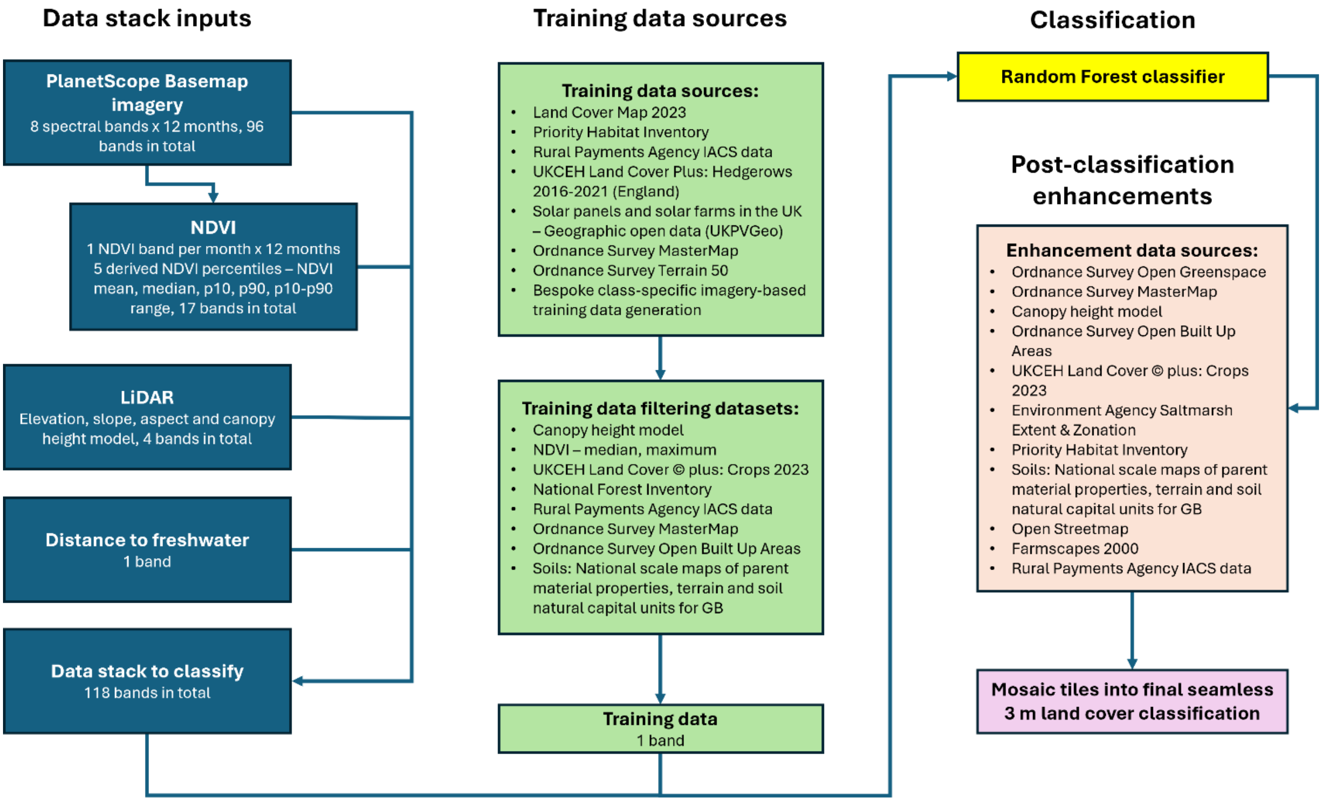

Figure 1. Overview of the LCM 3m processing workflow.

2.1 Classification nomenclature

LCM 3m is based on the 72-class hierarchical nomenclature presented in Table 1. This nomenclature broadly aligns to the UK Habitat Classification (UKHab) (Butcher et al., 2018) classes where appropriate, although does contain sub-classes with additional class information that do not directly align to specific UKHab classes.

Table 1. LCM 3m classification nomenclature.

UKHab Level 2 name / code	UKHab Level 3 name / code	UKHab Level 4 name / code	UKHab Level 5 name / code	Non UKHab sub-class	Class code
Woodland and forest (w)	Broadleaved and mixed woodland (w1)			Broadleaved and mixed woodland	1
				Broadleaved and mixed woodland over sealed surface	2
				Broadleaved and mixed woodland over watercourses	3
				Broadleaved and mixed woodland over gardens	4
	Coniferous woodland (w2)			Coniferous woodland	5
				Coniferous woodland over sealed surface	6
				Coniferous woodland over watercourses	7
				Coniferous woodland over gardens	8
Grassland (g)	Modified grassland (g4)			Modified grassland	9
				Modified grassland with stone wall	10
	Neutral grassland (g3)			Neutral grassland	11
				Neutral grassland with stone wall	12
				Coastal and floodplain grazing marsh	13
	Calcareous grassland (g2)			Calcareous grassland	14
				Calcareous grassland with stone wall	15
	Acid grassland (g1)			Acid grassland	16
				Acid grassland with stone wall	17
		Bracken (g1c)		Bracken	18
				Bracken with stone wall	19
Heathland and shrub (h)	Dwarf shrub heath (h1)			Dwarf shrub heath	20
				Dwarf shrub heath with stone wall	21
	Hedgerows (h2)			Hedgerows	22
	Dense scrub (h3)			Dense scrub	23
Wetland (f)	Bog (f1)			Bog	24
				Bog with stone wall	25
	Fen marsh and swamp (f2)			Fen marsh and swamp	26
				Rush pastures	27
				Rush pastures with stone wall	28
		Reedbeds (f2e)		Reedbeds	29
Cropland (c)	Arable and horticulture (c1)			Arable and horticulture with stone wall	30
		Cereal crops (c1c)		Spring barley	31
				Winter barley	32
				Spring wheat	33
				Winter wheat	34
				Maize	35
				Spring oats	36
				Winter oats	37

UKHab Level 2 name / code	UKHab Level 3 name / code	UKHab Level 4 name / code	UKHab Level 5 name / code	Non UKHab sub-class	Class code
		Non cereal crops (c1d)		Spring field beans	38
				Winter field beans	39
				Potatoes	40
				Peas	41
				Oilseed rape	42
				Beet (sugar beet / fodder beet)	43
				Other crops	44
		Intensive orchards (c1e)		Intensive orchards	45
			Miscanthus (c1d5)	Miscanthus	46
				Allotments	47
				Tall herbaceous vegetation	48
Urban (u)	Built-up areas and gardens (u1)	Developed land; sealed surface (u1b)	Buildings (u1b5)	Buildings	49
			Other developed land (u1b6) (sealed surface)	Other developed land (u1b6) (sealed surface)	50
		Suburban mosaic of developed and natural surface (u1d)		Suburban mosaic of developed and natural surface (gardens)	51
	Solar panel array (u1 83)			Solar panel array	52
Sparsely vegetated land (s)				Sparsely vegetated land	53
	Inland rock (s1)			Inland rock	54
	Supralittoral rock (s2)			Supralittoral rock	55
	Supralittoral sediment (s3)			Supralittoral sediment	56
Rivers and lakes (r)	Standing open water and canals (r1)			Standing open water and canals - unclassified	57
				Standing open water and canals - drains	58
				Standing open water and canals - reservoir	59
				Standing open water and canals - standing water	60
		Canals (r1e)		Canals	61
	Rivers and streams (r2)			Rivers and streams	62
Marine inlets and transitional waters (t)	Littoral rock (t1)			Littoral rock	63
	Littoral sediment (t2)			Littoral sediment	64
		Coastal saltmarsh (t2a)		Coastal saltmarsh - Mid-low	65
				Coastal saltmarsh - Pioneer	66
				Coastal saltmarsh - Spartina	67
				Coastal saltmarsh - Upper marsh	68
				Coastal saltmarsh - unclassified	69
		Saline lagoons (t2g)		Saline lagoons	70
				Tidal water	71
Other				Stone walls	72

2.2 Input data sets

Producing a national-level land cover map requires a range of data sets typically including satellite and context data, as well as training and validation data. The following sections outline the data sets used in production of the LCM 3m land cover map.

2.2.1 Satellite data

The principal data source for producing the LCM 3m is a time-series of normalized surface reflectance PlanetScope 8-band 3 m spatial resolution multi-spectral basemap imagery for a 12-month period acquired between the 1st of January 2023 and the 31st of December 2023, with a basemap image for each calendar month within this period (Planet Labs PBC, 2024). All eight spectral bands available in the PlanetScope basemap imagery are utilised, comprising coastal blue (431-452 nm), blue (465-515 nm), green I (513-549 nm), green (547-583 nm), yellow (600-620 nm), red (650-680 nm), red-edge (697-713 nm) and near infra-red (845-885 nm) bands. The basemap product comprises a best-pixel composite compiled from all available cloud-free PlanetScope imagery collected for the given month. This reduced cloud cover within the output composite image, although on some occasions cloud, or data holes where no cloud-free imagery was available, remained in the data. The monthly repeat frequency of the imagery basemaps is highly valuable for land cover and vegetation mapping, enabling the phenological characteristics of different vegetation types to be quantified in turn improving separation of multiple land cover types when this imagery is classified. The PlanetScope basemap imagery is tiled, with a total of 1071 tiles covering the extent of England (Figure 2).

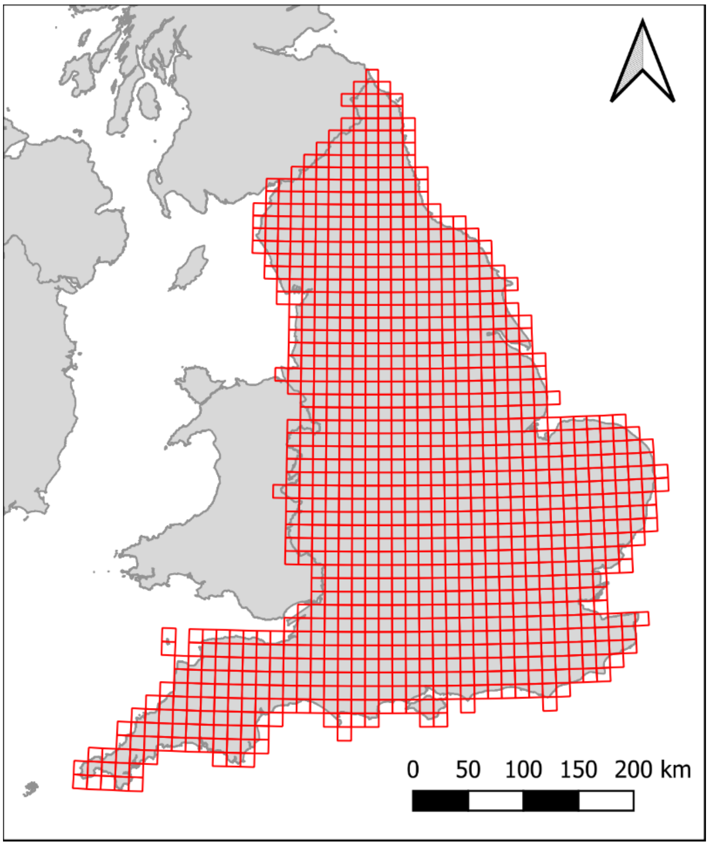

Figure 2. PlanetScope basemap tile grid covering England.

2.2.2 Context data

In addition to the satellite data, further context data sets are included as inputs into the classification process to enable improved classification of the target land cover classes. Context data is used for three purposes: 1) filtering of classification training data; 2) inclusion as layers in the data stack to be classified, and; 3) for the application of post-classification knowledge-based enhancements.

Context data sets include topographical data for elevation, with slope and aspect derived from this. The elevation data is sourced from the National Lidar Programme conducted by England's Environment Agency. Airborne LIght Detection And Ranging (LiDAR) data. The EA's LiDAR data is particularly important as it adds a structural dimension to the spectral dimension provided by high-resolution satellite imagery, a combination which is particularly relevant for woody types of vegetation (Csillik et al., 2019). The LiDAR data was captured from a fixed-wing aircraft in leaf-off conditions during 2016–2021 at a density of approximately 4 points per m^2. This data was subsequently processed to create digital terrain model (DTM) and a first-return digital surface model (DSM) data at 1 m spatial resolution, with the DTM data here used as the input elevation data set. Slope and aspect data sets are derived from this DTM. Additionally, a Canopy Height Model (CHM) was generated from the LiDAR data by calculating the difference between the DTM from the DSM. The CHM model is key for improving the classification of multiple classes, particularly woody features such as broadleaved and mixed woodland, coniferous woodland, dense scrub and hedgerows. The LiDAR-derived topographical data sets are resampled to 3 m resolution to match the PlanetScope basemap resolution and pixel grid.

LiDAR data is unavailable for an area of approximately 24 × 25 km in North Yorkshire. For these data gaps, NextMap DEM data resampled to 3 m was used to gap-fill elevation, with slope and aspect data derived from this. This maintained complete coverage of the elevation, slope and aspect topographic datasets for the full extent of England. It was not possible to generate CHM data for areas where LiDAR data is unavailable.

Distance to freshwater, generated from the Ordnance Survey VectorMap District data product, is also included as a context data set. This aids classification of land cover classes that can be influenced by proximity to water sources such as rivers, for example fen, marsh and swamp, and neutral grassland (Marston et al., 2023).

2.2.3 Training and validation data generation

Given the logistical, financial and time limitations of field data collection, it was not feasible, within the scope of this project, to conduct field data collection for all land cover classes across England. Therefore, training data for the classification is generated using a series of established data products in an automated manner, with a series of filtering steps applied to maintain data quality and improve the subsequent performance of the classifier. This is performed for each land cover class in the random forest classification, except for the buildings, freshwater and sealed surface, and suburban mosaic of developed and natural surface (gardens) classes as these are added as a post-classification stage using Ordnance Survey MasterMap data. The training data sources utilised are outlined in Table 2, with training data for some land cover classes sourced from more than one dataset.

Table 2. Training data sources for the LCM 3m.

Training data source	England 3m LCM class trained
LCM2023 10m classified pixels, GB. (Morton et al., 2024).	Broadleaved and mixed woodland, coniferous woodland, modified grassland, calcareous grassland, acid grassland, fen marsh and swamp, dwarf shrub heath, bog, inland rock, supra-littoral rock, supra-littoral sediment, littoral rock, littoral sediment and saltmarsh.
Rural Payment Agency Integrated Administration and Control System (IACS) field data for England.	Arable, inland rock, saltmarsh, dense scrub, supra-littoral sediment, solar panels.

Priority Habitat Inventory (England).	Broadleaved and mixed woodland, neutral grassland, calcareous grassland, acid grassland, fen marsh and swamp, bog, reedbeds, dwarf shrub heath (for lowland heaths), acid grassland (for lowland heaths) and dense scrub.
UKCEH Land Cover Plus: Hedgerows 2016-2021 (England). (Broughton et al., 2024).	Hedgerows.
Solar panels and solar farms in the UK - geographic open data (UKPVGeo). (Stowell et al., 2020).	Solar panel arrays.
OS Terrain 50 (foreshore and tidal water).	Tidal water.

Phenology-derived training data

For a number of land cover classes it was not possible to derive appropriate training data at the national level from existing available data sets, necessitating an alternative approach. Some classes exhibited specific known phenological patterns, resulting in identifiable spectral signatures at specific times of year that are observable in the monthly PlanetScope imagery. This enabled the production of training data from the satellite imagery itself based on the known phenological characteristics of that class. For example, to generate bracken training data, spring and summer NDVI and NDSWIR composites were created to exploit the distinctive seasonal development of bracken. Spectral distance metrics were then used to compare pixel characteristics against a representative sample of bracken reference points distributed across England. Pixels with the closest spectral match were identified through thresholding and selected as likely bracken locations. The resulting candidate pixels were subsequently refined using a series of masks to remove areas unlikely to contain bracken. Broadleaved and mixed woodland was excluded using Environment Agency LiDAR data, while agricultural land was removed using information from both the UKCEH Land Cover® plus: Crops data sets (2020–2024) and the wider UKCEH Land Cover Map series of data products (Levy et al., 2024; Marston et al., 2022, 2024; Morton et al., 2020a, 2020b, 2020c, 2021, 2024; Rowland et al., 2017, 2020, 2025). Areas that were consistently classified as arable land across these datasets were excluded, resulting in a more reliable set of training areas for bracken.

Similar approaches were taken for the miscanthus, tall herbaceous vegetation and rush pasture classes based on their characteristic phenological cycle during specific periods of the year, and the capability of the monthly PlanetScope imagery to capture this distinctiveness.

Training data filtering

A series of filtering steps are applied to remove incorrect and poor-quality training data and improve the overall quality of the dataset. The filtering steps applied fall into two categories, the first being dataset-specific filters, and the second being land cover class-specific filters. Dataset-specific filters applied are described in Table 3.

Table 3. Dataset specific training data filtering applied.

Dataset	**Filter**
Land Cover Map 2023 (10m classified pixels, GB).	All pixels with a probability threshold <80 are disregarded from the LCM2023 training dataset to retain only classified areas of higher confidence.

Rural Payment Agency Integrated Administration and Control System (IACS) field data for England.	Only polygons with a single farmer return land cover class for 2023 are retained, with all polygons with multiple land cover labels associated removed.
Solar panels and solar farms in the UK - geographic open data (UKPVGeo).	This data was filtered to remove all polygons with an area smaller than 1000 m^2. Polygons smaller than this typically corresponded to rooftop installations which would for this exercise be classified as buildings. Polygons larger than 1000 m^2 corresponded to larger solar farms situated in fields and were therefore retained.
UKCEH Land Cover Plus: Hedgerows 2016-2021 (England).	The UKCEH Land Cover Plus: Hedgerows 2016-2021 (England) (Broughton et al., 2024) dataset is used to identify locations of hedgerow presence across the study areas, canopy height model data was used to filter hedgerow training data, retaining only locations recorded as hedgerow with CHM values >50 cm.
Priority Habitat Inventory (England).	Priority Habitat Inventory (PHI) data was inspected for suitability for inclusion as training data. Where there was uncertainty as to the accuracy or where the data may no longer be current (for example an area recorded in the PHI data as grassland but which has subsequently experienced succession and is now dense scrub), those locations are disregarded from further analysis.

After the multi-source training data had been collated, a series of land cover class specific filters are applied to further improve the quality of the input data. These class-specific filtering processes drew on multiple datasets characterising features pertinent to the land cover class in question, including structural characteristics using CHM data, and proximity to feature data, for example proximity to field edges where mixed pixels are more likely to occur due to the heterogenous mix of land cover features often found on field boundaries. These steps systematically remove inappropriate training data locations. For example, LCM2023 is a valuable source of land cover training data, however this is optimised for production of land cover classifications using Sentinel-2 satellite imagery at 10 m resolution, which introduces limitations in its use for training classifications at 3 m resolution. A field classified as grassland in LCM2023 may be predominantly comprised of grassland, but may also contain isolated trees, shrubs, hedgerows etc. that are too small to be detected at 10 m resolution. These features are, however, detectable at 3 m resolution. When training a 3 m classification there is a risk that LCM2023 pixels selected from within this field and intended to be used as grassland training pixels could correspond to a non-grassland feature, polluting the training data and resulting in subsequent misclassification. To alleviate this problem, the CHM is used to filter the training data for classes such as the grassland classes to exclude all areas with CHM values above specific thresholds. This removes all areas corresponding to trees, shrubs etc., retaining a purer training data set for those classes.

Validation data sets

Validation data are necessary to establish the accuracy of land cover classifications (Foody et al., 2002). Field surveys were undertaken to collect reference data for evaluating classification accuracy. Surveyors systematically traversed survey areas and recorded the land-cover features encountered. Feature locations were captured using Leica Zeno 20 and Leica Zeno FLX100 differential GPS (dGPS) units, which provide substantially higher positional accuracy than standard GPS devices, typically achieving accuracies of 2–3 cm. For linear features, such as hedgerows, multiple location points were collected along their length, with a minimum spacing of 20 m between consecutive observations. At each survey location, cardinal photographs were taken facing north, east, south, and west, together with an image of the target feature. These photographs provide valuable contextual information and can support interpretation of land-cover classes during classification development. For larger landscape features, including agricultural fields and woodland blocks, land-cover information was recorded directly onto field maps during surveys and subsequently digitised.

Due to the logistical, financial, and temporal constraints associated with field data collection, comprehensive national-scale surveying across England was not feasible within the scope of this project. To improve both the geographic coverage and sample size of the validation dataset, the field survey observations were supplemented with reference data from existing validation data sets for example from Land Cover Map 2023

(Morton et al., 2024) and habitat mapping and plot data from the Countryside Survey (Wood et al., 2017) cross-checked against aerial imagery to confirm no land-cover change had occurred.

Supplementary validation points were also manually digitised from the PlanetScope satellite imagery cross-referenced with high-resolution aerial imagery basemaps and LiDAR data. This was applied to visually distinct classes, including open water, littoral sediment, saltmarsh, buildings, and sealed surfaces. In total, 35,231 validation points were used to assess the accuracy of the LCM 3m. These points were distributed across the full spatial extent of the mapping area (Figure 3).

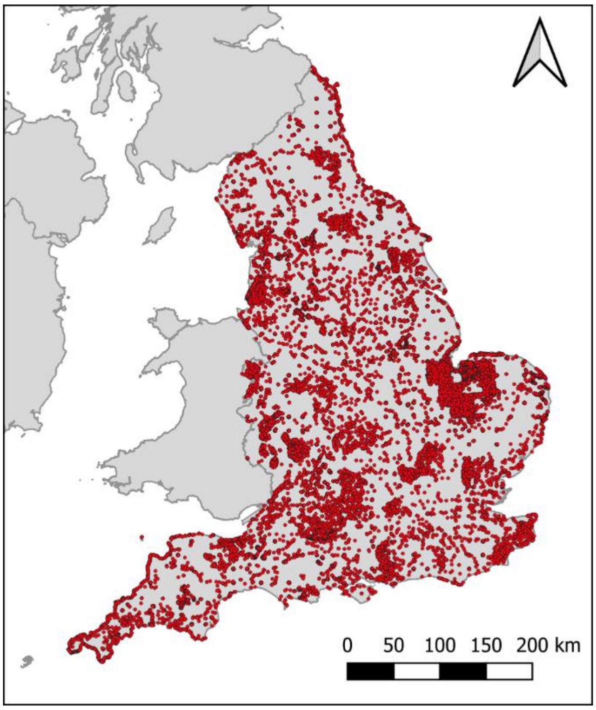

Figure 3. Distribution of the 35,231 validation points for LCM 3m.

2.2.4 Classification input data stack

The land cover classification process applies a random forest classifier to an input data stack comprising satellite imagery supplemented with contextual spatial data. Input data sets into the data stack for classification are:

- PlanetScope monthly basemap imagery, 8 bands x 12 months (96 bands in total).
- Normalised Difference Vegetation Index (NDVI), with an NDVI band generated from each monthly Planet basemap image (12 bands in total).
- NDVI percentile bands calculated from the full time-series of 12 monthly NDVI bands. These include mean NDVI, median NDVI, 90th percentile (p90) NDVI, 10th percentile (p10) NDVI and p10-p90 NDVI range.
- Topography, comprising elevation, slope and aspect bands.
- Canopy Height Model (CHM).
- Distance to freshwater features.

This produced a 118-band input data stack for each Planet Basemap tile area that is subsequently classified.

For a number of PlanetScope tiles in North Yorkshire LiDAR data is unavailable, with two tiles falling completely within the LiDAR data gap and a further nine tiles containing partial LiDAR coverage.

The two tiles with no LiDAR availability are classified without the CHM in the input data stack, which therefore comprised 117 bands. For the tiles with partial LiDAR coverage, two classifications were performed for each tile. For the first classification, areas with no LiDAR coverage are masked out. The classification is then performed for the remaining area with LiDAR data coverage, using only training locations from the non-masked areas. The second classification is the inverse of the first classification, masking out areas with LiDAR coverage, and then performing the classification only on the areas with no LiDAR coverage and using training data only from locations with no LiDAR coverage. The two respective classifications for the affected tile are subsequently mosaicked together, producing a complete coverage classification for that given tile.

2.2.5 Classification algorithm

The composite imagery was classified using a Random Forest (RF) algorithm (Breiman, 2001) implemented within the WEKA machine learning framework (Hall et al., 2009; Frank et al., 2016), employing an ensemble of 200 decision trees. To train the classifier, 10,000 pixel samples were selected for each land cover class using sampling with replacement. This approach ensures that all classes contribute an equal number of observations to the training dataset, thereby providing a balanced representation of class variability during model development. Balancing the training data is important for reducing bias towards dominant land cover classes. Without this step, classes with relatively few training observations may be underrepresented during model building, increasing the likelihood of confusion with more common classes and potentially resulting in their omission from the final classification. By maintaining equal sample sizes across classes, the RF classifier is better able to learn the spectral and contextual characteristics of both common and rare land cover types.

For each pixel, the trained RF model generates a probability of membership for every land cover class. The final class assignment is determined using a maximum-likelihood approach, whereby each pixel is allocated to the class associated with the highest predicted probability.

2.2.6 Post-classification refinements

After the RF classification stage, the output land cover map is then enhanced with a series of post-classification refinements. This improves the initial classification where certain classes are difficult to discriminate via the RF classification using only the PlanetScope imagery and context data, or where existing map data sets offer improved spatial accuracy over that which can be achieved from the RF classification. These post-classification refinements fall into three categories: 1) addition of buildings, sealed surface, suburban mosaic of developed and natural surface (gardens), freshwater and stone wall land cover classes onto the classification using independent data sets; 2) stratification of arable, saltmarsh and freshwater classes to give additional thematic detail and; 3) refinement of targeted areas of misclassification using class-specific corrections.

Land cover class addition
The first group of post-classification refinements involved the addition of further land cover classes onto the RF classification from two independent data sets, Ordnance Survey MasterMap and Farmscapes 2000. This was performed for classes where those data sets offer improved mapping of these classes, especially of smaller features, over what is achievable via 3 m satellite imagery classification.

Ordnance Survey MasterMap
Ordnance Survey MasterMap (OSMM) is here used a source for buildings, sealed surface, freshwater and suburban mosaic of developed and natural surface (gardens). The OSMM buildings data was stamped onto the RF classification above all other land cover classes. For the sealed surface and gardens OSMM land cover classes an alternative approach was employed, whereby the OSMM data is stamped selectively above some

spectrally classified classes, but also used to recategorise other classes. For example, OSMM sealed surface was stamped above all land cover except broadleaved and mixed woodland and coniferous woodland, in which case those pixels are recategorised to broadleaved and mixed woodland or coniferous woodland over sealed surface respectively. Similarly, OSMM freshwater is stamped above all classes except broadleaved and mixed and coniferous woodland, shrubs, buildings and sealed surface, with new classes created for broadleaved and mixed woodland and coniferous woodland above water respectively. OSMM data is also used to recategorise spectrally classified broadleaved and mixed woodland pixels to intense orchards where orchards are identified in the OSMM data.

Farmscapes 2020

Stone walls are common features across many areas of England, particularly in upland areas. As these walls are narrow features they are generally not identifiable in the 3 m resolution PlanetScope imagery, however the structural height of these features can be observed in the LiDAR derived CHM.

Here, the Farmscapes 2020 dataset produced by Google (Conserva et al., in review) which maps stone wall locations across large extents of England is used as an independent data source to add this class onto the RF classification. As stone walls only typically occupy a small proportion of a 3 x 3 m pixel, the underlying land cover class classified by the RF classifier is retained, with an additional label of ‘with stone wall’ added. For example, an acid grassland pixel will be recategorised as acid grassland with stone wall.

As the structural characteristics of stone walls are quantified in the CHM, these features are frequently misclassified by the RF classifier as hedgerows. Where pixels classified as hedgerows are coincident with the Farmscapes 2020 stone wall locations, hedgerow is recategorised to stone walls.

Land cover class stratification

Further post-processing stages were applied to the arable, saltmarsh and freshwater classes where context datasets enabled additional stratification of these classes.

Arable stratification

The UKCEH Land Cover® plus: Crops data set for 2023 was used to stratify pixels classified as arable by the RF classifier to the following crop types: spring barley, oilseed rape, winter wheat, winter barley, spring oats, maize, spring field beans, winter field beans, potatoes, peas, winter oats, spring wheat, beet, field beans and other crops. Where the UKCEH Land Cover® plus: Crops indicated grass or solar panels, arable pixels were reclassified to the modified grassland or solar panel array classes respectively.

Saltmarsh stratification

Pixels classified as saltmarsh by the RF classifier were stratified using the Environment Agency Saltmarsh Extent & Zonation data. The stratified saltmarsh classes are: pioneer, spartina, mid-low, upper marsh and unclassified saltmarsh. Locations classified by the RF classifier as saltmarsh and categorised as reedbeds in the Environment Agency Saltmarsh Extent & Zonation data are recategorised to the reedbeds class.

Freshwater stratification

Freshwater pixels are stratified into six classes using OSMM data. These classes are: canal, drain, reservoir, standing water (excluding reservoirs), rivers and streams, and other freshwater.

Woodland class stratification

Ground-level land cover features can be obscured in optical satellite imagery by overhanging broadleaved and mixed or coniferous woodland canopies. In these instances, integration of the RF classification with independent map datasets which accurately map the obscured features enables improved land cover information at these locations to be derived. Here, OSMM data mapping sealed surface, freshwater and suburban mosaic of developed and natural surface (gardens) is used to recategorise woodland pixels at these locations to new classes. Pixels classified as broadleaved and mixed or coniferous woodland are recategorised as broadleaved and mixed or coniferous woodland over water, over sealed surface, or over gardens respectively. In this manner, information about the distribution of broadleaved and coniferous trees is maintained, while providing additional information on underlying features. Additionally, classified broadleaved trees corresponding to areas identified within OSMM as orchards are here recategorised as intensive orchards.

Additional Knowledge Based Enhancements
A further series of knowledge-based enhancements (KBEs) are also applied to the classification. These include the reclassification of misclassified pixels of coastal classes (such as littoral sediment erroneously appearing inland) using a coastal mask, and conversion of misclassified arable pixels to modified grassland in urban green space as denoted by the Ordnance Survey Open Greenspace data set.

Refinement of spectrally similar calcareous and acid grassland classes is also performed using the National scale maps of parent material properties, terrain and soil natural capital units at 50 metre resolution for Great Britain, 2020 (Feeney et al., 2026) data set. This used the physio-chemical parent material characteristics information in this data set to recategorise acid grassland to calcareous grassland in areas of shallow or deep calcareous parent material, and conversely recategorise calcareous grassland to acid grassland where shallow non-calcareous parent material is present.

Finally, Priority Habitat Inventory (PHI) data is used to recategorise areas classified as grassland to coastal and floodplain grazing marsh where the PHI data recorded coastal and floodplain grazing marsh as being present. Similarly, pixels classified as freshwater or tidal water are recategorised as saline lagoons where identified by the PHI data.

Once the post-classification refinements were applied, the classifications for all tiles were mosaiced into a single classification providing full coverage of England at 3 m pixel resolution.

2.2.7 Data set projection

The LCM 3m dataset is supplied in the British National Grid coordinate reference system (EPSG:27700).

3. Results

3.1 Land cover classification

Figure 4 displays the national coverage of the LCM 3m land cover map. When displayed at the national level many smaller land cover features cannot be observed so Figure 4 uses a simplified display schema, however Figures 5 and 6 show more locally detailed examples of the LCM 3m for an urban setting (central London) and a predominantly agricultural area in Cambridgeshire.

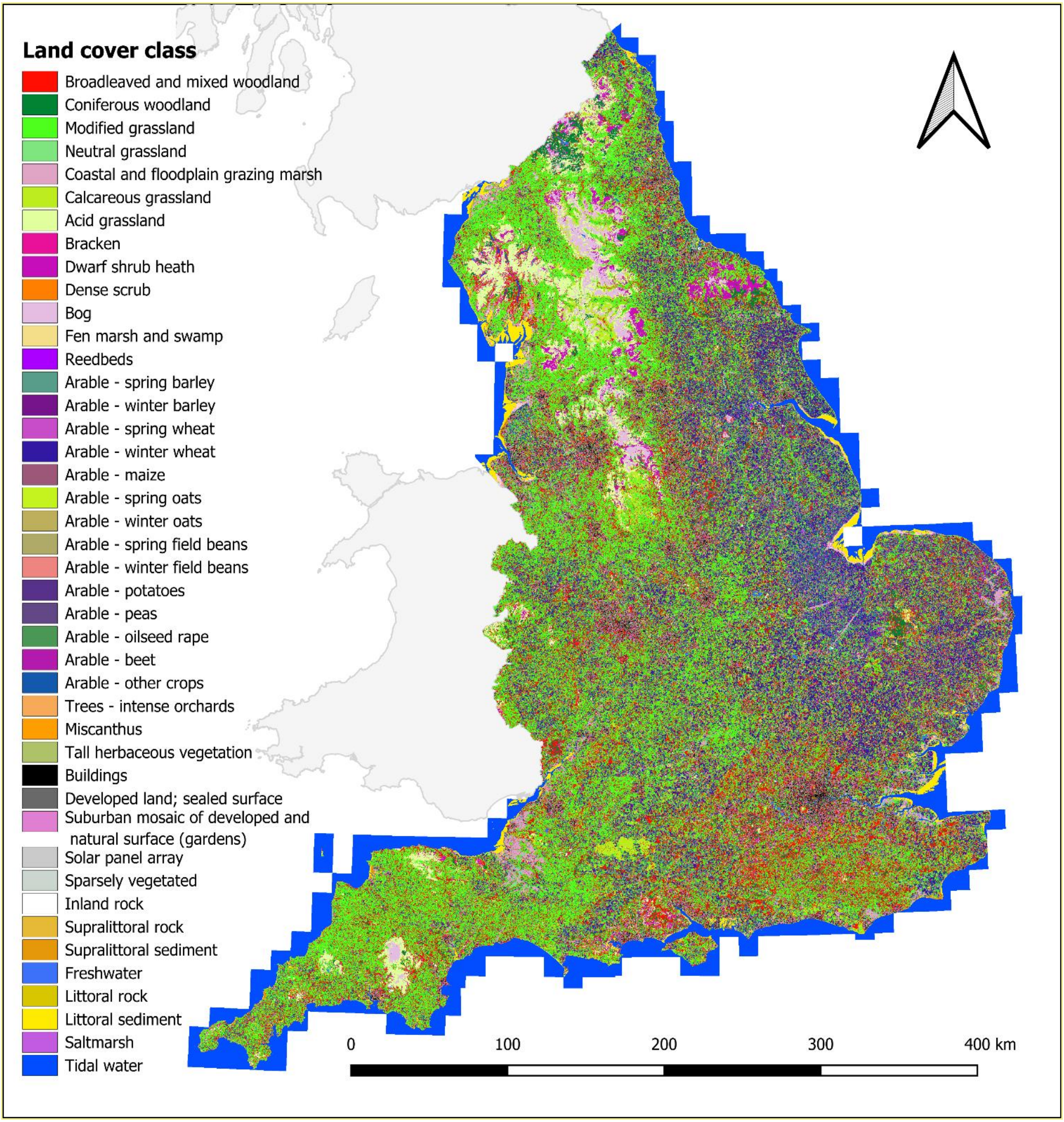

Figure 4. LCM 3m land cover map for England, displayed in a simplified classification schema.

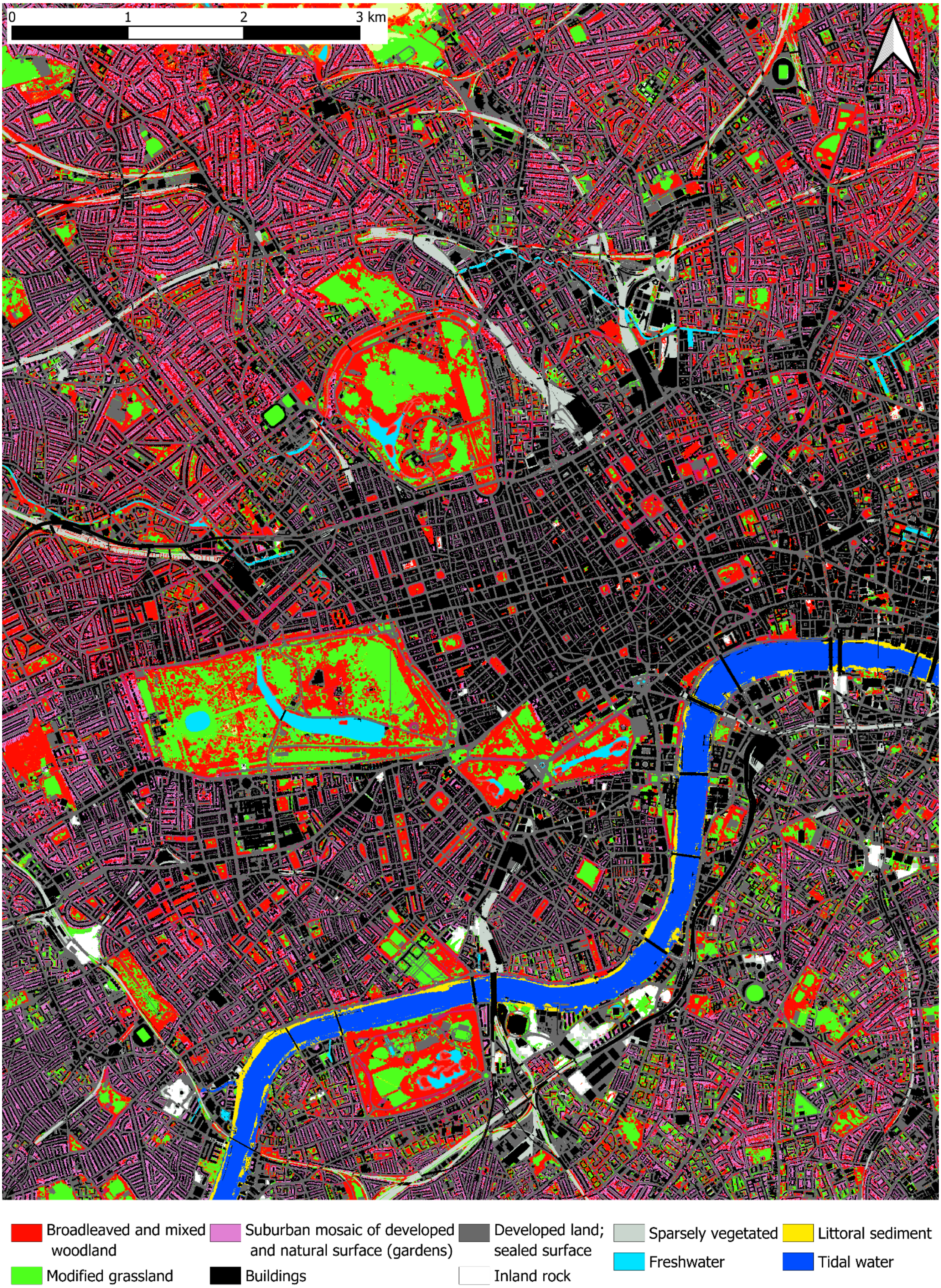

Figure 5. LCM 3m land cover map for England, displaying a built-up area in London.

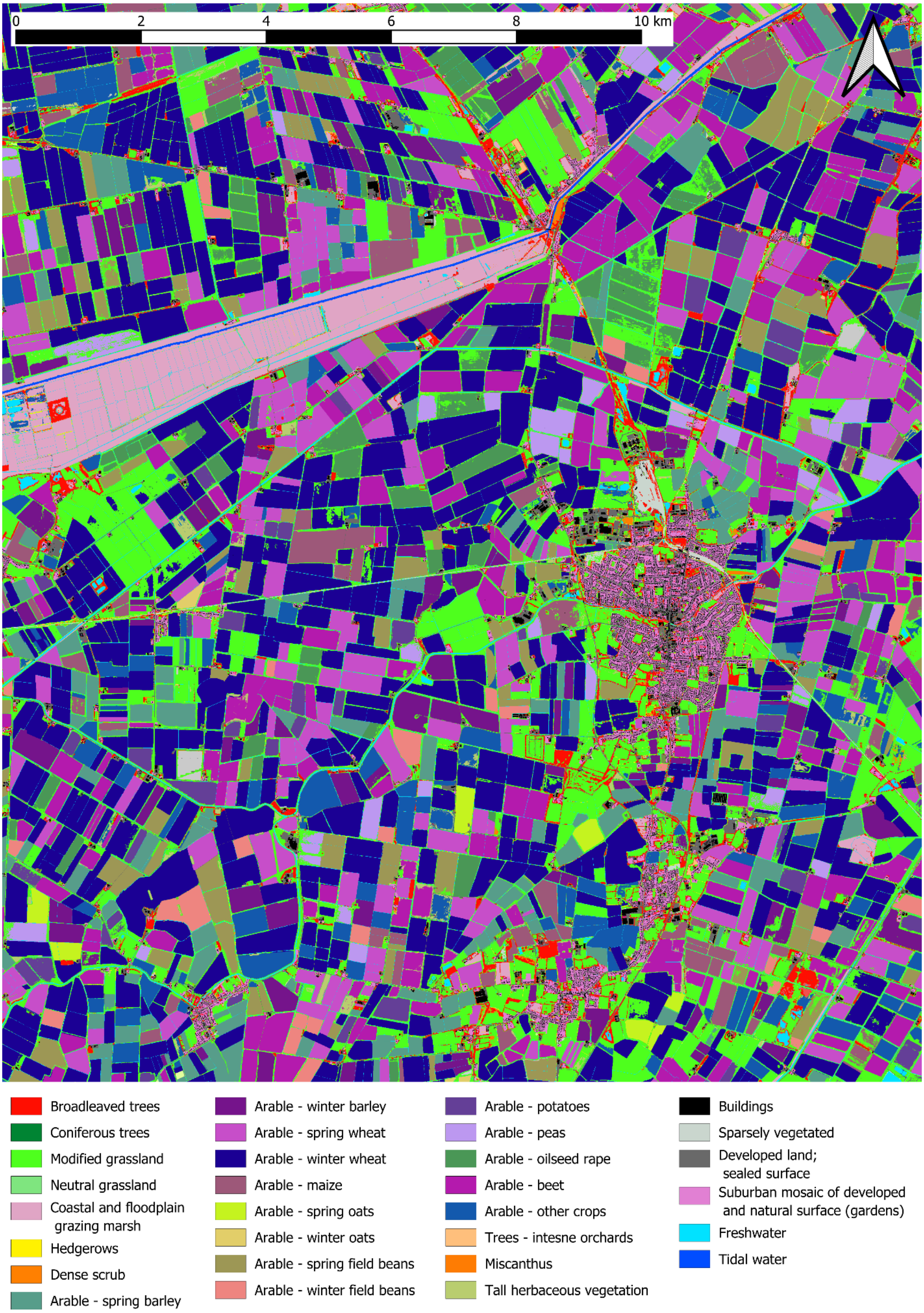

Figure 6. LCM 3m land cover map for England, displaying a predominantly arable area in the region surrounding March, Cambridgeshire.

3.2 Accuracy assessment

The LCM 3m was validated using 35,231 points distributed across England (Figure 3), with results summarised in a correspondence matrix (Table 4). Due to availability of validation data, accuracy assessment was performed for some land cover categories at the broader rather than most detailed class level. For example, accuracy assessment was performed for the overall arable land cover category rather than for the individual crop types. Likewise, accuracy assessment was performed for single overall classes of saltmarsh and freshwater, for a single broadleaved and mixed woodland class (combining broadleaved and mixed woodland, broadleaved and mixed woodland over sealed surface, broadleaved and mixed woodland over watercourses, broadleaved and mixed woodland over gardens, and intensive orchards), and for a single coniferous woodland class (grouping together coniferous woodland, coniferous woodland over sealed surface, coniferous woodland over watercourses, and coniferous woodland over gardens).

The accuracy assessment demonstrates an overall accuracy of 90.89%. The correspondence matrix (Table 4) shows the level of agreement between the classification and the reference data, as well as the areas of disagreement or confusion.

Table 4. Confusion matrix for the LCM 3m land cover classification against 35,231 reference points. BW = Broadleaved and mixed woodland, CW = Coniferous woodland, AR = Arable, MG = Modified grassland, NG = Neutral grassland, CG = Calcareous grassland, AG = Acid grassland, FMS = Fen marsh and swamp, DSH = Dwarf shrub heath, B = Bog, IR = Inland rock, TW = Tidal water, FW = Freshwater, SLR = Supralittoral rock, SLS = Supralittoral sediment, LR = Littoral rock, LS = Littoral sediment, SM = Saltmarsh, HE = Hedgerows, DS = Dense scrub, SP = Solar panel array, GA = Suburban mosaic of developed and natural surface (gardens), BU = Buildings, SS = Sealed surface, CFGM = Coastal and floodplain grazing marsh, RE = Reedbeds, THV = Tall herbaceous vegetation, SW = Stone walls, RP = Rush pasture, SV = Sparsely vegetated, BR = Bracken, MI = Miscanthus, AL = Allotments, PA = Producer's accuracy; UA = User's accuracy; OA = Overall accuracy.

	Reference																																		
Classified	**BW**	**CW**	**AR**	**MG**	**NG**	**CG**	**AG**	**FMS**	**DSH**	**B**	**IR**	**TW**	**FW**	**SLR**	**SLS**	**LR**	**LS**	**SM**	**HE**	**DS**	**SP**	**GA**	**BU**	**SS**	**CFGM**	**RE**	**THV**	**SW**	**RP**	**SV**	**BR**	**MI**	**AL**	**Total**	**UA**
BW	3533	71	54	37	8	1	1	1	2				7	1				1	54	16			17	10	1	4				7	1	18	5	3850	91.77
CW	22	1109											1																					1132	97.97
AR			8760	27	9	1							4		1			1	2		3	1					4			1		11		8825	99.26
MG	38		485	5144	267	295	255	3	17		1		2	7	7	3		19	54		36		2	3		12	5	44	9		1	40	1	6750	76.21
NG	3		1	43	391								1																					439	89.07
CG	4		4	25	6	998	26				3									2	6							1	1					1076	92.75
AG	6	1		46	11	20	517		41	39	1			2														8	7		30			729	70.92
FMS								16																		8								24	66.67
DSH						1	16		659	4					3																			683	96.49
B						2	16		9	289																								316	91.46
IR				5		7	1		1		189			2							3		1					1			1			211	89.57
TW												92	3			13	14	8								1								131	70.23
FW	4		3	2	2		1	2		1	1		527					8	4	1					3	11								570	92.46
SLR			1											479	6	25																		511	93.74
SLS															414		3	5																422	98.10
LR														9	1	883	1																	894	98.77
LS												32		3	2	17	460	37								1								552	83.33
SM								1							3			1072																1076	99.63
HE	5	1	5	8	2													1	479	2				1				7						511	93.74
DSH	26	1	6	19	2	1	5		6				2	2				5	25	198	1			2		1	3					1		306	64.71
SP				3																	938													941	99.68
GA	5		1	19											2							198	64	1										290	68.28
BU	5		3	1									4								3	1	1192	3				1		1				1214	98.19
SS	5	3	2	8	1						5							2	10		9		22	1081		4							1	1153	93.76
CFGM	1		3		1			4										1			4				96	3								113	84.96
RE								7										39								485								531	91.34
THV			69	3	9	1															1						182					5		270	67.41
SW																												88						88	100.00
RP	1	1		2			2		1						1														83					91	91.21
SV			8	2																	1		4	1						143			1	160	89.38
BR	10			4		4	15		5																						286			324	88.27
MI			7	2																												666		675	98.67
AL																																	373	373	100.00
Total	3668	1187	9412	5400	709	1331	855	34	741	333	200	124	551	505	440	941	478	1199	628	219	1005	200	1302	1102	100	530	194	150	100	152	319	741	381	35231	
PA	96.32	93.43	93.07	95.26	55.15	74.98	60.47	47.06	88.93	86.79	94.50	74.19	95.64	94.85	94.09	93.84	96.23	89.41	76.27	90.41	93.33	99.00	91.55	98.09	96.00	91.51	93.81	58.67	83.00	94.08	89.66	89.88	97.90	**OA=**	90.89

4. Known issues

The production of LCM 3m was performed in an iterative manner with classifications evaluated, areas of misclassification identified, and the production workflow adjusted to minimise these misclassifications. However, there are known issues with certain land cover classes due to their spectral similarity and temporary nature that remains challenging for satellite imagery-based land cover mapping.

Separating different grassland land-cover types using satellite imagery remains challenging due to the similarity on spectral signatures exhibited by different grassland community types. Variability in management practices such as grazing, mowing, and fertiliser application can cause the same grassland type to appear different over time, while different grassland types may appear similar during certain seasons. In addition, grasslands often occur as heterogeneous mixtures of grasses, forbs, scrub, and bare ground at spatial scales smaller than a satellite pixel, leading to mixed spectral responses. Consequently, it is challenging to reliably separate grassland types, especially modified and neutral grassland classes.

The classification of hedgerow features is predominantly driven by the LiDAR derived canopy height model (CHM) data. For the region of North Yorkshire where there is a data gap in the LiDAR coverage it is not possible to generate a CHM model, and therefore hedgerows in these areas are not mapped. Additionally, stone wall features in upland areas are generally initially classified as hedgerows by the RF classifier. Stone walls features are not classified spectrally by the RF classifier but are added as a post-classification stage. As part of this process, features classified as hedgerows but coincident with mapped stone walls in the Farmscapes 2000 data set are recategorised as stone walls, however some misclassification between these features in upland areas is likely to persist.

Construction areas where land is cleared prior to the commencement of construction activity for buildings, roads, railways and solar farms are particularly susceptible to misclassification as these are temporary features within the landscape. The complexity in mapping these areas is due to the land cover changing within the 12-month period of PlanetScope basemap acquisition, from the land cover type present prior to commencement of clearance, to cleared land, then to built-up areas including buildings and sealed surfaces. Therefore, at various points throughout the imagery acquisition period spectral signatures of multiple land cover types could be contained in the classifier input data stack for that location. Construction sites cleared of vegetation are typically classified as sparsely vegetated, however can also be classified as inland rock, or the land cover class present prior to clearance if that spectral signature predominated for the majority of the imagery acquisition period.

Non-building constructed features in the landscape that are captured in the LiDAR derived CHM data can also result in misclassification, typically with woodland classes. This can be observed on occasions for overhead power lines, for aircraft situated on airport aprons, and around and within large sports stadiums. Furthermore, polytunnels can also be misclassified as woodland, dense scrub or miscanthus classes due to their structural height similarity with some woody classes. This issue can be exacerbated when polytunnel construction occurs mid-way through the PlanetScope imagery acquisition period.

Young trees are difficult to classify reliably in satellite imagery because their small canopy size means they occupy only a fraction of each pixel. Rather than producing a clear spectral signal, they form part of a mixed pixel that also contains soil, grass, shrubs or other vegetation. This blending masks the distinctive reflectance patterns needed to separate trees from other land cover types, and makes it especially challenging to assign young trees to coniferous or broadleaved classes. For example, immature conifer plantations can often resemble broadleaved or mixed woodland in their spectral response because the young conifers do not yet dominate the pixel, increasing the likelihood of misclassification.

5. Summary

The LCM 3m provides a detailed representation of land cover patterns across England, comprising 72 land cover classes and achieving an overall accuracy of 90.89%. The increased spatial resolution, combined with integration of LiDAR-derived canopy height data and external spatial datasets, enables the detection and characterisation of landscape features that are poorly represented or absent in previous coarser-resolution national land cover products, including hedgerows, small vegetation features, and other fine-scale habitat elements.

Compared with previous 10 m land cover mapping approaches, the 3 m classification benefits from several methodological advances. These include the use of higher-resolution monthly PlanetScope Basemap imagery acquired year-round to better capture seasonal variation in vegetation phenology, and integration of LiDAR data for terrain and vegetation structure characterisation. Integration of third-party datasets such as Ordnance Survey MasterMap into the LCM 3m production workflow enable mapping of some land cover features such as buildings, roads, gardens and water bodies to a higher level of detail than would be possible using satellite imagery alone. The approach also supports stratification of a wider range of land cover classes, for example stratifying classes such as arable into individual crop types via integration with UKCEH Land Cover® plus: Crops, and draws upon an expanded set of reference datasets to improve training data quality and classification performance.

The resulting maps capture landscape heterogeneity at a much finer spatial scale than previous national-level land cover map products, improving the representation of habitat extent, patch configuration and ecological connectivity. This enhanced level of detail is particularly valuable for applications requiring accurate mapping of small or linear landscape features, such as habitat networks, green infrastructure and local-scale environmental assessment. While some sub-pixel habitat mosaics and highly obscured features remain challenging to detect using satellite imagery alone, integration with authoritative spatial datasets further improves feature representation where appropriate.

The national-scale LCM 3m dataset provides an important complement to existing land cover mapping products, with the potential to support a range of environmental and land management applications including habitat mapping, Biodiversity Net Gain monitoring, carbon accounting and biomass estimation, urban green infrastructure planning, transport corridor management, natural flood management, soil erosion assessment, and broader ecosystem service evaluations. Its combination of high spatial resolution enhanced thematic detail and integration with external datasets represents a step-change in the capacity to characterise and monitor England's landscapes.

6. Citation guidance

Any use of this data set should be accompanied by the following citation:

Marston, C.; Rowland, C.; Redhead, J.; Ridding, L.; Rowe, R.; Stevens, R.; Serra Gallego, J.; Williams, E.; Upcott, E.; Orsler, Z.; Marshall, Z.; Bolton, M.; O'Neil, A.; Tabor, M.; Pywell, R. (2026*). A high-resolution habitat map for England (LCM 3m).* NERC EDS Environmental Information Data Centre. https://doi.org/10.5285/8d275321-b5ce-4a10-b15f-ec37eaf6c971

7. Data availability and licensing

UKCEH adopts a graduated licensing approach that reflects its charitable objects to advance science, advance education and promote sustainable development for the public benefit. The approach seeks to maximise the societal value derived from UKCEH information products by supporting non-commercial research and education through a dedicated academic access route provided by EDINA's Digimap Service, while also enabling public sector, third sector and commercial organisations to apply UKCEH data in support of innovation, evidence-based policy making, environmental management and sustainable economic development.

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UKCEH applies its licensing approach to ensure broad access for research and public benefit purposes while generating revenues that can be reinvested in the maintenance, enhancement and long-term sustainability of UKCEH's environmental data assets and scientific capabilities.

8. Data display

A QGIS symbology file is supplied alongside the LCM 3m data product to facilitate visualisation of the dataset within QGIS, a widely used open-source Geographic Information System (GIS). Applying the supplied symbology provides an immediate and consistent representation of the land cover classes across England, allowing users to explore and interpret the data.

The land cover classification comprises 72 land cover categories, making it challenging to design a single symbology that clearly differentiates all classes while remaining intuitive and visually balanced across a wide range of mapping scales and geographic contexts. Consequently, the supplied QGIS symbology should be regarded as a starting point for data display rather than a definitive visualisation standard. Users are encouraged to adapt the symbology to meet their specific requirements. This may include modifying colours, grouping classes, changing class visibility, or emphasising particular land cover types relevant to their specific application. Customisation may be particularly beneficial when producing maps for specific audiences, publications, or analytical workflows.

In some cases, users may wish to adapt the symbology to improve accessibility, for example by selecting colour palettes that are more suitable for users with colour vision deficiencies. The flexibility of QGIS allows the supplied style to be readily modified to support these and other user-defined display requirements.

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Production of LCM 3m has involved use of a range of data products made available under licence from the following organisations:

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Intermap Technologies Inc. (or its suppliers): Where LiDAR data is not available cartographic data and DEM data for England from the digital elevation data of © Intermap Technologies Inc. or its suppliers (2003) has been used.

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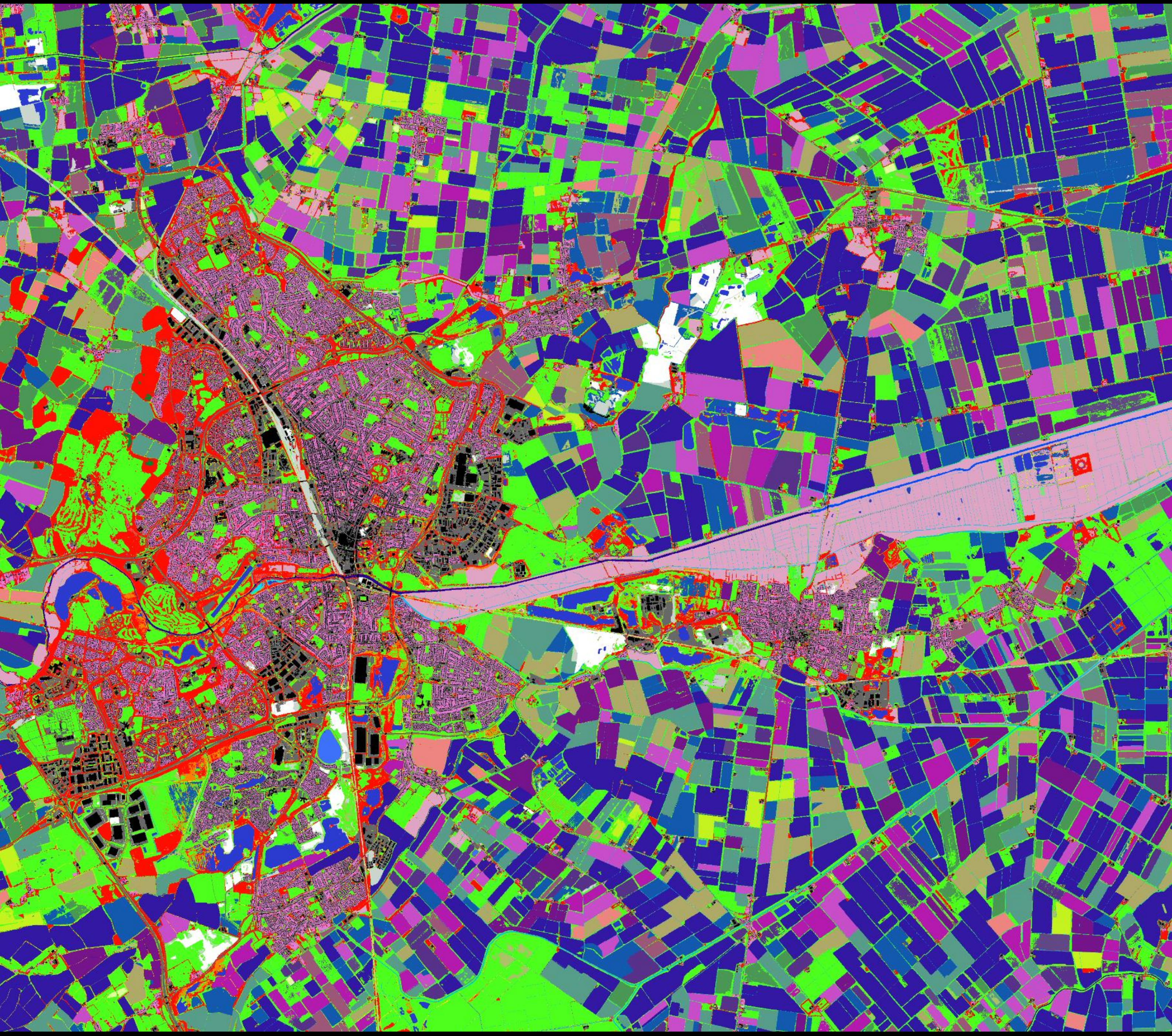

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