Worcestershire County Council

Worcestershire Habitat Inventory Refresh

Non-technical Guidance: Refreshed Habitat Inventory and Habitat Network Connectivity

REP/0002

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Acronyms and Abbreviations

API	Aerial Photo Interpretation
BAP	Biodiversity Action Plan
BDA	(Worcestershire) Biodiversity Delivery Area
BGS	British Geological Survey
CROME	Crop Map of England – Midlands
DSM	Digital Surface Model
DTM	Digital Terrain Model
EO	Earth Observation
ESA	European Space Agency
GIS	Geographic Information Systems
GRD	Ground Range Detected
IHS	Integrated Habitat System
LCP	Landscape Character Parcels
LDU	Landscape Description Units
LWS	Local Wildlife Site
NDMI	Normalised Differential Moisture Index
NDVI	Normalised Differential Vegetation Index
NDWI	Normalised Differential Wetness Index
NE	Natural England
OBIA	Object-Based Image Analysis
OSMM	Ordinance Survey MasterMap
Refreshed WHI	Refreshed Worcestershire Habitat Inventory 2021 (this study)
RGB	Red Green Blue
SAR	Synthetic Aperture Radar
UKHab	The UK Habitat Classification System
WBRC	Worcestershire Biological Records Centre
WCC	Worcestershire County Council
WHI	Worcestershire Habitat Inventory
WWT	Worcestershire Wildlife Trust

Glossary of Terms

Biodiversity Net Gain	Biodiversity Net Gain is an approach to development that leaves biodiversity in a better state than before. https://cieem.net/i-am/current-projects/biodiversity-net-gain accessed 06/2021
Confusion matrix	A confusion matrix is a table that is often used to describe the performance of a classification model (or "classifier") on a set of test data for which the true values are known. Each row of the matrix represents the instances in an actual class while each column represents the instances in a predicted class, or vice versa. The name stems from the fact that it makes it easy to see whether the system is confusing two classes (i.e. commonly mislabelling one as another).
Crick Framework	The Crick Framework is a way to categorise how well Earth Observation techniques can be used to identify habitats and features on the ground. https://jncc.gov.uk/our-work/the-crick-framework/ accessed 06/2021
Geospatial data	Geospatial data is information that describes objects, events, or other features with a location on or near the surface of the earth. Geospatial data typically combines location information (usually coordinates on the earth) and attribute information (the characteristics of the object, event or phenomena concerned) with temporal information (the time or life span at which the location and attributes exist). The location provided may be static in the short term or dynamic. Geospatial data typically involves large sets of spatial data gleaned from many diverse sources in varying formats and can include information such as census data, satellite imagery, weather data, habitat data and drawn images. https://www.ibm.com/topics/geospatial-data accessed 06/2021
Lawton Principles	Making Space for Nature, the review of nature conservation in England completed by Professor Sir John Lawton and published in 2010, advocates a landscape-scale approach to conservation, to create “a coherent and resilient ecological network”, guided by 4 key principles, summarised as “more, bigger, better and joined”.
Machine learning	Machine learning is a branch of artificial intelligence (AI) focused on building applications that learn from data and improve their accuracy over time without being programmed to do so. In data science, an algorithm is a sequence of statistical processing steps. In machine learning, algorithms are 'trained' to find patterns and features in massive amounts of data in order to make decisions and predictions based on new data. The better the algorithm, the more accurate the decisions and predictions will become as it processes more data. https://www.ibm.com/uk-en/cloud/learn/machine-learning accessed 06/2021

Multispectral imagery	A multispectral image includes information from across the electromagnetic spectrum including the light from frequencies beyond the visible spectrum, i.e. infrared and ultra-violet. Multispectral imaging measures light in a number (typically 3 to 15) of spectral bands. These bands can be displayed and visualised in different combinations and in different coloured filters e.g. red, green and blue, to provide more information.
Random Forest	Random forests or random decision forests are an ensemble learning method for classification, regression and other tasks that operates by constructing a multitude of decision trees at training time. For classification tasks, the output of the random forest is the class selected by most trees.
Remote sensing	Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance (typically from satellite or aircraft). Special cameras collect remotely sensed images, which help researchers "sense" things about the Earth. (USGS, https://www.usgs.gov/faqs/what-remote-sensing-and-what-it-used?qt-news_science_products=0#qt-news_science_products) accessed 06/2021
Segmentation and object-based image analysis	Segmentation is a computer-process whereby an image is broken into geographic areas with similar statistical properties representing land-based features. The segmentation algorithm interprets and digitises the areas and boundaries seen in imagery and creates a polygonised map of the result. Object-based image classification enables classification of those objects (e.g. into land use types) using their shape, size, spatial and spectral properties.
Sentinel-1	A European Space Agency satellite that collects radar images of the Earth's surface. https://sentinel.esa.int/web/sentinel/missions/sentinel-1 accessed 06/2021
Sentnel-2	A European Space Agency satellite that collects multi-spectral images of the Earth's surface. https://sentinel.esa.int/web/sentinel/missions/sentinel-2 accessed 06/2021
Training data	Training data is used to train a machine learning model to identify a distinct feature of interest for extraction from other features, in this case, distinct habitat classes. Ideally training data should consist of a representative sample from across the area of interest for each of the habitat classes, including urban, arable, terrestrial and freshwater classes.

Executive Summary

Worcestershire County Council (WCC) have appointed Arup to refresh their original 2010 county-wide habitat inventory using an innovative artificial intelligence and remote sensing data-based approach. The updated census of the habitats has been used to facilitate a high-level assessment of changes in habitat extent from the original baseline as well as an assessment of habitat network connectivity.

The refreshed county-wide baseline habitat inventory and habitat network connectivity assessment will form an evidence base for the Worcestershire Biodiversity Action Plan (BAP), aiding decision making, increasing biodiversity awareness and integration into environmental and ecological policy and good practice.

This report provides a non-technical summary of the project approaches, results and user guidance for those wishing to use the Refreshed Worcestershire Habitat Inventory (Refreshed WHI) and habitat network connectivity outputs.

A main result of the Refreshed WHI is that the areas of the priority habitats have generally increased by comparison to the original 2010 WHI. This is because the model has been able to classify habitats that the previous API-approach was not able to distinguish. Furthermore, the Refreshed WHI provides the user with a quantitative understanding of the accuracy and confidence when using the data at landscape and site scale.

The Refreshed Inventory contains full coverage of the county's urban areas, it also now contains ancient woodlands, wood-pasture and parkland, rivers and streams, canals, linear features such as hedgerows, lines of trees and transport corridors and new wet grassland habitat mapping.

The updated geometry of the Refreshed Inventory has enabled subdivision of former large polygon areas into individual habitats parcels and reduced the need for multiple matrix habitat attributions.

A main outcome of the connectivity analysis is that for each priority habitat the areas of conservation have been identified, along with areas of associated habitats and areas of potential habitat restoration, creation, enhancement and expansion. The habitat network connectivity outputs help to identify priority areas for habitat restoration across the county of Worcestershire.

Part I – The Refreshed Worcestershire Habitat Inventory

1 Introduction

The first part of the project was to develop the Refreshed Worcestershire Habitat Inventory (Refreshed WHI). This has been created through use of a range of remote sensing-based data, such as aerial photography and multispectral satellite imagery, in addition to information about the geology, soils and landscape character and the application of a machine-learning plus rule-based refinement approach.

The priority and semi-natural habitats of Worcestershire include woodland (including all broadleaved woodland, Biodiversity Action Plan woodland, wet woodland, ancient woodland and replanted ancient woodland), traditional orchards, all semi-natural grassland, possibly semi-improved/unimproved grassland, BAP grasslands including: calcareous grassland, neutral grassland and acid grasslands, heathland, wetlands (including fen marsh swamp and reedbeds), ponds, canals and standing water.

Before using the Refreshed WHI data, it is recommended that users refer to the guidance in Section 2 that follows and that they cross reference the information in this section with other signposted sections of this report as needed.

Section 3 presents the Refreshed WHI in terms of a county-scale, qualitative comparison of the original 2010 and the refreshed habitat inventories, describing the extent and distribution of the priority habitats. Section 4 describes the approach used to update the Original WHI. Section 4 provides information about the original 2010 WHI and the approach used to generate the Refreshed WHI, respectively. Appendix A additionally provides a series of larger-scale maps showing the Refreshed WHI along with the Worcestershire Biodiversity Delivery Areas (BDAs).

2 User Guidance: Refreshed WHI Data

The points below describe some key guidance considerations for various stakeholders (council members, ecological officers, wildlife trusts, planners, consultants) who plan to use the Refreshed WHI to help inform decision making, policy and planning.

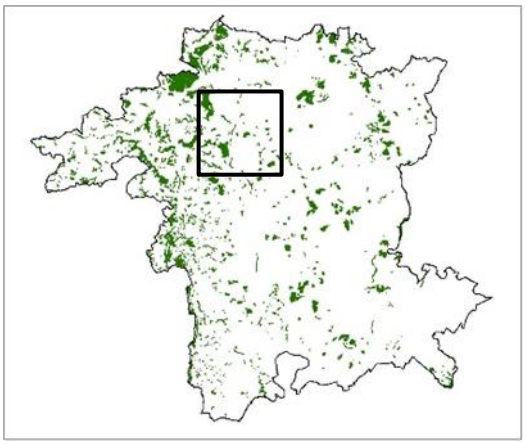
- **Modelling** – The Refreshed WHI has been developed through the application of predictive modelling (machine learning), which has been informed by a range of remote sensing data and from limited recent and historical ground survey data. The Refreshed WHI identifies the likelihood of a habitat class occurring at a location and does not provide an absolute identification. A benefit to the modelling approach is that its ability to distinguish different habitat classes is associated with an overall accuracy, which in this case is 0.62, this number summarises the proportion of samples that have been

correctly classified across the 56 classes modelled. As with the original 2010 WHI, which was largely based on identification of habitats through manual Aerial Photo Interpretation (API), the habitats identified in the Refreshed Inventory should be used as an indicator or guide as to what habitats likely exist on the ground rather than providing an absolute classification. The inventory will need to be validated with ground survey data as this becomes available.

- **Consideration alongside other available local data and knowledge** – Given the point above, it is important therefore that the Refreshed WHI is considered alongside other available data and expertise, local knowledge, and ground truth survey information. Particularly when assessing areas at site scale.
- **Priority habitat areas have generally increased** – The Refreshed Inventory has leveraged additional information from a wide variety of remote sensing and other data to distinguish different habitats from one another more effectively and quantitatively than the previous inventory. The priority habitat areas have generally increased because the model has been able to classify habitat that the previous approach, largely based on API, was not able to distinguish. This is an advantage and benefit. It does not mean that there is necessarily more habitat than there was in 2010.
- **Accuracy and Confidence** – The Refreshed Inventory provides an accuracy and confidence score for each habitat class. These scores are described further in Section 3.4. Additionally, the confusion matrix (presented in Appendix A2) shows which habitats were correctly predicted and which habitats were more difficult to uniquely distinguish causing confusion in the model's prediction. This matrix can be consulted to understand which habitat classes are potentially misclassified, i.e. to a similar habitat, and if so, which habitat that is likely to be. Furthermore, the 'habitat_source' attribution provides further information to support assessing confidence and accuracy of the assigned habitat. The flow charts below present the steps to follow for any user to evaluate the accuracy of the Refreshed WHI at landscape and site scale.
    - A caveat to the accuracy assessment used to describe the confidence of the outputs from the machine learning plus the rules is that it is only as reliable as the data behind them. It should be noted that over 73% of the training used was from the original WHI and has not been validated on the ground.
- **Legacy data** – All information from the original 2010 WHI has been retained in the Refreshed Inventory. Therefore, there should be little need to cross reference to the 2010 inventory separately or in addition to the Refreshed Inventory.
- **Refreshed WHI Attribution** – The Refreshed WHI contains all of the original 2010 inventory attribution along with the following new attribution:
    - **'habitat_cd2'** – the refreshed habitat Integrated Habitat System (IHS[1]) code.

[1] http://www.somerc.com/products-services/integrated-habitat-system-ihs/

- **'confidence'** – the confidence in habitat class from the model prediction (0 to 1), this number has been derived from the machine learning modelling approach.
- **'habitat_source'** – describes how the habitat classification was derived and can have the following values:
  - 'Confirmed' – the model first or second prediction (most likely habitat class) matches the original 2010 inventory habitat class.
  - 'Predicted' – where the model's first prediction has high accuracy or where there is no original WHI class.
  - 'Original WHI' – Where the model prediction is of low accuracy (likely that the habitat is not possible to classified based on a remote sensing approach) and therefore the original 2010 classification is retained.
  - 'Input data' – Where the class has been attributed on the basis of one of the input datasets (e.g. hedgerows or OS MasterMap).
  - 'Training data' – where the class has been attributed on the basis of new training data.
- **'matrix1_cd2, matrix2_cd2, matrix3_cd2'** – are the updated matrix habitat codes. The new matrix codes retain the original WHI attribution where it exists, otherwise they summarise matrix habitats (scattered trees, scrub, bare ground, tall herb and fern, bracken, reedbeds) predicted by the modelling.
- **'Label2'** – provides the Integrated Habitat System (IHS) code description corresponding with 'habitat_cd2'.
- **'UKhab'** – the UKhab equivalent code to the IHS code. This uses the correspondences from the UK Habitat Classification V1.0 correspondences spreadsheet (https://ukhab.org/).



1. Landscape scale e.g. Biodiversity Delivery Area (BDA)

Understanding the Refreshed WHI accuracy relating to the distribution of particular habitats across landscape area(s).

Review overall classification accuracy for the habitat (Table 1).

Review confusion matrix (Appendix A2) to see where similar habitats may have been misclassified, e.g. to a similar

Review the Crick Framework to understand the extent to which earth observation can distinguish the habitat and the datasets required.

Figure 1: Flow presenting the steps for any user to evaluate the accuracy of the Refreshed WHI at landscape scale. The box shown on the county map indicates the scale of interest.

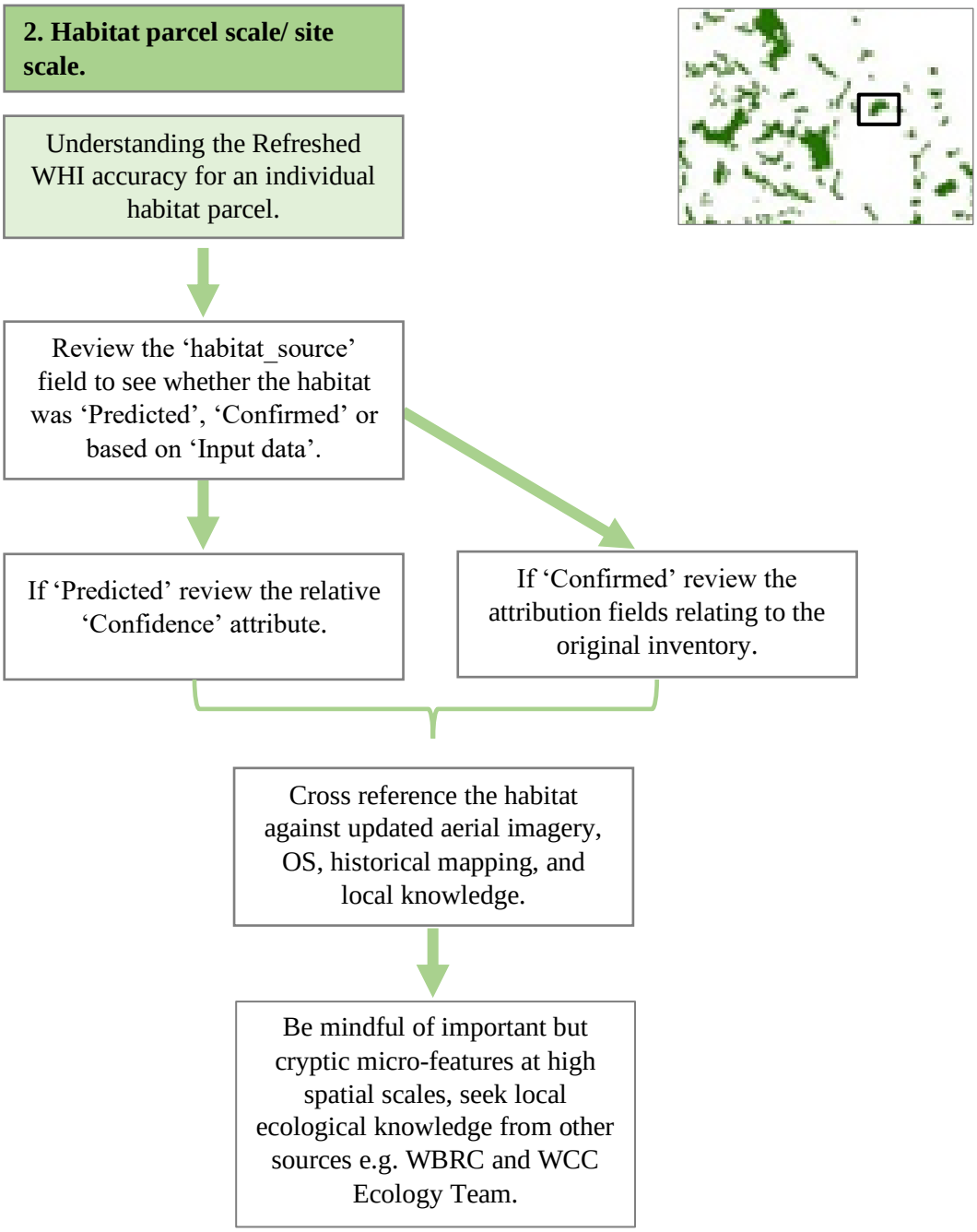


Figure 2: Flow chart presenting the steps for any user to evaluate the accuracy of the Refreshed WHI at site scale. The box shown on the map, which presents a sub-area of Worcestershire county, indicates the scale of interest.

- **Spatial scale** – The underlying data used to inform the modelling is of high resolution (generally 1m to 10m) and the segmentation geometry (inventory polygons) have a high spatial resolution and detail. Additionally, the Refreshed information has resulted in no loss of detail or aggregation of more detailed existing habitat information derived from site surveys. However, the Refreshed Inventory has been developed for county and landscape scale usage and in line with the Crick Framework[2], it is appropriate for identifying and monitoring the distinctiveness and change of broad and a subset of priority habitats listed under Annex I of the Habitats and Species Directive and the Section 41 of the Natural Environment and Rural Communities Act 2006.

3 Results – The Refreshed WHI

3.1 Overview

This section presents the Refreshed WHI derived from machine learning modelling and rule refinement. The Refreshed WHI contains all the attribution of the original inventory and new attribution to describe the updated assessment. An example of the updated attribution is shown in Figure 3 and has been described in Section 2 above. The Refreshed WHI provides the following:

- **Coverage** – the areas of the priority habitats have generally increased in the Refreshed Inventory relative to the 2010 WHI. This is because the model has been able to classify habitat that the previous API-approach was not able to distinguish, it does not mean that there is necessarily more priority habitat than there was in 2010. All urban areas are now included in the inventory (Figure 4).
- **Completeness** – all polygons within the county boundary have a habitat classification. This is in contrast to the original inventory in which the habitat class NA (null) was one of the top 5 habitat classes by areal coverage.
- **Confidence and accuracy** – each habitat classification has an associated confidence and accuracy score, aiding end users to consider the data in decision making in an informed way.
- **More detailed geometry** – the updated geometry of the inventory is a unique hybrid of MasterMap polygons and a segmentation output generated as part of this project (described in more detail in Section 4.2). This geometry has enabled subdivision of original larger habitat areas based on MasterMap polygons alone reducing the need for many matrix habitats in large areas. For example, individual fields that consisted of two of three different habitat classes due to the influence of factors such as slope, drainage and management have been subdivided.
- **Additional habitats** have been identified and included:

[2] JNCC. (2013). The Crick Framework. Retrieved from https://jncc.gov.uk/our-work/the-crick-framework/

  - Linear features, in particular hedgerows and lines of trees.
  - Rivers, streams and watercourses.
  - Urban habitat.

- **Additional data** (training and other data) shared as part of the project has been directly incorporated into the Refreshed WHI. These habitats include ancient semi-natural and replanted woodland, wood-pasture and parkland, orchards.

	id	mastermap_	habitat_cd	matrix1_cd	matrix2_cd	matrix3_cd	formation_	management	complex_cd	summary	process	modified_d	modified_u	keywords	comment	Label	Parish	habitat_cd2	confidence	matrix1_cd2	matrix2_cd2	matrix3_cd2	habitat_source	Label2	UKHab
1	639784	100000207...	WP1					WM5		WP1.W...	F	2018-05-10T00:00:...	JHiggs	Wood p...	Manage...	Woo...	Kem...	WP1	0.62				Training data	Wood pasture a...	g^ or w^ ...
2	639785	100000207...	WP1					WM5		WP1.W...	F	2018-05-10T00:00:...	JHiggs	Wood p...	Manage...	Woo...	Kem...	WP1	0.6				Training data	Wood pasture a...	g^ or w^ ...
3	639786	100000207...	WP1					WM5		WP1.W...	F	2018-05-10T00:00:...	JHiggs	Wood p...	Manage...	Woo...	Kem...	WP1	0.53				Training data	Wood pasture a...	g^ or w^ ...

Figure 3: Example area of Worcestershire county in aerial infrared photography, the same area showing the Refreshed WHI coloured by broad habitat class and an example of the data attribution table.

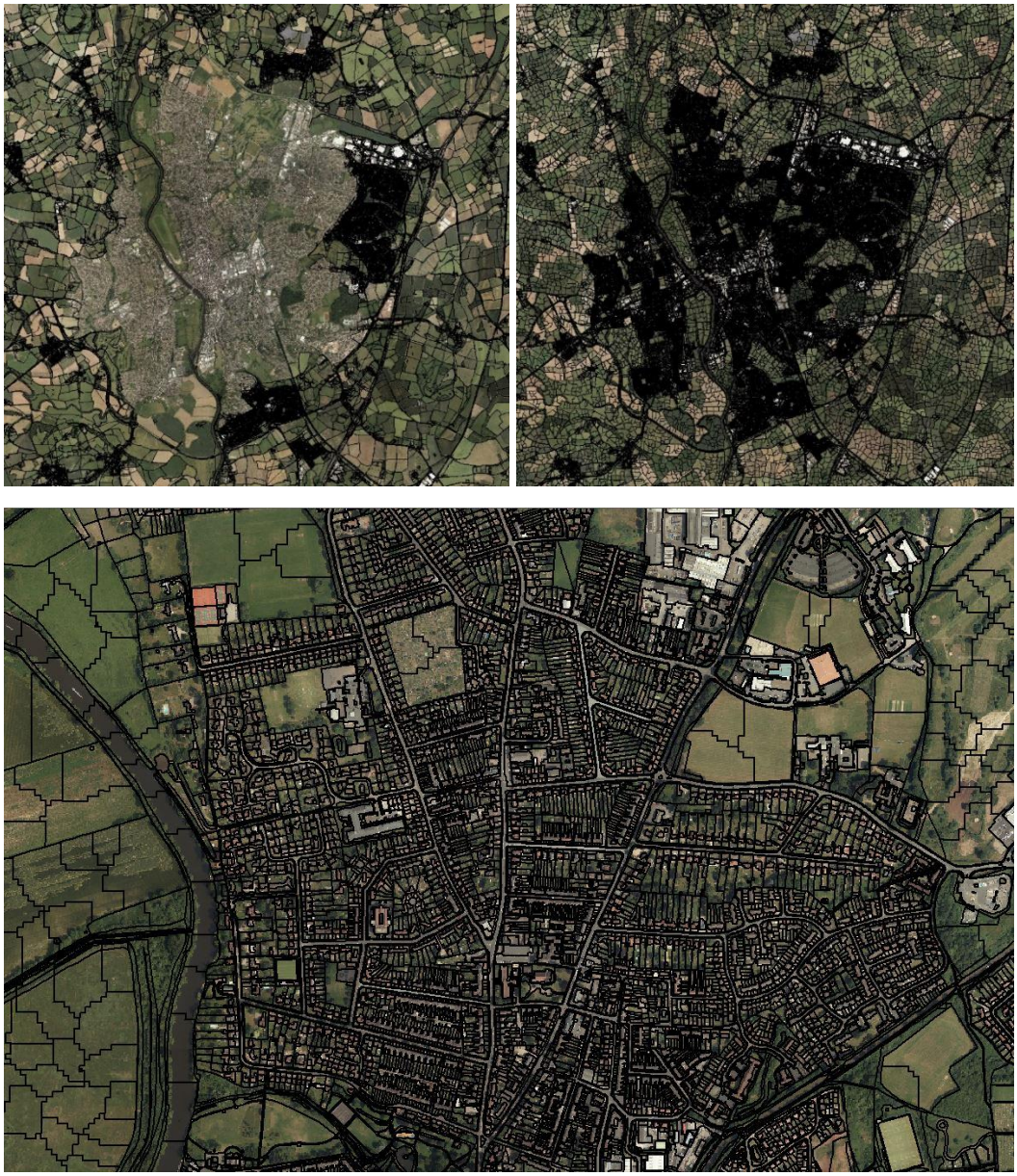


Figure 4: Example of the completed urban areas in the Refreshed WHI polygons (top right and zoom bottom image) versus the original inventory (top left image).

3.2 Comparison – Original and Refreshed WHI

This section provides a comparison of the extent and distribution of priority habitats in the Refreshed WHI 2021 with the original 2010 inventory.

For each habitat, two to three maps have been presented, from left to right these include the habitat extent presented in the 2010 inventory and one or two maps of the habitat extent from the Refreshed WHI. In addition to the map comparisons, some original description and context has been provided for each habitat, taken from the original 2010 inventory reporting.

It is important to note that because the original inventory was derived using a different mapping approach, these comparisons are not like for like, however, they are indicative and useful as a quick visual guide of change.

3.2.1 All Grassland coverage in Worcestershire

The original Worcestershire Habitat Inventory Report (WHI, 2010[3]) describes that grassland is one of the most extensive habitats in Worcestershire, covering nearly 50% (approximately 47%) of the county.

The report described that about 37% of the grassland in Worcestershire had no survey data other than that derived by Aerial Photograph Interpretation, with approximately 7% of the grassland in county was classified as improved, 23% as probably improved and roughly 14% possibly unimproved grassland. Biodiversity Action Plan (BAP) grassland habitats in Worcestershire were reported to include neutral meadows and pastures, acid grasslands, and calcareous grasslands. Review of the original inventory data indicates that these habitats covered about 1.4% of the county based on the 2010 baseline but may also be present in the areas classified as possibly unimproved grassland.

Figure 5 presents a high-level comparison of all grassland habitat in Worcestershire county from the original inventory (left) and the refreshed inventory (right). At county scale, it is possible to see that the extent and distribution of all grassland habitat is approximately equivalent today as in 2010. All grassland habitats of the refreshed inventory cover a slightly smaller total area, 44.22% of the county versus the 47% originally reported. By contrast the BAP grassland coverage (BAP acid, calcareous and neutral grassland habitats) of the refreshed inventory has increased to **2.45%** versus **1.4%** originally reported

[3] Worcestershire Habitat Inventory Report, Worcestershire County Council. (10/17/2010). By Rosemary Parker.

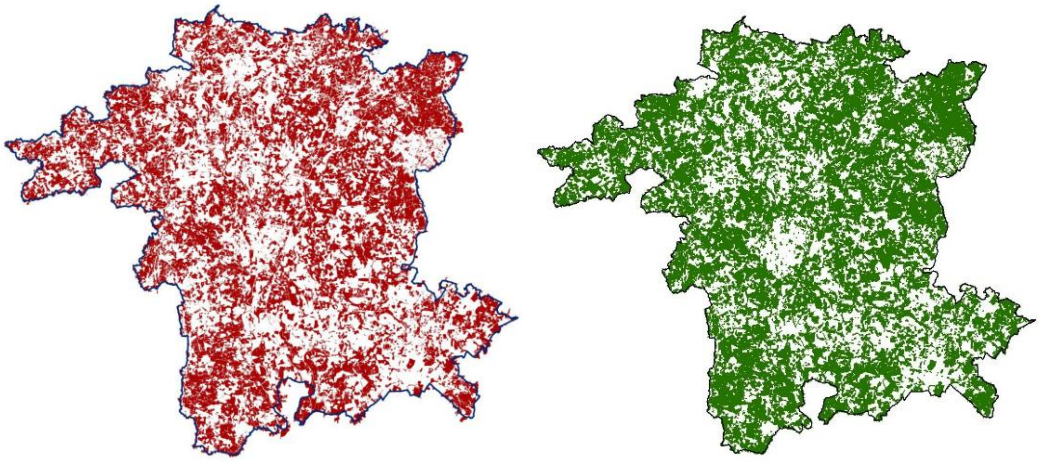


Figure 5: Original inventory all grassland coverage in Worcestershire (left); refreshed inventory coverage in Worcestershire (right).

3.2.2 BAP Grasslands

BAP Grassland habitats in Worcestershire include neutral meadows and pastures, acid grasslands, and calcareous grasslands. The extent of these habitats in the original and refreshed inventories is discussed below.

- **BAP Acid Grassland**

The original inventory describes that BAP acid grassland in Worcestershire is largely lowland acid grassland. The original WHI described that much of this habitat was mapped as the IHS broad acid grassland habitat type (GA0) as opposed to identifying strictly only (GA1). Acid grassland can be found on acidic, often sandy soils, which in Worcestershire are largely concentrated in the north of the county and on the Malvern Hills and Commons. The original inventory describes that on the Malverns, acid grassland can be found as part of a mosaic with heath habitats, as well as a habitat in its own right and often on the Malvern commons acid grassland communities can be found as a mosaic with other grassland or wetland community types. The 2010 inventory noted that recorded acid grassland covered just under **0.5%** of Worcestershire.

Figure 6 presents a high-level comparison of BAP acid grassland habitat in Worcestershire county from the original inventory (left) and the refreshed inventory (middle and right). The refreshed inventory estimates that GA0 and GA1 cover. The distribution of this habitat is approximately the same as mapped in 2010. The extent of the habitat (GA0 and GA1) is slightly greater and is estimated to cover approximately **0.56%** of the county relative to less than 0.5% as was identified originally.

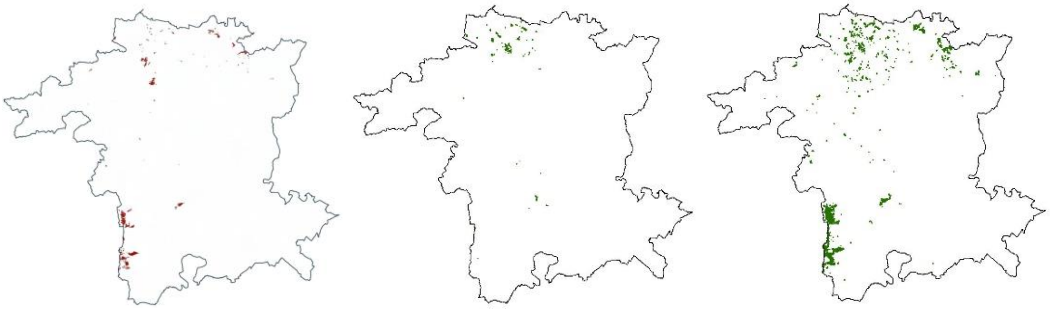


Figure 6: Original inventory all BAP acid grassland coverage in Worcestershire (left); refreshed inventory coverage in Worcestershire: GA1 only (middle); GA0 and GA1 (right).

The additional and extended coverage in the refreshed inventory is possibly related to the ability of the model predications to more quantitatively identify acid grasslands based on the combined soils, geology, time-series multispectral satellite imagery and training data than through API alone. Importantly, is has also been possible to explicitly present the GA1 coverage versus the GA0 and GA1 coverage and assess the accuracy and confidence of these habitats as presented in the refreshed inventory.

- **BAP Calcareous Grassland**

Lowland calcareous grassland can be found on areas of calcareous rock and on calcareous clays. They are usually enclosed grasslands that are managed as pasture, on shallow lime-rich soils in the lowlands, or are found on escarpments or dry valley slopes; they often support a very rich flora (WHI, 2010). The original inventory describes that calcareous grasslands are primarily found near Kington, in the Teme Valley and in the areas close to Bredon and Broadway where Worcestershire joins the Cotswolds and that small, discrete bands of calcareous geology may be found elsewhere in the county. The original inventory describes that BAP calcareous grassland makes up **0.18%** of the county, and its creation is restricted by geology and soil type.

Figure 7 presents a high-level comparison of BAP calcareous grassland habitat in Worcestershire county from the original inventory (left) and the refreshed inventory (middle and right). The distribution of this habitat is similar to that mapped in the 2010 inventory, with the exception that additional areas of calcareous grassland have been identified in the northwest and southeast of the county. As with the BAP acid grassland habitat, it has been possible to present the GC1 habitat separately with associated accuracy and confidence in addition to the GC0 and GC1 habitats combined (which is more equivalent to the original inventory mapping). The extent of GC0 and GC1 is slightly greater in the refreshed inventory and is estimated to cover approximately **0.23%** of the county.

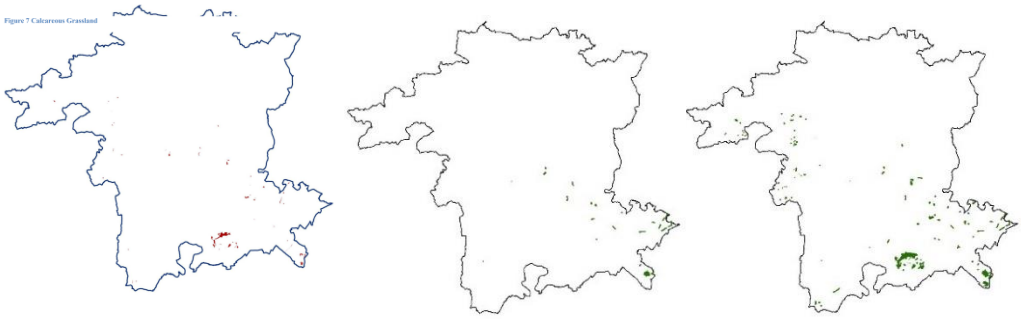


Figure 7: Original inventory all BAP calcareous grassland coverage in Worcestershire (left); refreshed inventory coverage in Worcestershire, GC1 only (middle); refreshed inventory coverage in Worcestershire, GC0 and GC1 (right).

- **BAP Neutral Grassland**

The original inventory described that neutral grassland including semi-improved or unimproved neutral meadows and pasture comprises **1.65%** of the county. It also described that extensive coverage of neutral grassland can be found throughout Worcestershire, though the Forest of Feckenham (Wychavon district) and Malvern Chase are particularly rich areas.

Figure 8 presents a high-level comparison of BAP neutral grassland in Worcestershire county from the original inventory (left) and the refreshed inventory (right). The distribution of the habitats is similar however the extent of identified BAP neutral grassland in the refreshed inventory is slightly greater covering approximately **1.66%** of the county.

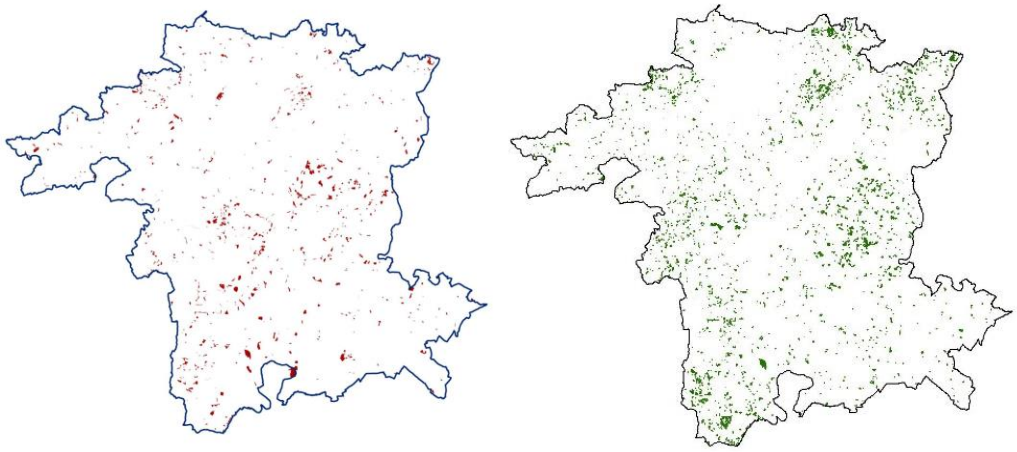


Figure 8: Original inventory BAP neutral grassland coverage in Worcestershire (left); refreshed inventory coverage in Worcestershire (right).

- BAP and semi-natural neutral grassland

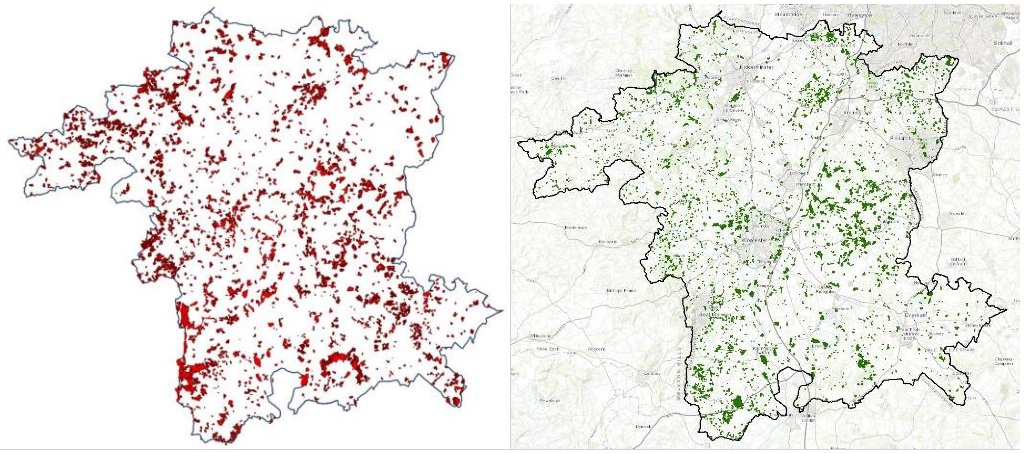


Figure 9: Original inventory BAP and semi-natural neutral grassland coverage in Worcestershire (left); refreshed inventory coverage in Worcestershire (right).

- **BAP, semi-natural and possibly unimproved neutral grassland**

The original Worcestershire habitat inventory describes that neutral grassland which is not classified as BAP habitat and possibly unimproved grasslands are important resources as both habitats provide not only restoration and enhancement potential, but also valuable habitat network elements for species that are dependent on grasslands for all or part of their lifecycle.

The original inventory further described that possibly unimproved grassland is a vast, relatively unrecorded resource covering **14%** of the county. It reported that these are grasslands which have either had no known survey, or, have formerly been subject to survey, and have since been recorded as destroyed in the grassland inventory by damaging operations rather than by management practices, though they appear to have retained interest from API.

Figure 9 presents a high-level comparison of BAP, semi-natural and possibly unimproved neutral grassland habitat in Worcestershire county from the original inventory (left) and the refreshed inventory (right). The distribution and extent of this habitat is similar to that mapped in the 2010 inventory. The refreshed inventory estimates that this habitat covers approximately **15%** of the county.

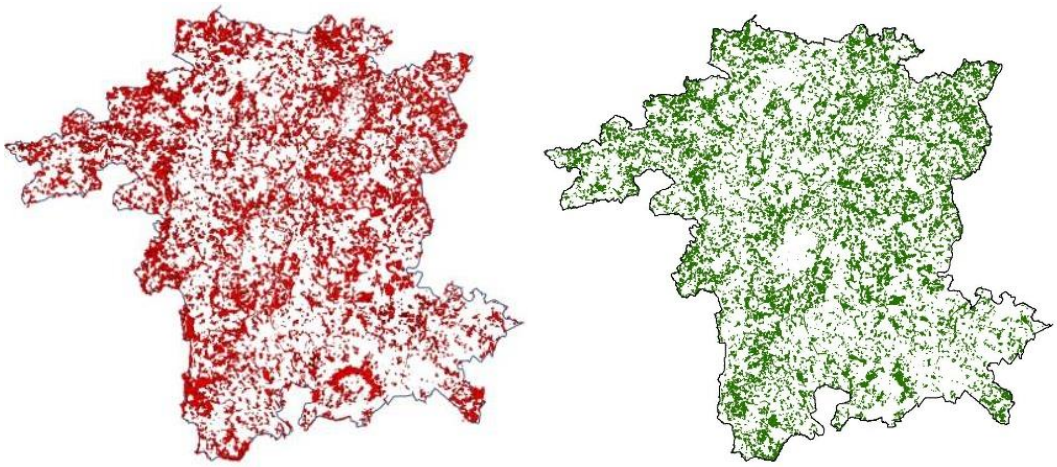
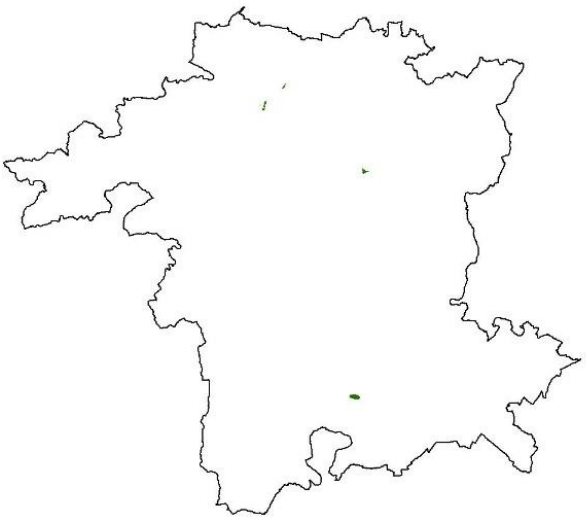


Figure 10: Original inventory BAP, semi-natural neutral and possibly unimproved grassland coverage in Worcestershire (left); refreshed inventory coverage in Worcestershire (right).

- **Floodplain grazing marsh**

The original Worcestershire inventory describes that grazing marsh is pasture, or meadow found in the floodplain which is periodically flooded. Ditches which maintain the water levels may contain standing brackish or fresh water may be a feature of these grasslands. Sites may contain seasonal water-filled hollows and permanent ponds with emergent swamp communities. This habitat complex is unusual in that it can only be derived by analysis of the overlap of suitable grazed habitats with areas likely to be inundated (UK Biodiversity Group, 1998a – see original WHI 2010 reporting). Grazing marsh is, as outlined by the definition above, difficult to identify. In the original inventory, no grazing marsh habitat map was presented. Figure 11 below presents the specific areas of grazing marsh pasture (GN4) identified in the refreshed inventory, which covers **0.11%** of the county.



N/A

Figure 11: Original inventory floodplain grazing marsh coverage in Worcestershire NA (left); refreshed inventory coverage in Worcestershire (right).

3.2.3 Standard and Traditional Orchards

The original inventory describes that Worcestershire was once famous for its orchards which covered much of the county but that their extent is now much reduced. Though it can be found throughout much of Worcestershire, orchard coverage is denser in some parts of the county. Primarily, these areas are in Wychavon district around the Lenches, the Forest of Feckenham area; the north-west of the county along the Teme Valley; in the Tenbury area and in the smallholdings surrounding the Wyre Forest. In the original inventory, orchards were mapped as either: Orchard (these are standard orchards with no other information), Traditional Orchard, Traditional Pear, Traditional Apple, Traditional Cherry, Traditional Plum or Traditional Mixed. Orchard habitat networks were created using a distance buffer around existing sites.

Figure 12 presents a high-level comparison of standard and traditional orchards in Worcestershire county from the original inventory (left) and the refreshed inventory (right). The distribution of this habitat is generally equivalent to that of the original inventory however the extent is greater. The refreshed inventory estimates that this habitat covers approximately just over **0.23%** of the county.

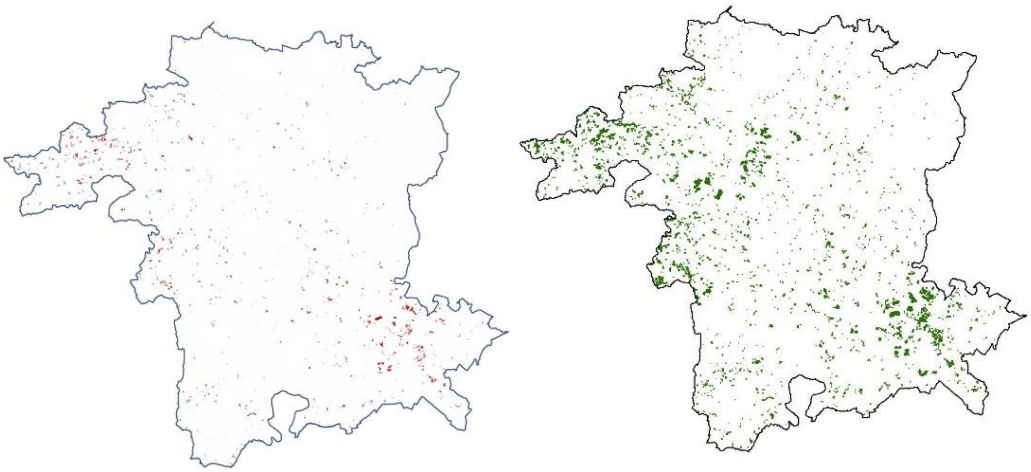


Figure 12: Original inventory standard and traditional orchards coverage in Worcestershire (left); refreshed inventory coverage in Worcestershire (right).

3.2.4 Woodland

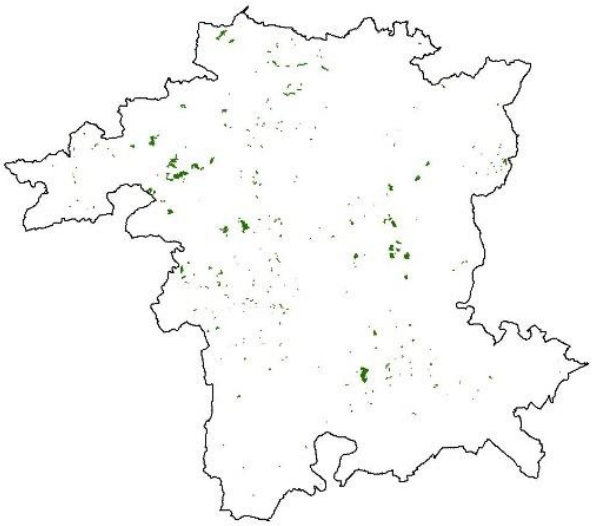
The original inventory reports that woodland in Worcestershire comprises planted coniferous woodland, mixed woodland, and deciduous woodland including wet woodland, scrub woodland, ancient woodland and other BAP woodland types. According to the original inventory, woodland is scattered throughout the county but it is much sparser, with smaller wooded areas, in the south of the county in the Vale of Evesham and Throckmorton, on the top of the Malvern Hills, and around

Longdon Marsh. Particularly important areas for woodland are Wyre Forest, Forest of Feckenham and the Teme Valley.

3.2.5 BAP Woodland

BAP woodland is was challenging to map from API, had limited survey data and as a result is underreported in Worcestershire (WHI, 2010). The original inventory reports that all woodland is covered in the Worcestershire is BAP woodland.

Recorded BAP woodland (excluding Ancient Woodland) covers only approximately **0.3%** of the county. There was no map of all BAP woodland presented in the original inventory report. The refreshed inventory estimates that approximately **0.38%** of the county is covered by all BAP woodland. The distribution of all BAP woodland is presented in Figure 13 below.



NA

Figure 13: Original inventory all BAP woodland coverage in Worcestershire (left); refreshed inventory coverage in Worcestershire (right).

- **Ancient woodland**

Ancient woodlands are those recorded as existing before 1600 and are often extremely biodiverse, especially floristically. This is a valuable and relatively extensive resource within the county (WHI, 2010). The original inventory indicates that ancient woodland is scattered throughout the county, though is described as practically absent in a few distinct areas, such as a large part of the Vale of Evesham, the Southern part of Malvern Chase and Longdon Marsh. By contrast, it is described that there are particular concentrations of ancient woodland in the North West of the county, along the Teme valley, the Northern part of Malvern Chase and the area around Kyre, Wyre Forest and around the Forest of Feckenham Area.

Figure 14 presents a high-level comparison of ancient woodland in Worcestershire county from the original inventory (left) and the refreshed inventory (right). In the refreshed inventory, ancient woodland is denoted by the UKHab secondary code '33'. The refreshed inventory indicates that ancient woodland covers approximately **5.13%** of the county.

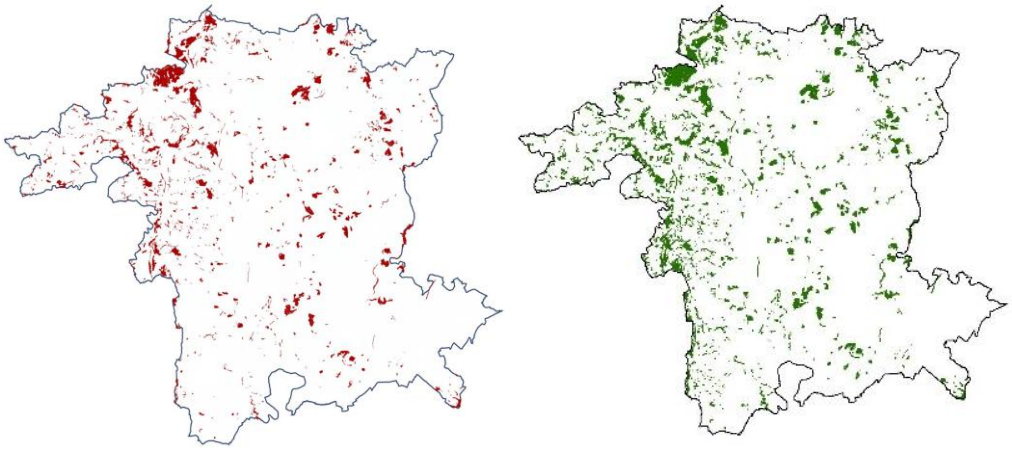


Figure 14: Original inventory all recorded Ancient Woodland coverage in Worcestershire (left); refreshed inventory coverage in Worcestershire (right).

- **Broadleaved Woodland excluding recorded BAP or Ancient Woodland**

Other broadleaved woodland which is not BAP or ancient woodland is still important habitat. The original inventory described that much of the other broadleaved woodland is unrecorded, and is potentially of national BAP quality, or unrecorded ancient woodland. Much woodland recorded in the WHI was interpreted from API, and while it is possible to determine coniferous or mixed woodland from deciduous, it is not possible to classify woodland in detail because species mix, management, and ground flora cannot be determined – for this woodland must be visited and surveyed on the ground (WHI, 2010).

Because much woodland was identified from aerial photographs where no survey information was available, it was only recorded down to the broad habitat type of either Woodland: Broadleaved, mixed and yew (WB0), Mixed (WB1), Scrub Woodland (WB2), or as Broadleaved Woodland (WB3).

Figure 15 presents a high-level comparison of Broadleaved Woodland excluding recorded BAP or Ancient Woodland in Worcestershire county from the original inventory (left) and the refreshed inventory (right). The distribution of this habitat is generally equivalent to that of the original inventory however the extent is greater. The refreshed inventory estimates that this habitat covers approximately just under **8%** of the county.

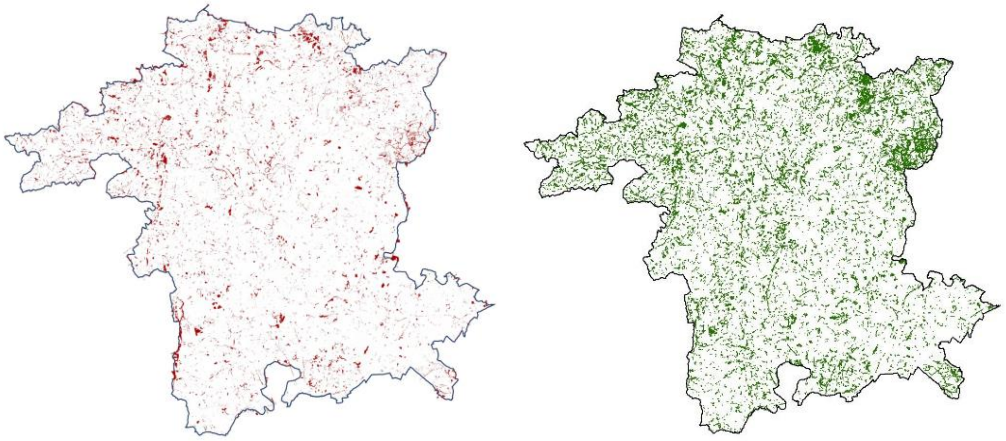


Figure 15: Original inventory Broadleaved Woodland not recorded BAP or Ancient Woodland coverage in Worcestershire (left); refreshed inventory coverage in Worcestershire (right).

- **Coniferous woodland**

The original inventory describes that coniferous woodland covers approximately **0.5%** of the county. It is found predominantly in plantations to the North and Northwest of the county.

Figure 16 presents a high-level comparison of coniferous woodland in Worcestershire county in the original inventory (left) and the refreshed inventory (right). The distribution of this habitat is generally equivalent to that of the original inventory however the extent is slightly greater. The refreshed inventory estimates that this habitat covers approximately **0.8%** of the county.

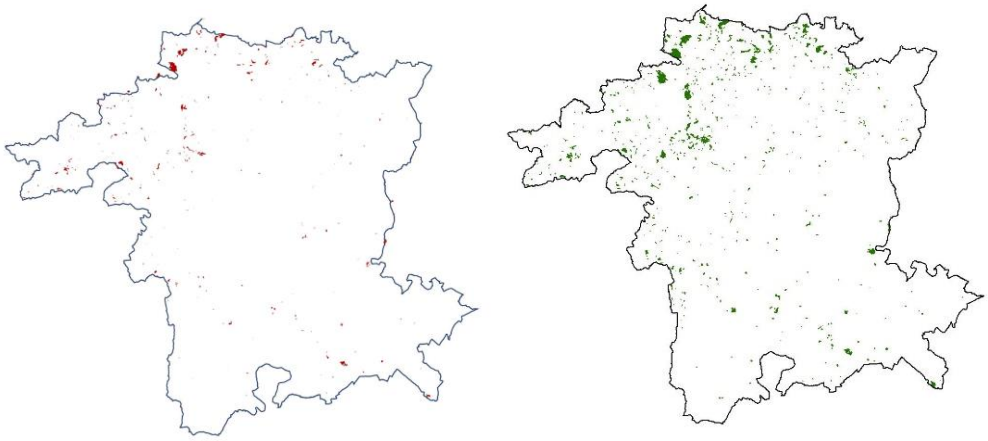


Figure 16: Original inventory coniferous woodland coverage in Worcestershire (left); refreshed inventory coverage in Worcestershire (right).

3.2.6 Wetland

The original inventory describes that wetland is an important habitat in Worcestershire, but that there are now very few sizeable areas of wetland remaining in Worcestershire. Wetland in Worcestershire comprises fen, springs and flushes, marginal swamp vegetation, reedbed, and wet grassland including floodplain grazing marsh. Fens, reedbed and some wet grasslands are BAP habitats.

Available data on the location of wetlands and wetland features in Worcestershire is poor; additionally, much of the existing survey data for wetlands is largely over 10 years old and cannot practically be relied upon for accuracy (WHI, 2010).

According to the original inventory, much remaining wetland and wet woodland comprises widespread small/micro features within drier habitats; as such they are easily overlooked and under-recorded, especially from API. Additionally it was reported that wetlands have suffered considerably from drainage, conversion to arable and agricultural improvement in recent years, and as much of the existing Worcestershire survey data for wetlands is largely over 20 years old, it cannot realistically be relied upon for accuracy. New wetland survey data was supplied as part of the project to help inform the modelling of these habitats.

The original inventory described that known wetland occurs over **0.1%** of the county, though this did not consider grazing marsh, wet woodland, or previously unrecorded wetland which may not be visible from API.

Figure 17 presents a high-level comparison of wetlands in Worcestershire county in the original inventory (left) and the refreshed inventory (right). It is clear that the refreshed inventory has mapped a greater extent and distribution of wetland habitats across the county. This is in part because the inventory has included new training data and also because of increased capability of predictive modelling to identify these habitats. The refreshed inventory estimates that this habitat covers approximately **0.31%** of the county.

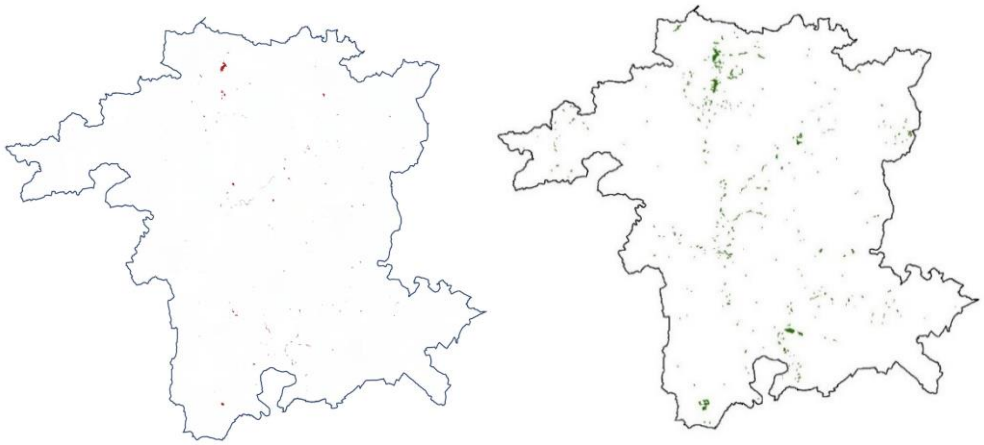


Figure 17: Original inventory wetland coverage in Worcestershire (left); refreshed inventory coverage in Worcestershire (right).

- **Wet grassland (newly attributed)**

Areas of wet grassland have been newly mapped as part of this project. In the refreshed inventory wet grassland is now attributed with the UKHab secondary code '119' (seasonally wet). This habitat includes improved (GI0), probably improved (GP0), possibly unimproved (GU0) and neutral grassland (GN*) types.

Figure 18 presents a high-level comparison of roughly equivalent habitat extent and distribution using the 'Wetland Vision and potential Floodplain Grassland' coverage in Worcestershire (left) and the wet grassland and wetland coverage in the refreshed inventory (right). The Refreshed WHI has mapped significantly more coverage of wet grassland habitat than originally estimated, this has been possible due to the systematic and quantitative approach (described further in the Technical Guidance Report).

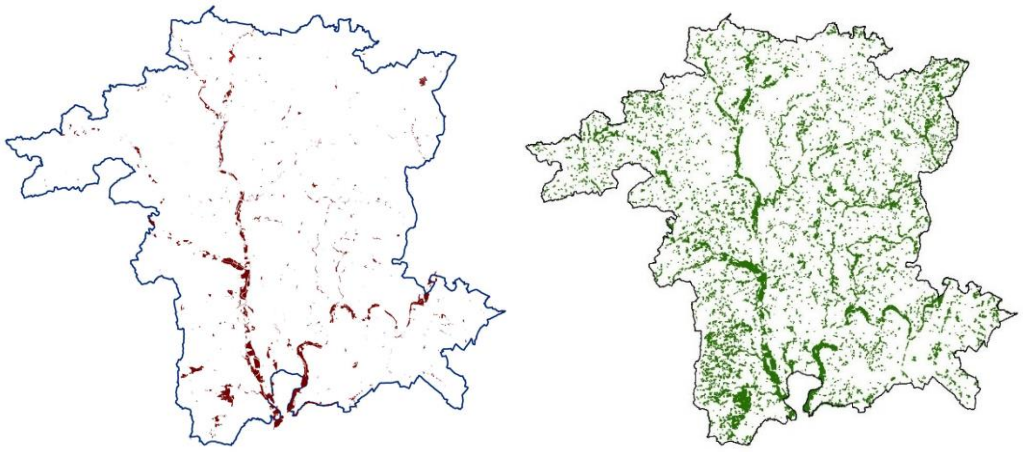


Figure 18: Original inventory 'Wetland Vision and potential Floodplain Grassland' coverage in Worcestershire (left); refreshed inventory 'wet grassland' UKHab code '119' and wetland coverage in Worcestershire (right).

3.2.7 Ponds, Canals and other standing water

The original inventory describes that ponds and other areas of standing water such as reservoirs and pools can be found throughout the county. Worcestershire has some areas of brackish, or slightly saline, open water, river and wetland. This is due to salt deposits in the Salwarpe valley and terraces, especially close to Droitwich. Cover of ponds is sparser, understandably, on hillslopes throughout the county and also in the Vale of Evesham. Canals and linear features were not typically captured through the original WHI data capture process.

Figure 19 presents a high-level comparison of ponds, canals and other standing water in Worcestershire county in the original inventory (left) and the refreshed

inventory (right). The extent of this habitat has increased by comparison to the original inventory. The refreshed inventory estimates that this habitat covers approximately **0.6%** of the county.

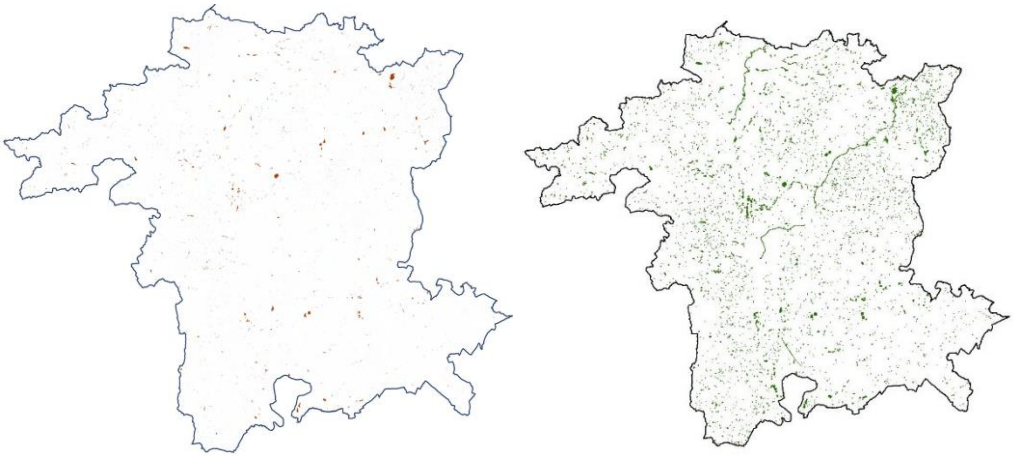


Figure 19: Original inventory ponds, canals and other standing water coverage in Worcestershire (left); refreshed inventory coverage in Worcestershire (right).

3.2.8 Heathland and Acid Grassland

Heathland is a geologically restricted habitat in the county, and cover of heathland is much lower than formerly recorded. Heathland in Worcestershire is found on nutrient poor acidic soils on sandstones and quartzites (WHI, 2010).

In Worcestershire this habitat is now largely confined to mosaics of acid grassland/heath on the Malvern, Clent, Waseley, Romsley and Lickey Hills, in Wyre Forest district and in Wychavon district at Hartlebury (WHI, 2010). Heath wood can be found in Wyre Forest, Redditch hills, and Habberley. Heathland elements under woodland cover may be omitted from the WHI, and so further survey is needed. Heathland and acid grassland combined cover just under **0.6%** of the county.

Figure 20 presents a high-level comparison of heathland and acid grassland in Worcestershire county in the original inventory (left) and the refreshed inventory (right). The extent and distribution of this habitat is approximately the same as presented in the original inventory with the refreshed inventory estimating that this habitat covers approximately **0.62%** of the county.

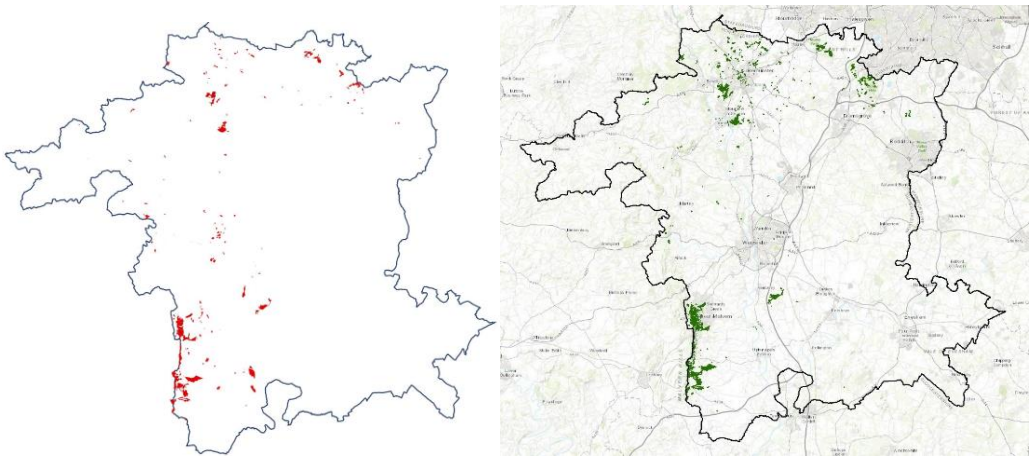


Figure 20: Original inventory Heathland and Acid Grassland coverage in Worcestershire (left); refreshed inventory coverage in Worcestershire (right).

3.2.9 Rivers and Streams

Rivers and other linear features were not mapped as part of the original WHI project, but are important habitats, with all of the watercourses in Worcestershire being designated as Local Wildlife Site (LWS) in their own right, and also providing habitat for several BAP species. As part of the refreshed inventory, rivers and streams were mapped. Figure 21 presents rivers and streams (AR0) habitat included in the refreshed inventory. This habitat is estimated to cover approximately **0.6%** of the county **(around 1,300km length)**.

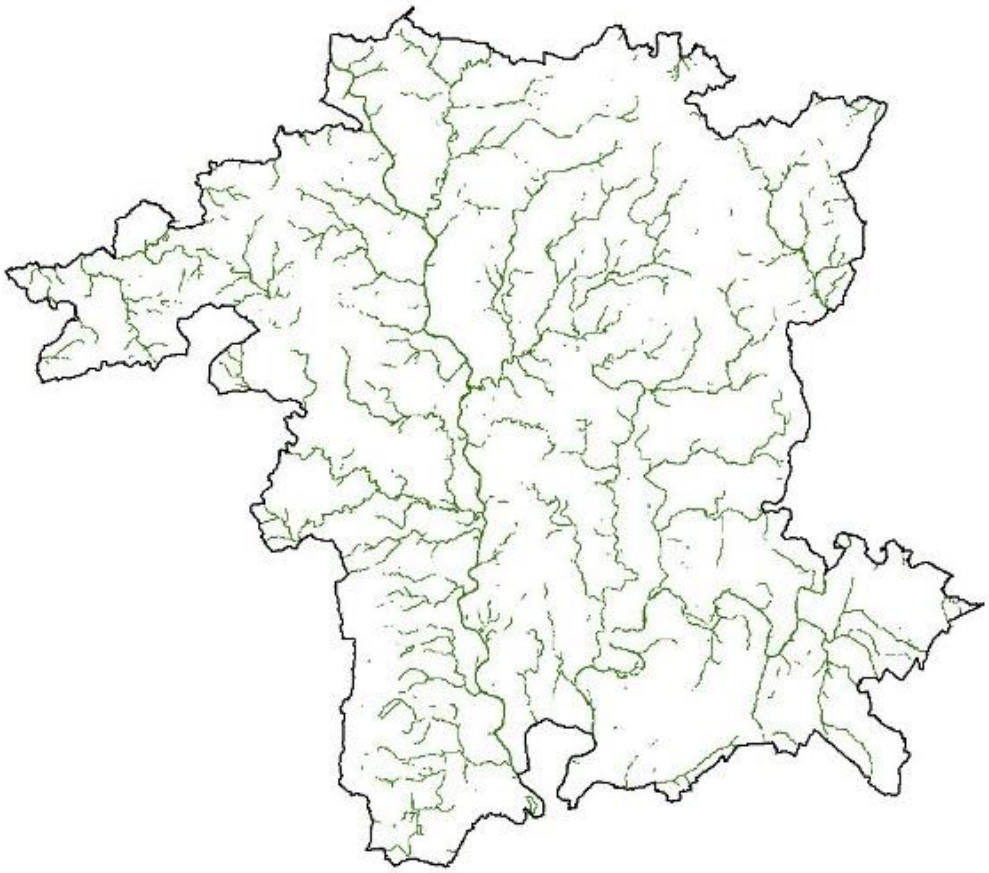


Figure 21: Refreshed Inventory rivers and streams coverage in Worcestershire.

3.2.10 Hedgerows and Lines of Trees

Hedgerows were not mapped as part of the original WHI. Significant effort was made to include these habitats as part of the refreshed inventory. Figure 22 presents the hedgerows and lines of trees habitat included in the refreshed inventory. These data have been used to help inform the Refreshed Inventory using the rule refinement and matrix code attribution approach (see further information in subsection 4.5.1). This habitat is estimated to cover approximately **1.74%** of the county **(around 9,400km length).**

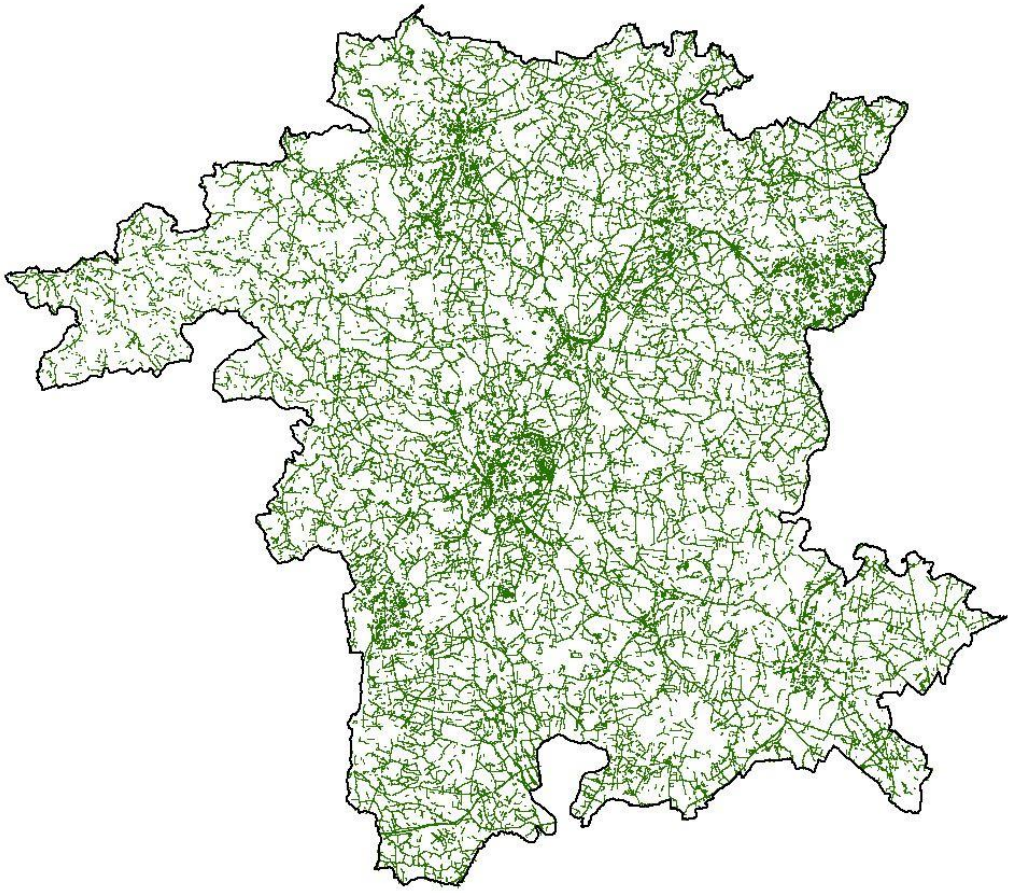


Figure 22: Refreshed Inventory hedgerows and line of trees coverage in Worcestershire.

3.2.11 Urban Areas

Urban areas were also not mapped in the original inventory. The urban areas of the county have been mapped in the refreshed inventory, including Droitwich, Kidderminster, Evesham, Redditch, Bromsgrove, Pershore and Great Malvern providing **100%** coverage. Figure 23 presents habitat UR0 as mapped in the refreshed inventory. This habitat is estimated to cover approximately **8%** of the county.

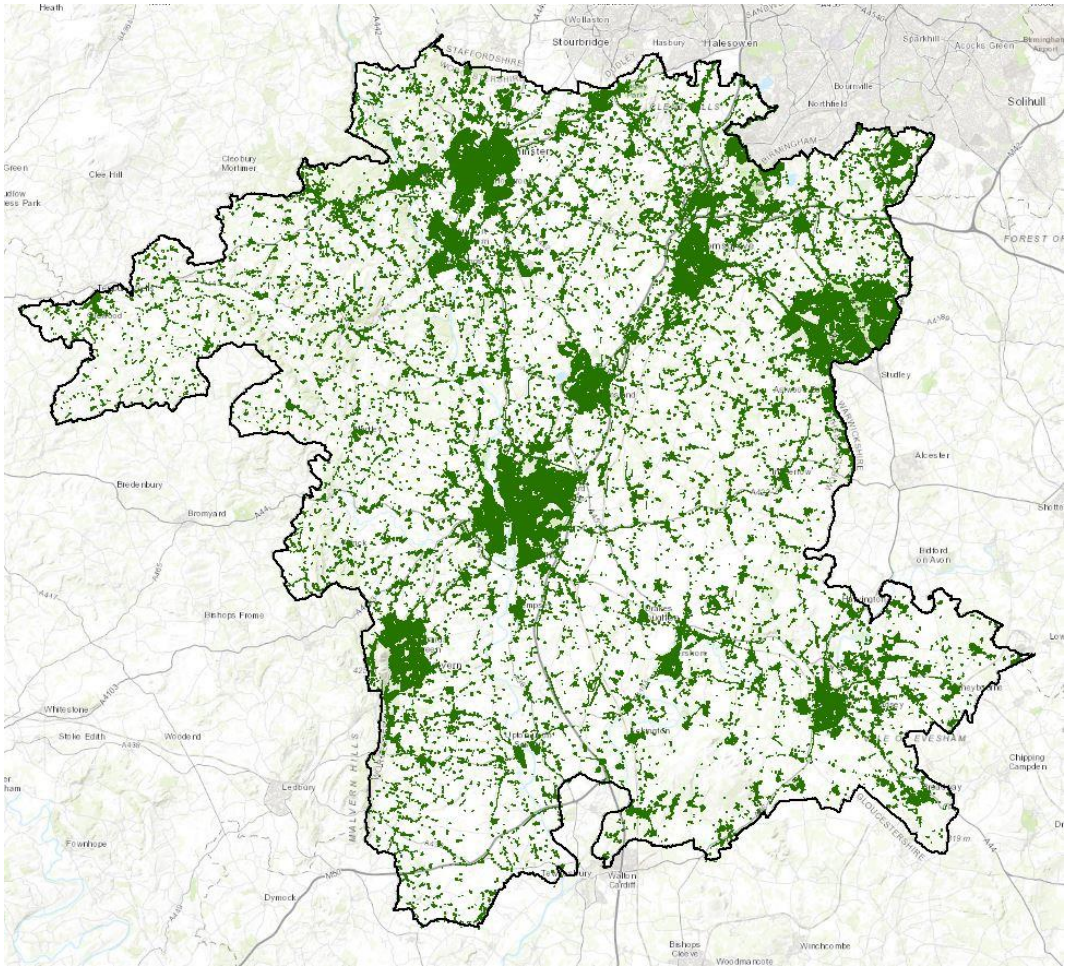


Figure 23: Refreshed WHI, urban areas (UR0) in Worcestershire County.

3.3 Summary

In general, the Refreshed WHI shows that the extent and distribution of priority habitats in Worcestershire is similar to the original inventory. However, some important differences have been highlighted at county scale. These key points have been summarised below. There are likely to be further key differences and observations at local scale.

- The areas of the priority habitats have generally increased in the Refreshed WHI by comparison to the original WHI. This is because the model has been able to classify habitat that the previous API-approach was not able to distinguish, it does not mean that there is necessarily more habitat than there was in 2010.
- All grassland habitats of the refreshed inventory cover a slightly smaller total area, 44.22% of the county versus the 47% originally reported. By contrast the BAP grassland coverage (BAP acid, calcareous and neutral grassland habitats) of the refreshed inventory has increased to 2.45% versus 1.4% originally reported. This difference is likely to arise from the increased capability of the modelling to accurately predict specific BAP grasslands with confidence and

reclassify habitats previously classified with little certainty as possibly as possibly unimproved or probably improved.

- The extent of standard and traditional orchards in the Refreshed WHI appears to be significantly greater (estimated to cover 0.23% of the county) than presented in the original inventory. This is partly because additional new training data has been included in the inventory, shared for the purpose of this project and due to the greater capability of the machine learning approach to identify the regular pattern of orchard trees.
- Generally, more woodland has been mapped and this broad habitat has been more accurately sub-classified. A greater extent of BAP woodland, ancient woodland and conifer woodland and significantly more Broadleaved Woodland excluding recorded BAP or Ancient Woodland has been identified in the Refreshed WHI by comparison to the original inventory.
- The Refreshed WHI has identified significantly more wetland habitat coverage across the county (0.31% coverage in contrast to the original 0.1% county coverage). This is likely to result from the ability of the predictive modelling to account for the proximity of habitats to water.
- Significantly more ponds, canals and other standing water habitat has been identified in the Refreshed WHI.
- The area of heathland and acid grassland habitat in both inventories is roughly equivalent.

Also, important habitat classes have been added to make the total coverage and inventory of the Refreshed WHI complete relative to the original WHI. These additional habitats include:

- Wet grassland has been newly mapped and is estimated to cover up to 7% of the county. The approach to mapping the new wet grassland habitat has been described in the Technical Guidance Report.
- Hedgerows and lines of trees are estimated to extend approximately 9,400km in length across the county.
- Rivers and streams estimated to extend about 1,300km in length across the county.
- Urban areas estimated to cover approximately 8% of the county.

3.4 Refreshed WHI Accuracy and Confidence Assessment

The model accuracy has been assessed by its ability to predict the habitat class for the test dataset, which was not used for the model training.

- The **overall accuracy of the random forest model**[4] at distinguishing 56 different habitat classes is **0.62**, this number summarises the proportion of samples that have been correctly classified.
- The **confusion matrix**, presented in Appendix A2, shows which habitats were correctly predicted and which habitats were more difficult to uniquely distinguish causing confusion in the model's prediction**.**
- **Overall accuracy of the Refreshed WHI** after the rules have been applied to interpret the outputs of the random forest model considering the original habitat classification and additional input datasets is estimated at **0.81**.
- Each habitat classification has been assigned a relative **confidence score** between 0 and 1 based on the models' ability to distinguish the likely habitat helping data users to see how confident they can be with the classification.
- Furthermore, the **habitat source** attributions also enable users to assess the level of certainty attributed to a habitat, with source values 'Training data' and 'Predicted' having the highest confidence followed by 'Confirmed' and 'Original WHI'.

Table 1: Breakdown of the model accuracy and confidence per habitat class.

No.	Habitat IHS code (habitat_cd2)	Balanced Accuracy	Mean Confidence	Habitat description
1	AS0	0.86	0.57	Standing open water and canals
2	AS4	NA	0.93	Eutrophic standing waters
3	BR0	0.76	0.53	Bracken
4	BR1	NA	0.86	Continuous bracken communities with a diverse vernal flora
5	BRZ	0.50	0.58	Other continuous bracken
6	CR0	0.86	0.52	Arable and horticulture
7	CR1	0.95	0.60	Grass and grass-clover leys
8	CR2	0.95	0.61	Cereal crops
9	CR3	0.75	0.49	Non-cereal crops including woody crops
10	CR31	0.75	0.44	Intensively managed orchards
11	CR3Z	0.58	0.72	Other non-cereal crops including woody crops
12	CR4	0.75	0.48	Freshly ploughed
13	CR5	0.75	0.55	Whole field fallow
14	CR6	0.68	0.68	Arable headland or uncultivated strip
15	EM0	0.78	0.40	Fen, marsh and swamp
16	EM1	0.83	0.80	Swamp
17	EM11	0.90	0.61	Reedbeds
18	EM312	NA	0.80	Springs
19	GA0	0.73	0.37	Acid grassland
20	GA1	0.90	0.40	Lowland dry acid grassland
21	GC0	0.74	0.46	Calcareous grassland
22	GC1	0.75	0.54	Lowland calcareous grassland
23	GC112	0.75	0.87	Unimproved species rich calcareous grassland

No.	Habitat IHS code (habitat_cd2)	Balanced Accuracy	Mean Confidence	Habitat description
24	GI0	0.74	0.41	Improved grassland
25	GN0	0.71	0.40	Neutral grassland
26	GN1	0.83	0.61	Lowland meadows
27	GN11	0.83	0.70	Lowland hay meadows (Alopecurus pratensis, Sanguisorba officinalis)
28	GN12	0.80	0.57	Lowland meadows and pastures
29	GN3	0.76	0.49	Coarse neutral grassland
30	GN4	0.75	0.62	Grazing marsh pasture
31	HE0	0.83	0.56	Dwarf shrub heath
32	HE1	1.00	0.87	European dry heaths
33	LF1	0.75	0.26	Hedges / Line of trees
34	OT0	0.57	0.10	Tall herb and fern (excluding bracken)
35	OT0	0.57	0.10	Tall herb and fern (excluding bracken)
36	RE0	NA	0.66	Inland rock
37	RE1	0.70	0.39	Natural rock exposure features
38	RE2	0.75	0.80	Artificial rock exposures and waste
39	RE21	0.68	0.61	Quarry
40	RE24	1.00	0.42	Refuse tip
41	RE2Z	0.50	0.33	Other artificial rock exposure and waste
42	SC0	0.65	0.17	Scrub
43	TH1	0.75	0.70	Tall herb and grasses or 'saum' vegetation
44	UR0	0.91	0.59	Built-up areas and gardens
45	WB2	0.68	0.27	Scrub woodland
46	WB3	0.89	0.59	Broadleaved woodland
47	WB31	0.75	0.75	Upland oakwood
48	WB32	0.79	0.81	Upland mixed ashwoods
49	WB3312	1.00	0.77	Asperulo-Fagetum beech forests
50	WB34	0.75	0.53	Alluvial forests with Alnus glutinosa and Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae)
51	WB36	0.82	0.81	Lowland mixed deciduous woodland
52	WB361	NA	0.90	Old acidophilous oak woods with Quercus robur on sandy plains
53	WC0	0.83	0.77	Coniferous woodland
54	TS0	0.68	0.16	Scattered trees
55	PA0	0.53	0.10	Patchy bracken
56	BG1	0.73	0.15	Bare ground
57		NA	0.30	NA
58	<Null>	NA	0.01	NA
59	AR0	NA	0.39	Rivers and streams
60	AS41	NA	0.74	Natural eutrophic lakes with Magnopotamion or Hydrocharition-type vegetation
61	AS6	NA	1.00	Brackish standing water with no sea connection
62	CG1	NA	0.52	Lowland calcareous grassland
63	CR61	NA	0.98	Arable field margins
64	CRZ	NA	0.20	Other arable and horticulture
65	EM2	NA	0.69	Marginal and inundation vegetation
66	EM3	NA	0.46	Fens

No.	Habitat IHS code (habitat_cd2)	Balanced Accuracy	Mean Confidence	Habitat description
67	FT0	NA	0.30	Orchard
68	FT1	NA	0.30	Traditional orchard
69	FT11	NA	0.29	Traditional pear orchard
70	FT12	NA	0.21	Traditional cherry orchard
71	FT13	NA	0.23	Traditional apple orchard
72	FT14	NA	0.30	Traditional plum orchard
73	FT15	NA	0.30	Traditional mixed orchard
74	GA1Z	NA	0.46	Other lowland dry acid grassland
75	GN1Z	NA	0.36	Other lowland meadows
76	GN31	NA	0.89	Rank neutral grassland
77	GN32	NA	1.00	Tussocky neutral grassland
78	GNZ	NA	0.31	Other neutral grassland
79	GP0	NA	0.25	Grassland, probably improved
80	GU0	NA	0.25	Grassland, possibly unimproved
81	HE11	NA	0.99	Calluna vulgaris dry heath
82	LF0	NA	0.36	Boundary and linear features
83	LF11	NA	0.93	Hedgerows
84	LF12	NA	1.00	Line of trees
85	LF1Z	NA	0.72	Other hedges/line of trees
86	LF2	NA	0.33	Other boundaries and linear features
87	LF21	NA	0.30	Line of trees (not originally intended to be stock proof)
88	LF22	NA	0.25	Bank
89	LF25	NA	0.31	Wall
90	LF27	NA	0.37	Transport corridors
91	LF271	NA	0.33	Transport corridor without associated verges
92	LF272	NA	0.42	Transport corridor associated verges only
93	OV0	NA	0.28	Unknown terrestrial vegetation
94	OV1	NA	0.24	Unknown terrestrial vegetation, possibly wetland
95	RE16	NA	0.45	Rock outcrop
96	SC11	NA	1.00	Dense/continuous scrub: native shrubs
97	UV0	NA	0.10	Unknown terrestrial vegetation
98	WB0	NA	0.39	Broadleaved, mixed, and yew woodland
99	WB1	NA	0.65	Mixed woodland
100	WB321	NA	0.78	Tilio-Acerion forests of slopes, screes and ravines (upland)
101	WB343	NA	0.98	Willow carr
102	WB34Z	NA	0.08	Other wet woodland
103	WB36Z	NA	0.86	Other lowland mixed deciduous woodland
104	WB3Z	NA	0.88	Other broadleaved woodland
105	WP1	NA	0.62	Wood pasture and parkland
106	NA	NA	NA	NA

4 Approach for the Refreshed WHI

4.1 Introduction

A digital (machine learning), remote sensing-based approach has been used to create the Refreshed WHI and to provide an updated census of the habitats of Worcestershire. This section describes what is meant by a 'machine learning, remote sensing-based approach' and describes the approach and data used for Worcestershire. An overview of the concept and approach applied to refresh the WHI is presented in Figure 24.

One of the limitations of the original 2010 inventory (WHI, 2010) was that it was largely based on manual API of images captured in 2005 and as a consequence it was not possible to distinguish unimproved grassland with any level of confidence. By contrast the remote sensing data and machine-led approach adopted for the Refreshed Inventory has a number of benefits including:

- Building on application of the Crick Framework[5], which was developed as a tool to assess the extent to which Earth Observation (EO) could identify habitats, a wider range of spatial remote sensing data can be considered in addition to RGB (red, green, blue) aerial imagery, enabling a systematic and quantitative approach to habitat identification.
- These data provide quantitative values that can be interpreted objectively reducing subjectivity in the overall habitat interpretation.

In combination with application of machine learning methods, the process of habitat identification and classification through various remote sensing data is more efficient and more consistent (when reproduced) than possible through manual interpretation of aerial imagery alone.

To inform the machine learning modelling, an object-based image analysis was adopted for the habitat inventory refresh. Pixels in the imagery are first grouped into homogenous areas of vegetation, such as woodland or grassland stands. This means that not only the spectral values of the individual pixels are considered in determining the habitat type but also the variation in spectral values, i.e. whether the vegetation is largely homogenous, such as for arable field, or more heterogenous, such as for an area of heathland. This process has been described in more detail in subsection 4.2

Imagery data used to inform the modelling includes the recent aerial photography provided by WCC. Additionally, multi-temporal images from the European Space Agency's (ESA) multispectral Sentinel-2 satellite sensor have been used. These data provide information corresponding with plant phenology and can be used to derive indices that provide additional information of value for identifying habitats. For example, information on productivity (NDVI) and moisture content (NDMI). In addition to the multispectral satellite data, ESA Synthetic Aperture Radar

[5] JNCC. (2013). The Crick Framework. Retrieved from https://jncc.gov.uk/our-work/the-crick-framework/

(SAR) images from the Sentinel-1 satellite sensor have been used, providing information on surface roughness, which can correspond with vegetation heterogeneity particularly when assessed through time. Other digital data that have been used in the analysis include geology, soils, climate etc. These various input data have been summarised and presented in subsection 4.3, Table 2. Zonal statistics were calculated to quantitatively summarise the input data characterising the different habitats. These statistics were used in the modelling. For further details about this approach please refer to the Technical Guidance Report.

Additionally, the modelling requires habitat data suitable for training the machine learning model. These data are required to help characterise the information that define that habitat. The training data used in this project is described in more detail in subsection 4.4. They include a subset of data from the original WHI for the more widespread habitats, whilst excluding those of low confidence, and more recent survey information, such as from local wildlife sites.

A range of machine learning models have been tested, including support vector machines, gradient boosted machines, random forests, to see which provide the best performance. The random forest machine learning classification model was selected to model the Refreshed WHI and this is described in more detail in subsection 4.5.

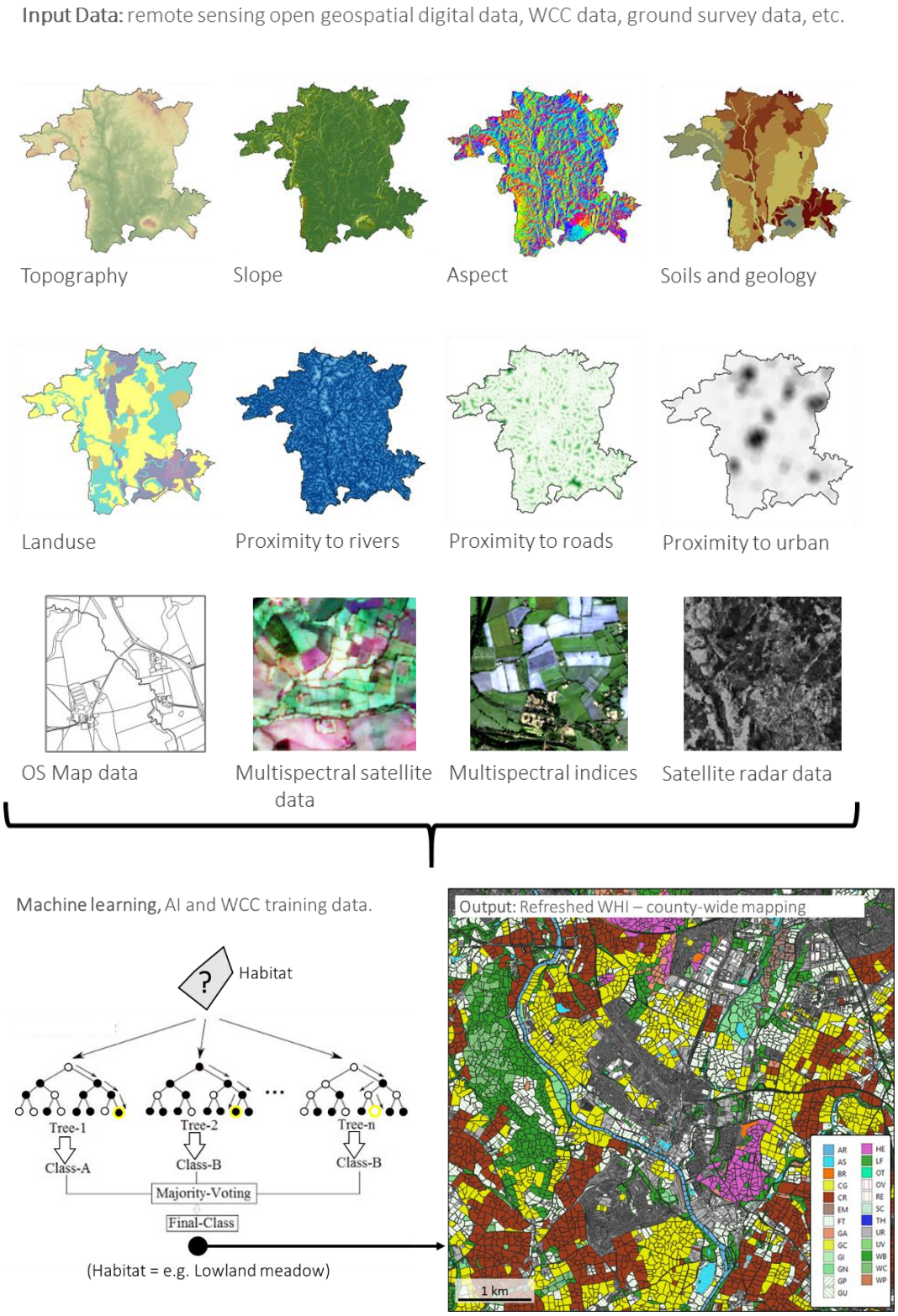


Figure 24: Overview of the machine-learning and remote sensing data-led approach to creating the Refreshed WHI.

The Refreshed WHI uses a combination of the object-based segmentation geometry and Ordinance Survey MasterMap (OSMM) polygons (and described

further in subsection 4.2 below). It retains the original WHI attribution so that the updated and original habitat classes can be compared and that no original information is lost. The habitat classes mapped from remote sensing are those identified in the Crick Framework as distinguishable from multi-spectral imagery and have been classified as according to the IHS. Additionally, the UKHab equivalent to the IHS code has been provided. UKHab is the habitat classification used by the Natural England's Biodiversity Metric for measuring Biodiversity Net Gain, which is due to become a mandatory planning requirement for most new development in England.

4.2 Object-Based Image Analysis

The Refreshed WHI polygon geometry has been created using object-based image analysis in combination with incorporation of the latest OSMM geometry. This approach is similar to that used for creating the original version of WHI in respect that individual polygons are classified as a particular habitat class, the distinction for the update is that this will be done through an automated process rather than through manual image analysis. An example comparison of the original WHI polygon geometry with the Refreshed WHI is shown in Figure 25.

Figure 25: Example of the original WHI polygon geometry (left) and the Refreshed Inventory polygon geometry (right).

The object-based image analysis was performed using an image segmentation approach to identify the objects (homogenous areas in imagery) for classification. The image segmentation also incorporated polygons from recent version of OSMM for areas such as road verges and urban areas that were not included in the original WHI mapping. The segmentation analysis was undertaken on a mosaicked Sentinel-2 image from May 2018. May was selected as vegetation will be in leaf, but there should be less influence from land management activities, such as the cutting of hay and hedges, at this time of year.

4.3 Spatial Datasets (model inputs)

A series of open data and client source digital geospatial data were reviewed and selected to form the inputs of the spatial modelling. The input datasets and the information they provide for the informing the habitat modelling has been summarised in Table 2. Further detail about these datasets (along with a summary table of the datasets that have been scoped out of the modelling) can be found in the Technical Guidance Report available on the Council's website. These datasets have different formats and contain different types of information (for example satellite images captured from multispectral or radar sensors) at different spatial resolutions; therefore, a number of pre-processing steps were undertaken to prepare them for input to the modelling. These steps have been described in the Technical Guidance Report.

Table 2: Spatial datasets used to inform the modelling. Further information about these datasets can be found in the Technical Guidance Report.

No.	Dataset	Data Source	Description	Application
1	Aerial photography (visible)	WCC	Three band (Red, Green, Blue; RGB), visible-wavelength imagery with 10cm pixel resolution. Resampled to 50cm for modelling. captured between 2016 and 2019 during months May to September	High spatial resolution enables delineation of habitat structural details, e.g. crop rows, hedgerows, canopy morphology. This compliments information provided by the high spectral resolution but lower spatial resolution Sentnel-2 data.
2	Aerial photography (infrared)	WCC	Captured on the same dates as the visible imagery described above and with 50cm pixel resolution.	As above, however, with the addition of including high-resolution infrared data, which provides information on vegetation health and is useful in identifying different habitat types.
3	Sentinel-1 radar imagery (four scenes, one to cover each seasons)	Open, ESA	Synthetic Aperture Radar (SAR) images from the European Space Agency's (ESA) Sentinel-1 satellites. Sentinel-1 wide swath Ground Range Detected (GRD) imagery has been included for the same data capture periods as the Sentinel-2 multispectral imagery (18 February 2018, 13 May 2018, 30 June 2018, 27 October 2018)	Provides information on surface roughness, which can correspond with vegetation heterogeneity. Time-series data of this nature provides information about seasonal growth and for example crop management cycles.
4	Sentinel-2 multispectral imagery (four scenes, one to cover each season)	Open, ESA	Level-2A multispectral imagery from ESA's Sentinel-2 satellites resampled to 10m spatial resolution. The imagery contains spectral information collected across 12 bands or wavelengths, with each reflectance wavelength revealing information about the material from which it has been reflected. Imagery from 2018 has been selected as this provided an extended period of cloud-free weather and coincides with the data capture period for the more recent aerial photography. There are largely cloud-free images for February, May, June and October which cover the winter (leaf-off), spring, early summer and autumn periods.	Multispectral imagery provides more information about the character of different habitat types. For example, the spectral signature of a bare crop field will appear different to the same crop field when it is in early season crop growth and later season crop growth. As a time-series, this signature helps to distinguish that such character is typical of crop fields but is different for example to the characteristic spectral signature from an acid grassland.

No.	Dataset	Data Source	Description	Application
5	2m Digital Surface Model (DSM) data produced by photogrammetry	WCC	As provided in the dataset column.	Provides information about the landscape character, its geometry, elevation and aspect, which all influence habitat formation.
6	5m Digital Terrain Model (DTM) data produced by photogrammetry	WCC	As provided in the dataset column.	Provides information about the landscape character, its geometry, elevation and aspect, which all influence habitat formation.
7	5m slope data derived from the photogrammetry DTM	WCC	As provided in the dataset column.	Provides information about the landscape character, its geometry, elevation and aspect, which all influence habitat formation.
8	5m slope aspect data derived from the photogrammetry DTM	WCC	As provided in the dataset column.	Slope aspect or orientation of slope is measured clockwise in degrees from 0 to 360, where 0 is north-facing, 90 is east-facing, 180 is south-facing, and 270 is west-facing. The aspect provides important information related to climate; for example, amount of rainfall received and rainfall intensity, windspeed, hours of sunlight received etc. which influence habitat development.
9	Distance to roads	Open + Arup-derived	This series of proximity layers have been derived from OS VectorMap District data (https://www.ordnancesurvey.co.uk/business-government/products/vectormap-district)	Some habitats prefer high-water-content soils that exist close to surface water bodies, other habitats preferentially occur along transport corridors or close to urban areas. The proximity of existing habitats to these features therefore provides important information about habitat type and formation
10	Distance to urban areas		As provided in the dataset column.	
11	Distance to rail			
12	Distance to surface water			

No.	Dataset	Data Source	Description	Application
13	British Geological Survey (BGS) 1:50 000-meter scale Superficial Deposits	WCC	As provided in the dataset column. These data were made available by the BGS for the purpose of this project under a Complementary Digital Data Licence. They have been rasterised at 10m x 10m grid resolution to inform the modelling.	Geology determines the chemical composition of the ground surface and often determines the type of soil that develops, for example calcareous versus acidic soils. A number of habitat types, for example calcareous grassland and acidic grasslands tend to form where the geological and soil conditions are appropriate therefore the geology forms an important input for the habitat modelling.
14	British Geological Survey (BGS) 1:50 000-meter scale Bedrock Geology	WCC		
15	Landscape Description Units, LDUs (tree cover character, land use and historic settlement)	WCC	Worcestershire County Council have produced high-resolution Landscape Description Units (LDUs) that cover the entire county. An LDU represents a Landscape Type in a specific location. These are the basic building blocks of the landscape and are defined by a combination of six key characteristics relating to geology, topography, soils, tree cover character, land use and historic settlement pattern. This is open data and was created in 2013 by WCC and has been downloaded for this project from https://data.gov.uk[6].	These various historical and physical data provide important information to inform habitat modelling.
16	Landscape Character Parcels, LCPs (higher resolution soil data)	WCC	The LCPs were created by WCC and provide higher resolution soil data by comparison to the LDUs. LCP soil data has been used to inform the modelling.	Soil type plays an important role in habitat formation. A number of habitat types, for example calcareous grassland and acidic grasslands tend to form where the geological and soil conditions are appropriate.
17	HadUK-Grid climate data	Open	20-year seasonal and annual climate variables from the Met Office HadUK-Grid[7] gridded land surface climate observation datasets have been downloaded. These data have 1km x 1km spatial grid resolution on the Ordnance Survey's	Climate variability is an important variable in habitat formation, for example the spatial distribution and amount of rainfall or hours of

[6] https://data.gov.uk/dataset/4a372a34-fad6-4dba-8f1a-ef9b1e4ce1c1/landscape-description-units
[7] https://www.metoffice.gov.uk/research/climate/maps-and-data/data/haduk-grid/haduk-grid

No.	Dataset	Data Source	Description	Application
			National Grid and provide climatic information that is relevant to habitat formation. The climatic variables include: Air temperature (min, max, mean), Precipitation, Sunshine duration, Relative humidity, Vapour pressure, Ground frost (days), Snow lying (days). A summary of this data is presented in the Technical Guidance Report.	sunlight an area receives can influence wetland versus heathland formation for example.
18	Normalised Differential Vegetation Index (NDVI)	Arup-derived	The NDVI is used to distinguish areas of vegetation. This index has been calculated using the Sentinel-2 multispectral imagery. For further information on the index calculation, please see the Technical Guidance Report.	The NDVI is used to distinguish areas of vegetation. This information also helps to therefore distinguish areas that are not vegetation such as urban habitat and water habitats.
19	Normalised Differential Wetness Index (NDWI)	Arup-derived	The NDWI distinguishes wetter surface areas from drier surface areas. This index has been calculated using the Sentinel-2 multispectral imagery. For further information on the index calculation, please see the Technical Guidance Report.	The NDWI helps to identify wetter areas from drier areas, which is an important factor helping to distinguish wetland versus dryland habitats.
20	Normalised Differential Moisture Index (NDMI)	Arup-derived	This NDMI correlates with the moisture content of vegetation. This index has been calculated using the Sentinel-2 multispectral imagery. For further information on the index calculation, please see the Technical Guidance Report.	The NDMI is useful for identifying habitats with differing levels of moisture content of vegetation.
21	CROME[8] data	Open	The Crop Map of England (CROME) Midlands is a polygon vector dataset mainly containing the crop types of England. The dataset contains approximately 32 million hexagonal cells classifying England into over 20 main crop types, grassland, and non-agricultural land covers, such as Woodland, Water Bodies, Fallow Land and other non-agricultural land covers. For further information please see the footnote.	The CROME data provides information specifically helping to identify different crop types and to distinguish arable land, which may vary significantly in appearance across the year, from permanent habitats.

[8] Crop Map of England, downloaded from: https://data.gov.uk/dataset/21c91d36-1770-475e-99ce-5c54ea4b3eae/crop-map-of-england-crome-2016-midlands

No.	Dataset	Data Source	Description	Application
22	Ancient Woodland Inventory data[9]	Open	The Ancient Woodland Inventory identifies over 52,000 ancient woodland sites in England. Ancient woodland is identified using presence or absence of woods from old maps, information about the wood's name, shape, internal boundaries, location relative to other features, ground survey, and aerial photography.	This specific data supports with identification of the semi natural ancient and replanted ancient woodland areas in the county.
23	Hedgerow derived dataset	WCC	This dataset has been created using the Digital Surface Model (DSM) derived from the aerial photography dataset supplied by WCC. Areas of woodland and hedgerows were identified using the DTM slope-based filter in QGIS, these features were then extracted based on their proximity to field boundaries in OSMM.	This data has been used to help identify the hedgerow and line of trees habitats in the modelling.

[9] Natural England. (n.d.). Ancient Woodland Inventory. Retrieved from https://data.gov.uk/dataset/9461f463-c363-4309-ae77-fdcd7e9df7d3/ancient-woodland-england

4.4 Training Datasets

Training data is used to train the machine learning model to identify the distinct habitat classes. Ideally training data should consist of a representative sample from across the county for each of the habitat classes, including urban, arable, terrestrial and freshwater classes.

For this study, the training datasets included new training data from the Worcestershire Wildlife Trust and Worcestershire Biological Records Centre, such as from recent surveys of local wildlife sites. Additionally, a stratified random sample of points taken from polygons in the original WHI, excluding classes such as 'probably improved grassland' and 'possibly unimproved grassland', have been included. It was necessary to still use a proportion of this data to make sure that there are enough samples with a good spatial distribution county-wide to train the model appropriately, in particular having training samples covering all soils types present in the county and all capture dates for the aerial imagery.

4.5 Machine Learning Analysis

For this study, the random forest machine learning classification model was selected. It is commonly used for land cover classification due to its level of performance when compared against other modelling algorithms. The random forest model was trained using the variables selected as described in Table 2 and the training dataset created as described in Section 4.4.

4.5.1 Rule-based refinement and Refreshed Inventory Attribution

Only certain levels of habitat class discrimination are possible using a remote sensing approach (as set out in the Crick Framework). To ensure that no detail from the original 2010 inventory was lost a series of rules were implemented to the modelled output. The rule-based approach ensures that there is no aggregation to over-arching/lower tired habitat classes. The rules have been described fully in the Technical Guidance Report.

4.5.2 Ancient semi natural woodland and planted ancient woodland

As noted in the original inventory, due to the specific ecological classification of these habitats, it is very challenging to identify these even through the greater range of quantitative remote sensing data analysed in this project. Ancient semi natural and planted woodland habitat (ASNW and PAWS respectively) have been incorporated into the Refreshed Inventory as definitive data and attributed using the UKHab secondary codes ('33', '36', '37').

4.5.3 Wood-pasture and parkland

Similarly to ASNW and PAWS, Wood-pasture and parkland is challenging to identify through the modelling process and therefore definitive habitat data shared by the council for this project has been incorporated into the Refreshed Inventory and attributed using the UKHab secondary code (‘20’).

4.5.4 Linear features (hedgerows, lines of trees, transport corridors and water courses)

Linear features are typically narrow and as such are challenging to identify based on the Crick Framework and using remote sensing data. There was also no training data to inform the modelling of these features in the Refreshed Inventory. To overcome this these habitats have not been modelled but have been incorporated and attributed by the rule system as described in subsection 4.5.1 and in further detail in the Technical Guidance Report.

Additionally, a separate hedgerows/ line of trees raster dataset has been developed for Worcestershire county as part of this project. This was derived by identifying and extracting these features from the high-resolution digital surface elevation data that was derived from the aerial imagery and shared under the project contract. The approach to deriving the data has been described in more detail in the Technical Guidance Report.

Part II – Habitat Connectivity Analysis

5 Introduction

This section of the report presents the habitat network connectivity analysis undertaken for Worcestershire county. The aim of the habitat network maps is to help identify possible locations for actions to improve ecological resilience of the current habitat network in line with Lawton principles **'more, bigger, better and joined'.**[10]

Outputs for the Worcestershire habitat connectivity analysis include individual priority habitat connectivity maps for the 10 priority habitats listed in Section 5.1 and a single 'merged' output, which provides a summary of habitat network connectivity for the county and includes the Primary priority habitat(s) present and the topmost zone ordered to reflect the Lawton Principles:

I. Improve the quality of current sites by better habitat management.

II. Increase the size of current wildlife sites.

III. Enhance connections between, or join up, sites, either through physical corridors, or through 'steppingstones.

IV. Create new sites.

V. Reduce the pressures on wildlife by improving the wider environment, including through buffering wildlife sites.

These data have been shared in file geodatabase format and have been made available at the Worcestershire County Council website as part of this project. Examples of the outputs have been presented in Section 7 along with a description of the data attribution. Section 6 provides user guidance for the connectivity outputs. Section 8 provides a description of the habitat network connectivity approach selected for Worcestershire county. This section also summarises the connectivity analysis input values for the key parameters for each of the priority habitat listed. Further detail and information on the habitat connectivity analysis can be found in the Technical Guidance Report.

5.1 Worcestershire Priority Habitats

The network connectivity of the following WC priority habitats (1 to 10 below) was analysed using the Natural England connectivity tool (described in Section 8. This list includes the newly created wet grassland (WGR) habitat which was created in the Refreshed Inventory.

1. Lowland calcareous grassland (LCG)
2. Lowland dry acid grassland (LAG)

[10] Lawton, J. et al. (2010) Making Space for Nature: a review of England's wildlife sites and ecological network. Report to Defra.

3. Lowland fens (LFN)
4. Lowland heathland (LHL)
5. Lowland meadows (LMW)
6. Reedbeds (RBD)
7. Wet grassland (WGR)
8. Ancient semi-natural woodland (ASNW)
9. Wood-pasture and parkland (WPP)
10. Traditional orchards (TRO)

Excluded priority habitats are lakes and rivers, which are analysed by a separate process and national outputs have been published by Natural England. Habitat network maps for some priority habitats have not been created as part of this analysis, e.g. coastal floodplain grazing marsh. There is very little grazing marsh habitat (GN4) in Worcestershire, which has been considered as an associated habitat in the analysis of other habitat types. Additionally, the analysis for woodland is focussed on ancient and semi-natural woodlands from the Ancient Woodland Inventory[11] with other woodlands treated as associated habitats. Linear features such as hedgerows, have also been excluded from the network connectivity analysis.

6 User Guidance: Habitat Network Connectivity

The aim of the habitat network connectivity outputs is to help identify possible locations for actions to improve ecological resilience of the current habitat network in line with Lawton principles 'more, bigger, better and joined'.

Components for habitat connectivity analysis are divided into **A) 'Existing Habitat'** and **B) 'Network Enhancement and Expansion'** and are outlined below (after the Natural England approach; Edwards et al., 2020[12]):

A. Existing Habitat – Existing habitats need to be associated with the following four components (Figure 26):

1. **Primary Habitat:** The habitat which is the focus of the individual habitat network e.g. lowland heathland.
2. **Associated Habitat:** Other habitat types that form a mosaic or an ecologically coherent group within the landscape and may, for example, be essential for some species associated with the primary habitat.
3. **Habitat Creation/Restoration:** Areas where work is underway to either create or restore the primary habitat.

[11] https://data.gov.uk/dataset/9461f463-c363-4309-ae77-fdcd7e9df7d3/ancient-woodland-england
[12] Edwards J, Knight M, Taylor S & Crosher I. E (March 2020) 'Habitat Networks Maps, User Guidance v.2', Natural England.

4. **Restorable Habitat:** Areas of land, predominantly composed of existing semi-natural habitat where the primary habitat is present in a degraded or fragmented form and which are likely to be suitable for restoration.

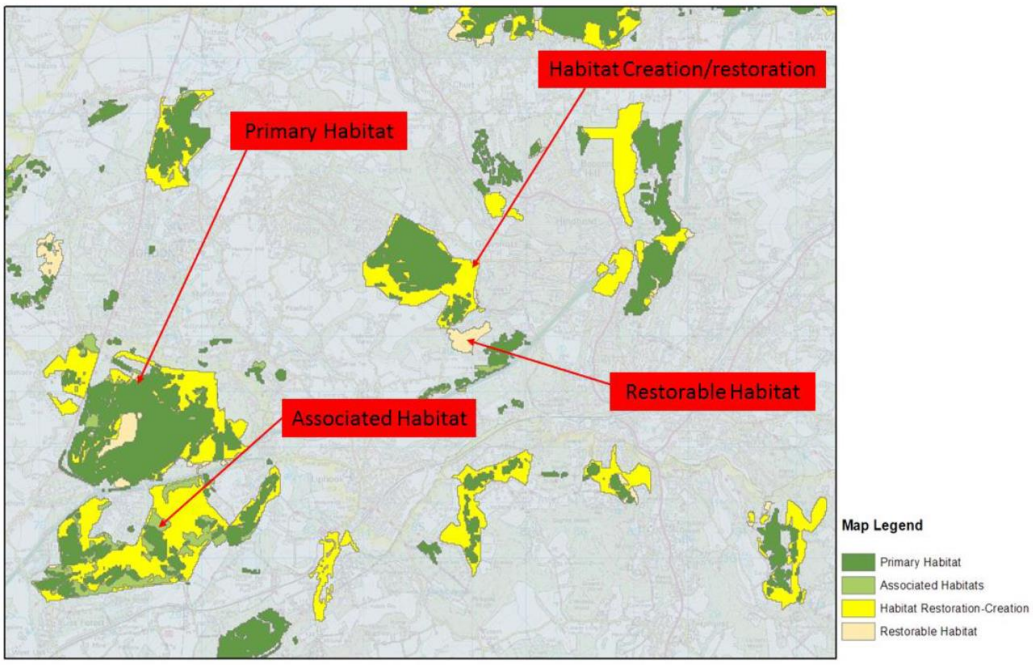


Figure 26: Components of the Existing Habitat (after Edwards et al., 2020).

(B) Network Enhancement and Expansion – The following 4 network zones around the habitat components described above have been mapped (see Figure 27).

5. **Network Enhancement Zone 1:** Land connecting existing patches of primary and associated habitats which is likely to be suitable for creation of the primary habitat. Factors affecting suitability include the following: proximity to primary habitat, land use (urban/rural), soil type, slope and proximity to coast. Action in this zone to expand and join up existing habitat patches and improve the connections between them can be targeted here.
6. **Network Enhancement Zone 2:** Land connecting existing patches of primary and associated habitats which is less likely to be suitable for creation of the primary habitat. Action in this zone that improves the biodiversity value through land management changes and/or green infrastructure provision can be targeted here.
7. **Fragmentation Action Zone:** Land within Enhancement Zone 1 that connects existing patches of primary and associated habitats which are currently highly fragmented and where fragmentation

could be reduced by habitat creation. Action in this zone to address the most fragmented areas of habitat can be targeted here.

8. **Network Expansion Zone:** Land beyond the Network Enhancement Zones with potential for expanding, linking/ joining networks across the landscape i.e. conditions such as soils are potentially suitable for habitat creation for the specific habitat in addition to Enhancement Zone 1. Action in this zone to improve connections between existing habitat networks can be targeted here.

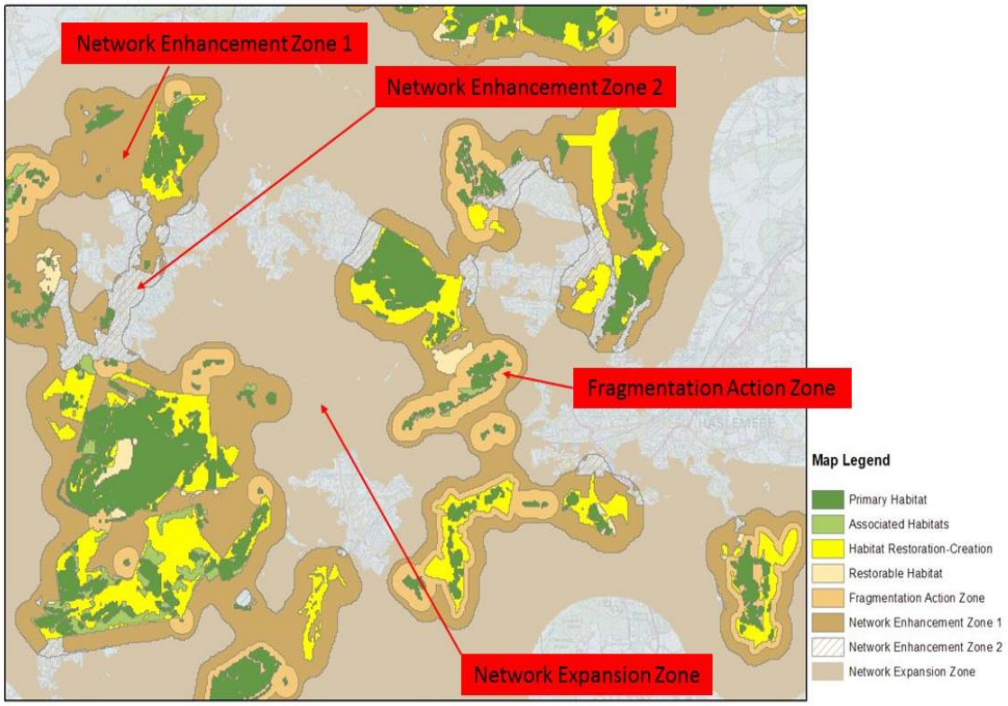


Figure 27: Components of the Network Enhancement and Expansion Zones (after Edwards et al., 2020).

The habitat network connectivity outputs are based on the Refreshed Inventory, this has enabled the connectivity of new additional priority habitats such as wet grassland to be assessed.

The connectivity outputs help to identify priority areas for habitat restoration at county scale. As they have been produced through a geospatial process using remote sensing data and without ground-truthing, the outputs should only be used to help inform decisions around habitat management and any interventions for a particular site should take account of local knowledge of the area and ecological expertise. As such, it is recommended that the maps are used in conjunction with other datasets and with local ecological expertise and on-the-ground-knowledge to help identify opportunities for action.

It should be noted that as new habitat survey data and ground truth data become available, it is possible that these new data will influence the distribution of habitat connectivity networks and this should be considered and discussed in decision making.

Because this information is aligned with the Natural England approach, it can be compared, assessed, and integrated with other available habitat data at a broader scale and is in line with national best practice.

7 Worcestershire County Habitat Connectivity Outputs

Drawing 001 below shows an example of the connectivity analysis output for Lowland Meadows at county scale along with a zoomed excerpt of this output for the Worcester area in Figure 28. Additionally, Drawing 011 below shows the combined ('merged') habitat connectivity output. These maps have been provided as examples and the full digital datasets can be interrogated online. Section 7.1 describes the attribution and information provided in these data.

7.1 Attribution Information

Individual output data attribution:

Attribution of the individual priority habitats include the 'Class' attribute which denotes which of the 'Existing Habitat' and 'Network Enhancement and Expansion' the area has been identified as.

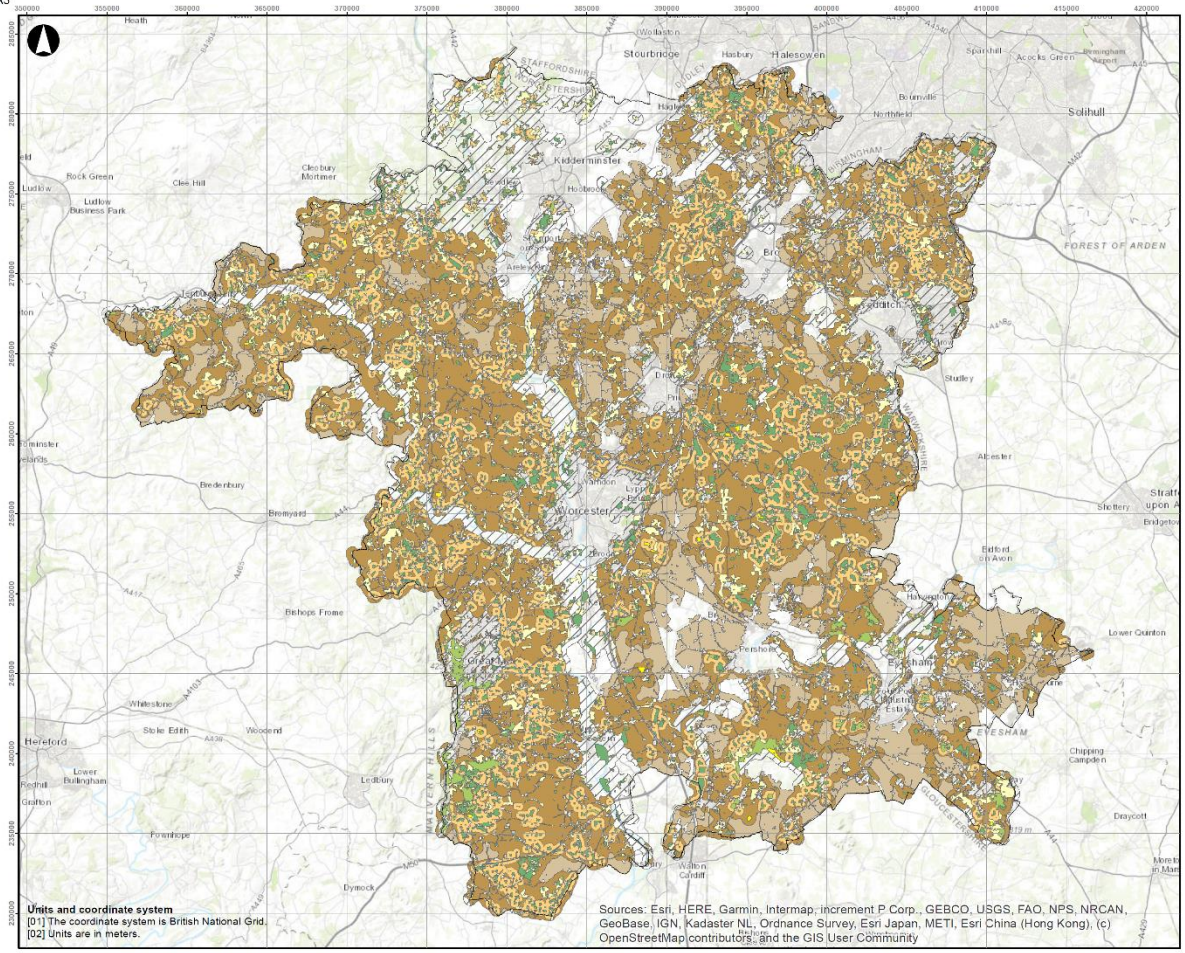
Merged output data attribution:

The **Zone** column contains the highest priority zone that polygon is assigned to, with Primary Habitat areas representing the highest priority zones and Network Expansion areas representing the lowest priority zones. If there are primary habitats present, then this land area will be attributed as Primary-Habitat. If no primary habitats are present but the polygon contains habitats that are identified as associated habitats to nearby primary habitat then this will be attributed as Associated-Habitat etc.

- The **Primary_Habitat** column contains the primary habitat(s) that are present in the polygon.
- The **Associated_Habitat** column lists the primary habitat(s) that associated habitats present may form a mosaic or ecologically coherent group within the landscape.
- The **Habitat_Creation_Resoration** column lists the primary habitat(s) under habitat restoration or creation options through Environmental Stewardship or Countryside Stewardship.
- The **Restorable_Habitat** column lists the primary habitat(s) that existing semi-natural, degraded or fragmented habitat may be restored to.

- The **Network_Enhancement_Zone_1** column lists the primary habitat(s) that the land is likely to be suitable for creation of based on factors including proximity to primary habitat, land use (urban/rural) and soil type.
- The **Network_Enhancement_Zone_2** column lists the primary habitat(s) that the land is in proximity to but may be less suitable for creation of those habitats than areas in zone 1.
- The **Fragmentation_Action_Zone** column lists the primary habitat(s) where there is high fragmentation to existing patches of habitat which could be reduced through habitat creation.
- The **Network_Expansion_Zone** column lists the primary habitat(s) where there is potential for expanding, linking/ joining networks in the landscape beyond the network enhancement zones.

A3



Inset Map Legend

Worcestershire County

Main Map Legend

Worcestershire County Boundary

Lowland meadows (LMW)

Class

- Primary Habitat
- Associated Habitats
- Habitat Restoration-Creation
- Restorable Habitat
- Fragmentation Action Zone
- Network Enhancement Zone 1
- Network Enhancement Zone 2
- Network Expansion Zone

Notes, Guidance and Limitations

[01] This habitat connectivity map has been developed using the Refreshed Worcestershire Habitat Inventory (WHI) 2021 produced as part of 'Contract No. 11/10/19/0230/022. January 2020 v2'.
[02] 11 habitat network connectivity maps have been produced, 10 of these are for individual priority habitats and 1 is a merged output, which brings together all of the overlapping connectivity zones of all of the individual priority habitat outputs. It is recommended that these maps are considered in combination in order to appreciate the complete picture of habitat network connectivity for Worcestershire county.
[03] The aim of the habitat network maps is to help identify possible locations for actions to improve ecological resilience of the current habitat network in line with Lawton principles 'more, bigger, better and joined'.
[04] The connectivity outputs help to identify priority areas for habitat restoration at county scale. As they have been produced through a geospatial process using remote sensing data and without ground-truthing, the outputs should only be used to help inform decisions around habitat management and any interventions for a particular site should take account of local knowledge of the area and ecological expertise.
[05] Further details of the methodology used to develop the refreshed Worcestershire habitat inventory and the habitat connectivity maps and about the output data, uses and limitations can be found in the project Technical Report 2021. It is recommended that this report is consulted for further guidance in using this data.
[06] The habitat connectivity analysis has been undertaken using a version of the Natural England (NE) habitat connectivity tool (after Edwards et al. 2020), adapted specifically for use at county scale and with the refreshed Worcestershire habitat inventory data.

The NE tool mapping components for the habitat connectivity analysis are divided into **A) 'Existing Habitat'** and **B) 'Network Enhancement and Expansion'** these include:

A. Existing Habitat - Existing habitats need to be associated with the following four components:

1. Primary Habitat: The habitat which is the focus of the individual habitat network e.g. lowland heathland.
2. Associated Habitat: Other habitat types that form a mosaic or an ecologically coherent group within the landscape and may, for example, be essential for some species associated with the primary habitat.
3. Habitat Creation/Restoration: Areas where work is underway to either create or restore the primary habitat.
4. Restorable Habitat: Areas of land, predominantly composed of existing semi-natural habitat where the primary habitat is present in a degraded or fragmented form and which are likely to be suitable for restoration.

(B) Network Enhancement and Expansion – The following 4 network zones around the habitat components described above have been mapped:

5. Network Enhancement Zone 1: Land connecting existing patches of primary and associated habitats which is likely to be suitable for creation of the primary habitat. Factors affecting suitability include the following: proximity to primary habitat, land use (urban/rural), soil type, slope and proximity to coast. Action in this zone to expand and join up existing habitat patches and improve the connections between them can be targeted here.
6. Network Enhancement Zone 2: Land connecting existing patches of primary and associated habitats which is less likely to be suitable for creation of the primary habitat. Action in this zone that improves the biodiversity value through land management changes and/or green infrastructure provision can be targeted here.
7. Fragmentation Action Zone: Land within Enhancement Zone 1 that connects existing patches of primary and associated habitats which are currently highly fragmented and where fragmentation could be reduced by habitat creation. Action in this zone to address the most fragmented areas of habitat can be targeted here.
8. Network Expansion Zone: Land beyond the Network Enhancement Zones with potential for expanding, linking/ joining networks across the landscape i.e. conditions such as soils are potentially suitable for habitat creation for the specific habitat in addition to Enhancement Zone 1. Action in this zone to improve connections between existing habitat networks can be targeted here.

Limitations
The current maps are a product of the data input and manipulation parameters used within the tool both of which may be amended to suit specific local situations. As such the maps should not be considered as Arup's definitive advice on where an ecological network or Nature Recovery Network should be created or specifically where action needs to take place but we hope that they may act as a guide for local consideration taking full account of local opportunities and constraints. We suggest that the maps are used in conjunction with other datasets and with local knowledge to identify opportunities for action.

Issue	Date	By	Chkd	Appd
P1	16-03-21	DC	GC.RA	GC

ARUP

13 Fitzroy Street,
London W1T 4BQ
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MXD Location

Metres
0 3,400 6,800 13,600

Client
worcestershire county council

Job Title
Worcestershire Habitat Inventory Refresh

Habitat Connectivity Map: Lowland meadows (LMW)

Scale at A3
1:270,000

Job No	Drawing Status
272854-00	Final
Drawing No	Issue
001	F1

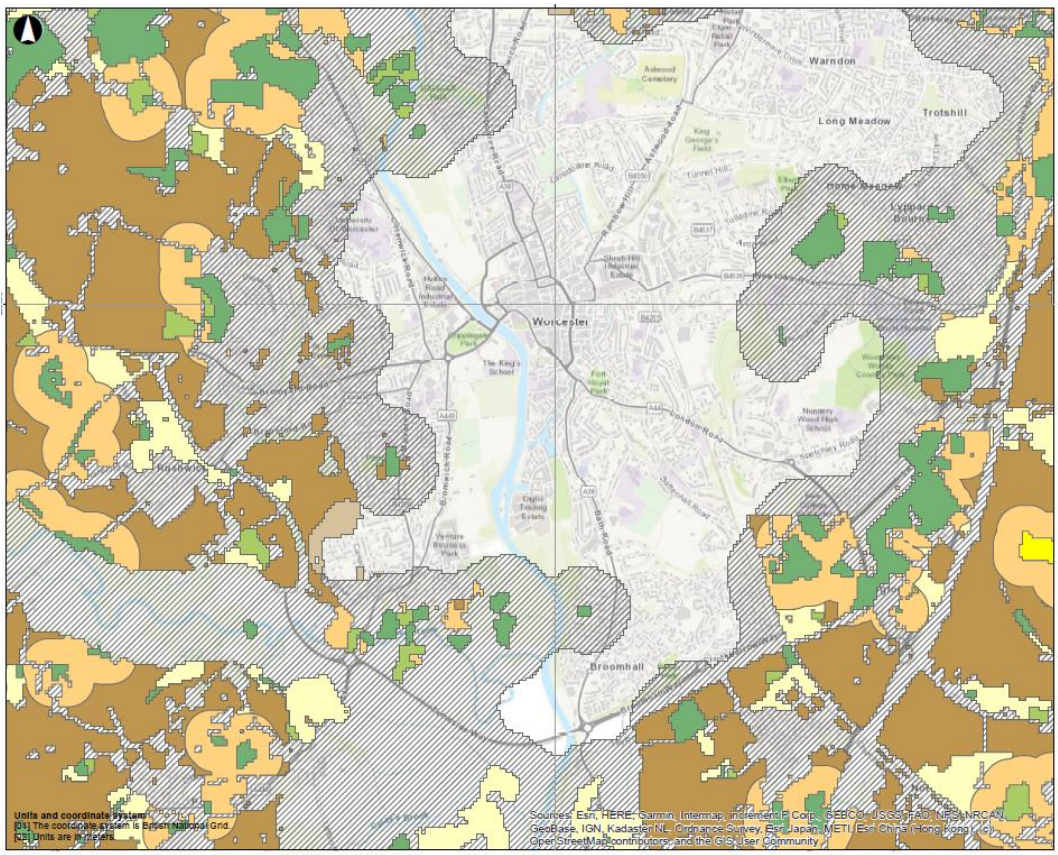
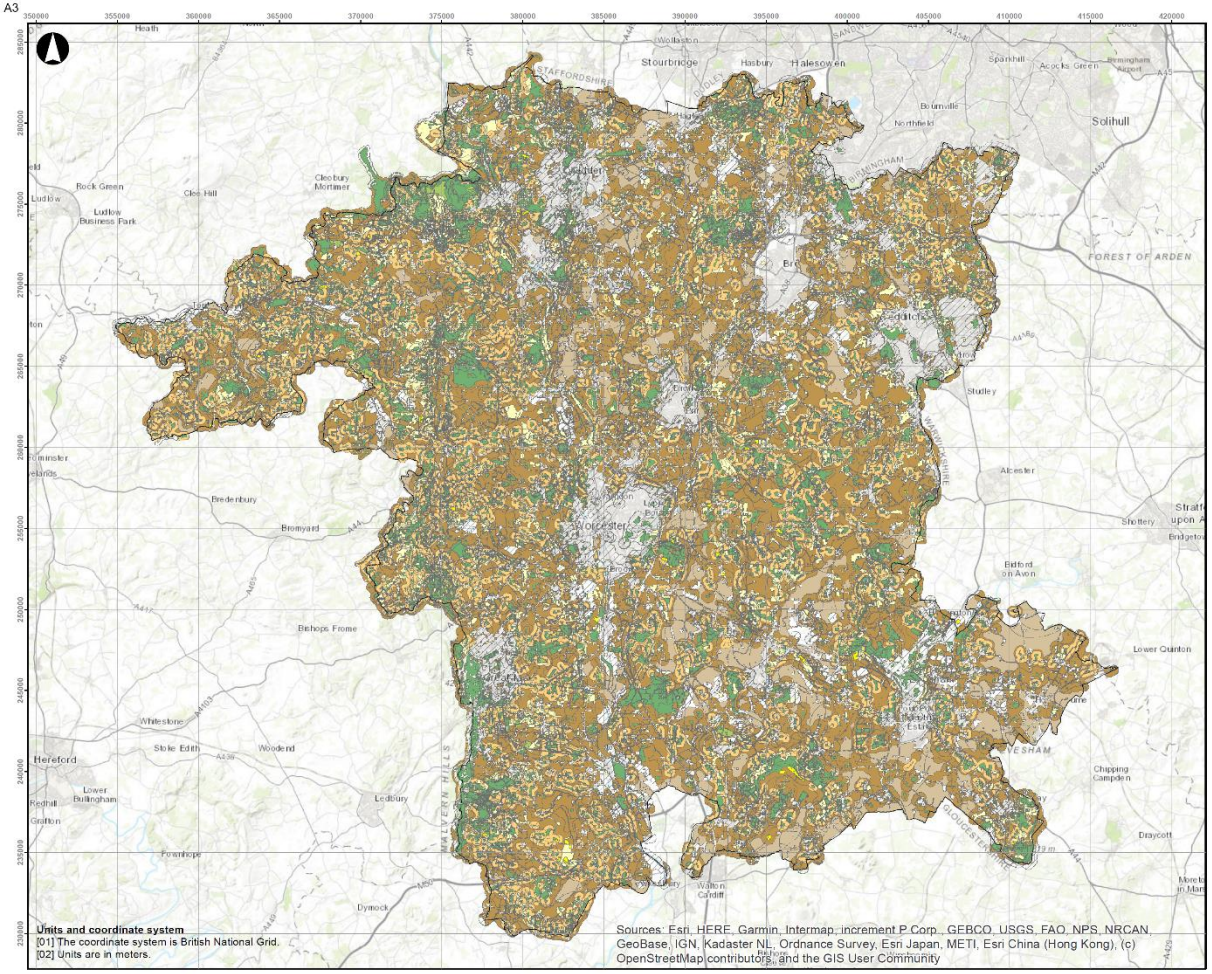


Figure 28: Example zoomed area of the Lowland Meadows (LMW) output at 1:30,000 scale.

A3



Inset Map Legend

Worcestershire County

Main Map Legend

Worcestershire County Boundary

Class

- Primary Habitat
- Associated Habitats
- Habitat Restoration-Creation
- Restorable Habitat
- Fragmentation Action Zone
- Network Enhancement Zone 1
- Network Enhancement Zone 2
- Network Expansion Zone

Notes, Guidance and Limitations

[01] This habitat connectivity map has been developed using the Refreshed Worcestershire Habitat Inventory (WHI) 2021 produced as part of 'Contract No. 11/10/19/0230/022. January 2020 v2'.
[02] 11 habitat network connectivity maps have been produced, 10 of these are for individual priority habitats along with ancient semi-natural woodland and 1 is a merged output, which combines all of the overlapping connectivity zones of all of the individual outputs. It is recommended that these maps are considered in combination in order to appreciate the complete picture of habitat network connectivity for Worcestershire county.
[03] The aim of the habitat network maps is to help identify possible locations for actions to improve ecological resilience of the current habitat network in line with Lawton principles 'more, bigger, better and joined'.
[04] The connectivity outputs help to identify priority areas for habitat restoration at county scale. As they have been produced through a geospatial process using remote sensing data and without ground-truthing, the outputs should only be used to help inform decisions around habitat management and any interventions for a particular site should take account of local knowledge of the area and ecological expertise.
[05] Further details of the methodology used to develop the refreshed Worcestershire habitat inventory and the habitat connectivity maps and about the output data, uses and limitations can be found in the project Technical Report 2021. It is recommended that this report is consulted for further guidance in using this data.
[06] The habitat connectivity analysis has been undertaken using a version of the Natural England (NE) habitat connectivity tool (after Edwards et al. 2020), adapted specifically for use at county scale and with the refreshed Worcestershire habitat inventory data.

The NE tool mapping components for the habitat connectivity analysis are divided into **A) 'Existing Habitat'** and **B) 'Network Enhancement and Expansion'** these include:

A. Existing Habitat - Existing habitats need to be associated with the following four components:

1. **Primary Habitat:** The habitat which is the focus of the individual habitat network e.g. lowland heathland.
2. **Associated Habitat:** Other habitat types that form a mosaic or an ecologically coherent group within the landscape and may, for example, be essential for some species associated with the primary habitat.
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Limitations
The current maps are a product of the data input and manipulation parameters used within the tool both of which may be amended to suit specific local situations. As such the maps should not be considered as Arup's definitive advice on where an ecological network or Nature Recovery Network should be created or specifically where action needs to take place but we hope that they may act as a guide for local consideration taking full account of local opportunities and constraints. We suggest that the maps are used in conjunction with other datasets and with local knowledge to identify opportunities for action.

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NXD Location

Metres
0 3,400 6,800 13,600

Client
worcestershire county council

Job Title
Worcestershire Habitat Inventory Refresh

Habitat Connectivity Map: Merged Output

Scale at A3
1:270,000

Job No	Drawing Status
272854-00	**Final**
Drawing No	Issue
011	**F1**

8 Natural England Tool Overview

As part of this project four different approaches to habitat network connectivity were reviewed in terms of their advantages and disadvantages. This review has been summarised in the Technical Guidance Report. Based on this review and discussion with the project stakeholders, the Natural England (NE) tool was selected as the preferred approach to habitat network connectivity analysis for Worcestershire. As described in Section 6 the tool mapping components for habitat connectivity analysis are divided into 'Existing Habitat' and 'Network Enhancement and Expansion' zones. The following section summarises the input datasets required to inform the key parameters of the connectivity tool.

8.1 Input datasets

In order to run the NE tool on the Refreshed WHI, several modifications were required. These included using soil information from the Land Cover Parcel (LCP) dataset in place of the original NE NSRI Soilscapes[13] data, which is for licensed use only.

The soils data is used within the habitat network maps to help determine the extent of Network Enhancement Zone 1 and the Expansion Zone only where soils and other conditions exist for habitat creation and restoration are more suitable. Network Enhancement Zone 2 extends over other areas e.g. areas without suitable soil types or over areas of urban development to identify where other actions, such as the provision of green infrastructure or changes in land management, might also be undertaken to improve resilience.

The input datasets used to run the analysis are as follows:

Component	Datasets used and description
Primary Habitat	The Refreshed WHI.
Associated Habitat	A range of habitats that typically occur as a mosaic with the primary habitat, care is taken to avoid including habitats that simply lie adjacent to the primary habitat i.e. transitional habitats, particularly where the extent of such habitats overwhelms and/or distorts the network map for the primary habitat. The source of this is the Refreshed WHI with IHS codes matched to the priority habitats that Natural England have identified as being associated, for example lowland heathland is associated with acid and neutral grassland and wetland habitats.
Restorable Habitat	Datasets of non-priority habitats. For the national analysis, NE included habitats such as good quality semi-improved grassland and fragmented habitats. For Worcestershire, the approach has been to use classes from the WHI such as possibly unimproved grassland, grazing marsh and broad classes for habitats such as wetland and heathland (provided in the Technical Guidance Report).

[13] http://www.landis.org.uk/soilscapes/soilguide.cfm

Component	Datasets used and description
Habitat restoration or creation	The data on existing habitat restoration and creation has been obtained from the Environmental Stewardship and Countryside Stewardship schemes datasets, which are available as open datasets. This is a point dataset, with options associated with Rural Land Registry boundaries. As the latter is not available, points have been joined to the OS MasterMap polygon that each point lies within. For Worcestershire the same scheme options as those used by NE in their national analysis have been implemented. For example, lowland fens are associated with Higher Level Stewardship options: HQ7 (Restoration of fen), HQ8 (Creation of fen) and Countryside Stewardship options: WT8 (Management of fen) and WT9 (Creation of fen).
Network Enhancement Zone	For the network enhancement zone, Natural England use additional datasets to narrow down where habitats may occur. For Worcestershire the following datasets have been used: Soil associations derived from a spatial analysis of the LCP soil attribution and the distribution of habitats in the existing Worcestershire Habitat Inventory. Any soil class intersecting at least 10% of each habitat class has been included (see the Technical Guidance Report for more details). A layer of urban settlements and road networks has been derived from OS MasterMap (see Figure 29) and habitat creation has been excluded from these areas.

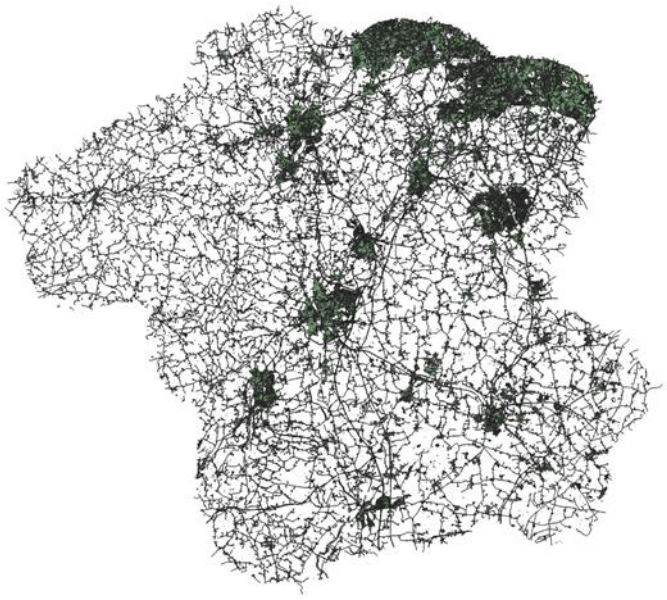


Figure 29: Urban areas and road networks derived from OS MasterMap (2019). Habitat creation is excluded from these areas.

8.2 Key parameters

The tool parameters described below can be adjusted on a habitat-by-habitat basis. This section describes these parameters and how they work.

Buffer distances:

The Network Enhancement Zone boundaries are drawn around the 4 habitat components (primary habitat, associated habitat, restorable habitat and habitat restoration or creation) – based on a standard, though variable, distance of 500m. The buffer is variable in that it is stretched where a slight extension would capture more habitat and/ or present a more complete network, i.e. its reach is extended in the direction of another relevant habitat patch. It works in the following way (see also Figure 31):

- Habitat patches are buffered by 500m.
- Any overlapping buffers are merged.
- Any holes (marked H in Figure 31) left when buffers are merged within patches of >100ha are filled in.
- The buffers are then reduced to 250m in order to constrain them where they aren't meeting other buffers. The resulting buffer area shown in orange in the figure below.
- This leads to a theoretical maximum buffer distance of around 1km. but in practice most buffers will not exceed far beyond 500m.

This 500m distance between patches has been selected based on Natural England's review of the literature and evidence relating to other network mapping approaches. The Enhancement Zone drawn through this standard approach is intended as a guide only and seeks to show the location of habitat patches that are more clustered together within the landscape to focus action to build greater ecological resilience of existing habitat patches. The distance used may be varied within the tool to prepare bespoke network maps for specific species if there is enough evidence available to justify this.

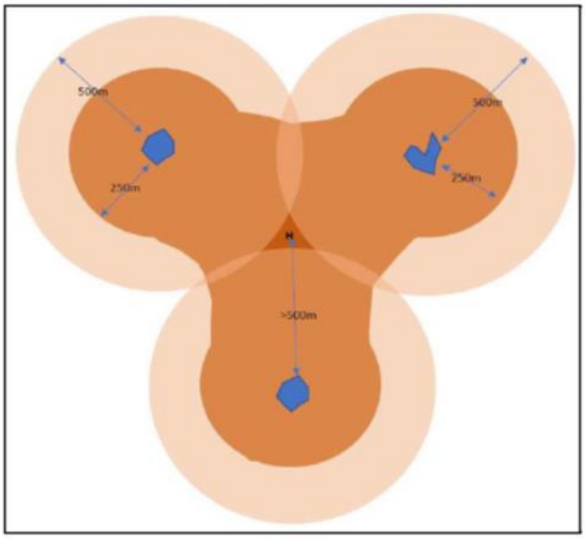


Figure 30: The variable buffering process, as presented in Edwards et al. (2020).

Patch size:

Patch size is used as part of the calculation to carry out the fragmentation assessment used within the analysis. The patch size varies according to the habitat type so habitats that are largely made up of relatively smaller patches are not disproportionately selected for fragmentation action thereby ignoring habitats with generally larger patches (however they will be selected more frequently due to their high levels of fragmentation). Figure 31 below provides further information on this.

Habitat	% of Habitat	Patch Size (ha)	
Blanket bog	10%	165	Larger less fragmented patches
Upland heath		75	
Coastal sand dunes		65	
Lowland raised bog		35	
Limestone pavement		20	
Coastal salt marsh	20%	25	
Coastal vegetated shingle		25	
Maritime cliff & slope		35	
Lowland acid grassland		50	
Lowland heath		50	
Lowland fen		20	
Upland calcareous grassland		25	
ASNW		50	
Lowland Calcareous grassland	30%	25	
Reedbed		15	
Lowland meadows	40%	20	Smaller more fragmented patches
Purple moor-grass		20	
Upland hay meadow		10	

Figure 31: Thresholds used for patch size assessment from Edwards et al. (2020).

Appendix A

Refreshed WHI Maps and BDAs

A1 Refreshed WHI Maps and BDAs

A1.1 Worcestershire BDAs

Biodiversity Delivery Areas (BDSs) were developed by the Worcestershire Biodiversity Partnership in 2011 as the focus for the delivery of the Biodiversity Action Plan (BAP).

They have been carefully selected as the parts of the county with the greatest potential to deliver the BAP targets for both species and habitats. The documents were originally developed in 2011 but were updated and refreshed in 2016. There are five areas of focus:

1. Bow Brook
2. Wyre Forest Acid Grassland and Heaths
3. Forest of Feckenham
4. Malvern Chase and Laugherne Valley
5. Severn and Avon Vales

Supporting documents outlining the targets for and projects which are being delivered in these BDAs are available from the council website.

In this Appendix, the BAP Targets for key habitats within each of the 5 BDAs, as defined in 2016, have been provided below for ease of cross-reference with the Refreshed WHI.

A1.1.1 Bow Brook

BAP Targets for key habitats within the Bow Brook Biodiversity Delivery Area:	
Fen and Marsh	Feckenham Wylde Moor nature reserve remains as the last fragment within the Bow Brook catchment of a once much more extensive area of marsh.
Lowland wet grassland	Much of the historic wet grassland resource within the floodplain has been subject to drainage and agricultural improvement. Huge potential exists for restoration.
Rivers and streams	The Bow Brook is a significant tributary of the River Avon.
Neutral grassland (lowland meadow)	Found throughout the area as small scattered and isolated fragments. A number of sites are in conservation ownership. Resource includes the Eades Meadow and Foster's Green NNR.
Wet woodland	Areas of wet woodland are frequent along parts of the brook.
Wood pasture, parkland and veteran trees	Veteran trees, including hedgerow trees, streamside trees and in-field trees, are found scattered throughout the area.
Hedgerows	Strong hedgerow networks provide priority habitat for key species including brown hairstreak butterfly.

BAP Targets for key habitats within the Bow Brook Biodiversity Delivery Area:	
Traditional orchards	Found throughout the area with a concentration in the south. Many sites are now small and fragmented. A number of Worcestershire orchards support noble chafer populations.

A1.1.2 Wyre Forest Acid Grassland and Heaths

BAP Targets for key habitats within the Wyre Forest Acid Grasslands and Heaths Biodiversity Delivery Area:	
Acid grassland	Acid grassland is present on all of the large sites in conservation management in this area. Outside of these, scattered and degraded acid grassland sites are frequent.
Lowland heathland	Several large nature reserves in this area are managed for the protection and restoration of heathland, which in Worcestershire occurs almost exclusively in the Wyre Forest district.

A1.1.3 Forest of Feckenham

BAP Targets for key habitats within the Forest of Feckenham Biodiversity Delivery Area:	
Ancient/species-rich hedgerows	Hedgerow networks contribute to the wooded character, provide connectivity between woodland blocks and habitat for brown hairstreak and other fauna.
Neutral grassland (lowland meadow)	Found throughout the area as small, scattered and isolated fragments. A number of sites are in conservation ownership. Resource includes the Eades Meadow and Foster's Green NNR.
Traditional orchards	Found throughout the area with a concentration in the south around Evesham and the Lenches. Many sites are now small and fragmented. A number of Worcestershire orchards support noble chafer populations.
Veteran trees with lowland wood pasture and parkland	The area contains a high number of hedgerow pollards and several significant wood pasture and parkland sites in conservation ownership, notably Hanbury Park and Pipershill.
Woodland	Small to medium-sized ancient semi-natural woodlands are an important characteristic, particularly in the north of the area.
Ponds	Several important 'pondscapes' exist within the project area that support meta-populations of great crested newt.

A1.1.4 Severn and Avon Vales

BAP Targets for key habitats within the Severn and Avon Vales Biodiversity Delivery Area:	
Fen and Marsh	Longdon Marsh was once the most extensive area of marshland in the county prior to repeated phases of drainage. Restoration of this area is a high priority.
Lowland wet grassland	Huge potential exists for restoration of this habitat. Many projects are already in existence or underway and joining up these sites must be a key element of delivery.

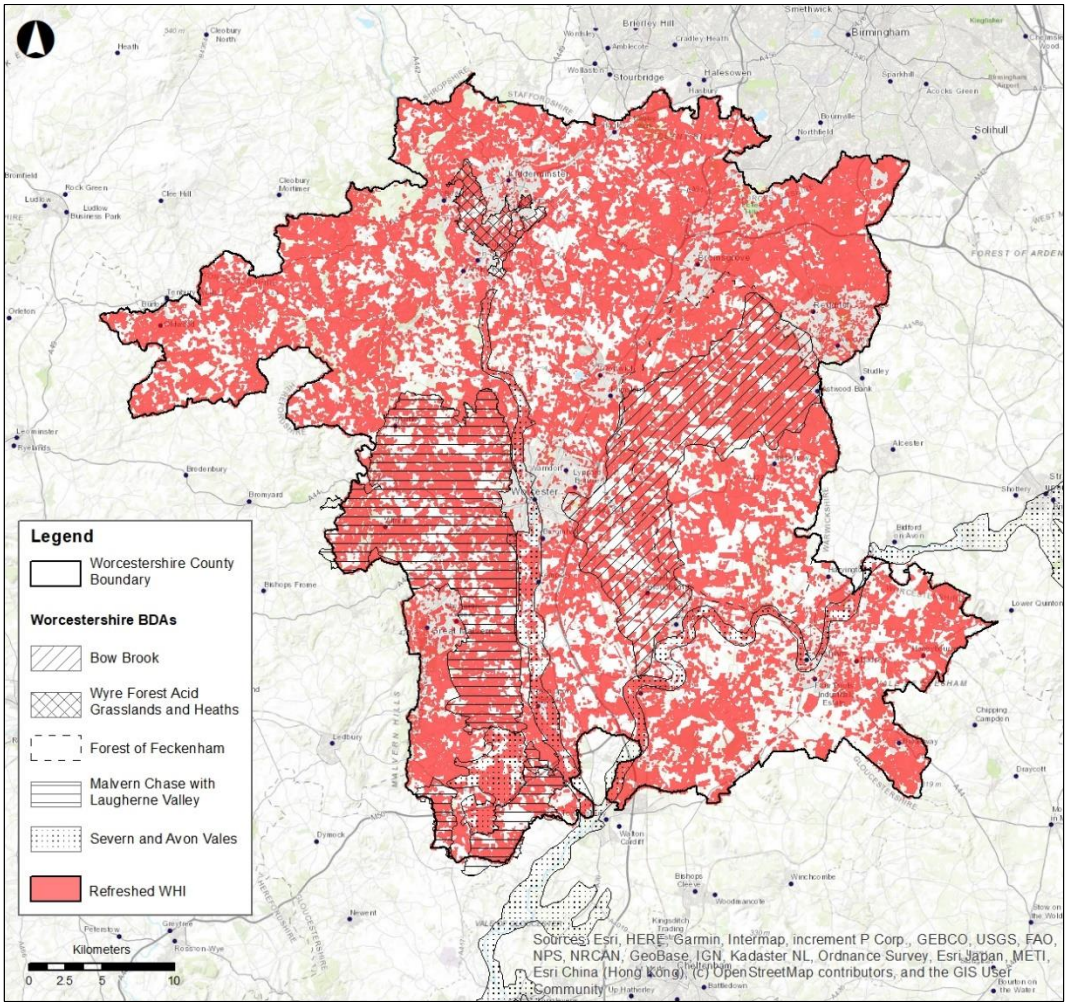
BAP Targets for key habitats within the Severn and Avon Vales Biodiversity Delivery Area:	
Rivers and streams	The Rivers Severn and Avon and their floodplains are the core of this project area. Re-connecting river and floodplain and restoring bankside habitat is be a high priority.
Neutral grassland (lowland meadow)	Found throughout the area as small scattered and isolated fragments.
Wet woodland	Found throughout the area along the rivers and their tributaries.
Reedbed	Found in fringes along many sections of river and tributary channel and as a key part of wetland sites within the floodplain.

A1.1.5 Malvern Chase and Laugherne Valley

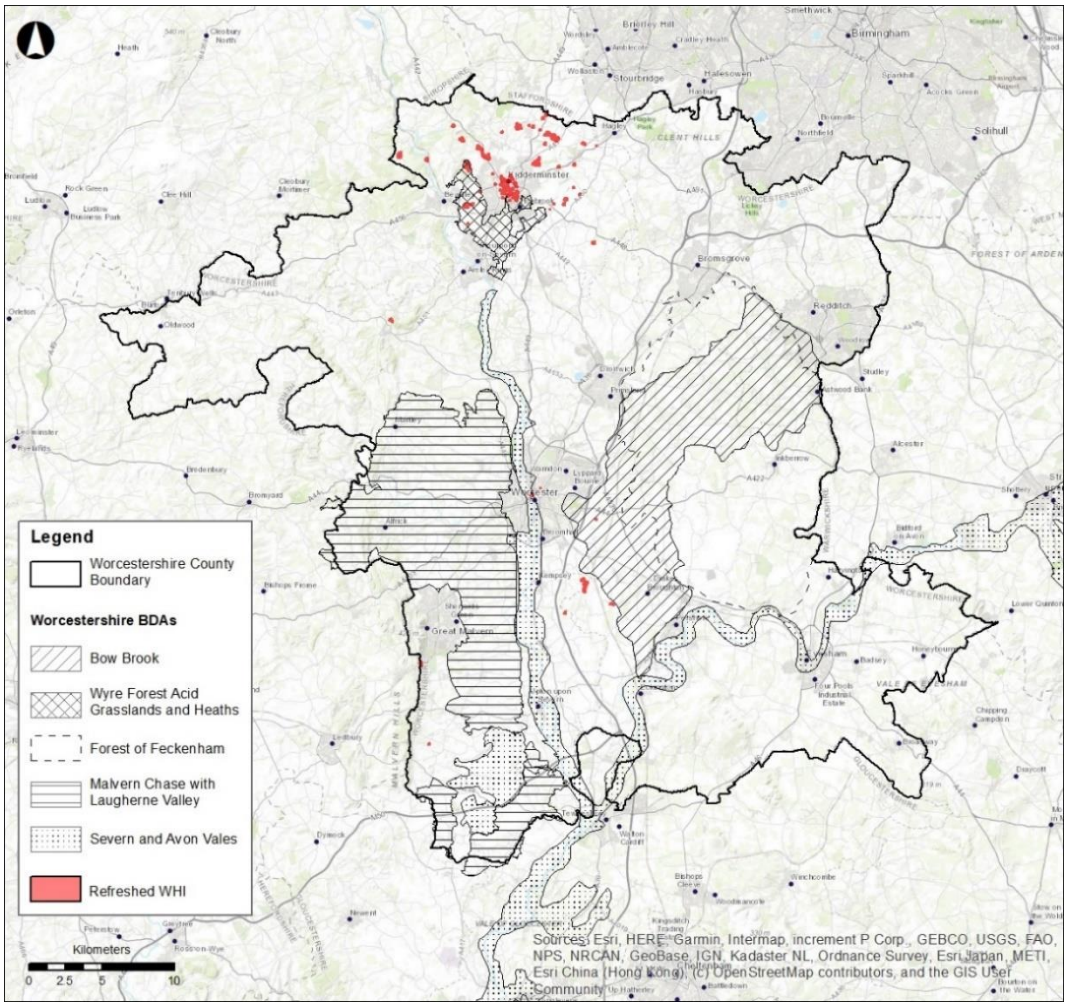
BAP Targets for key habitats within the Malvern Chase with Laugherne Valley Biodiversity Delivery Area:	
Ancient/species-rich hedgerows	Hedgerow networks contribute to the wooded character, provide connectivity between woodland blocks and habitat for dormice and other fauna.
Neutral grassland (lowland meadow)	Found throughout the area as small, scattered and isolated fragments. A number of sites are in conservation ownership.
Traditional orchards	Orchards are found throughout the area, with a concentration in the north. Many are small, remnant sites with aging trees. Many orchards here support populations of noble chafer.
Veteran trees with lowland wood pasture and parkland	The area contains a high number of hedgerow pollards and several significant wood pasture and parkland sites.
Woodland	The ridgeline of the Abberley and Suckley Hills is heavily wooded. Elsewhere, small ancient woodlands are frequent.
Ponds	Ponds are an important component of the farmed landscape, providing habitat for a range of species including great crested newt.
Acid grassland	Occasional fragments of acid grassland are found here associated with the various Commons.

A1.2 Refreshed WHI Maps and BDAs

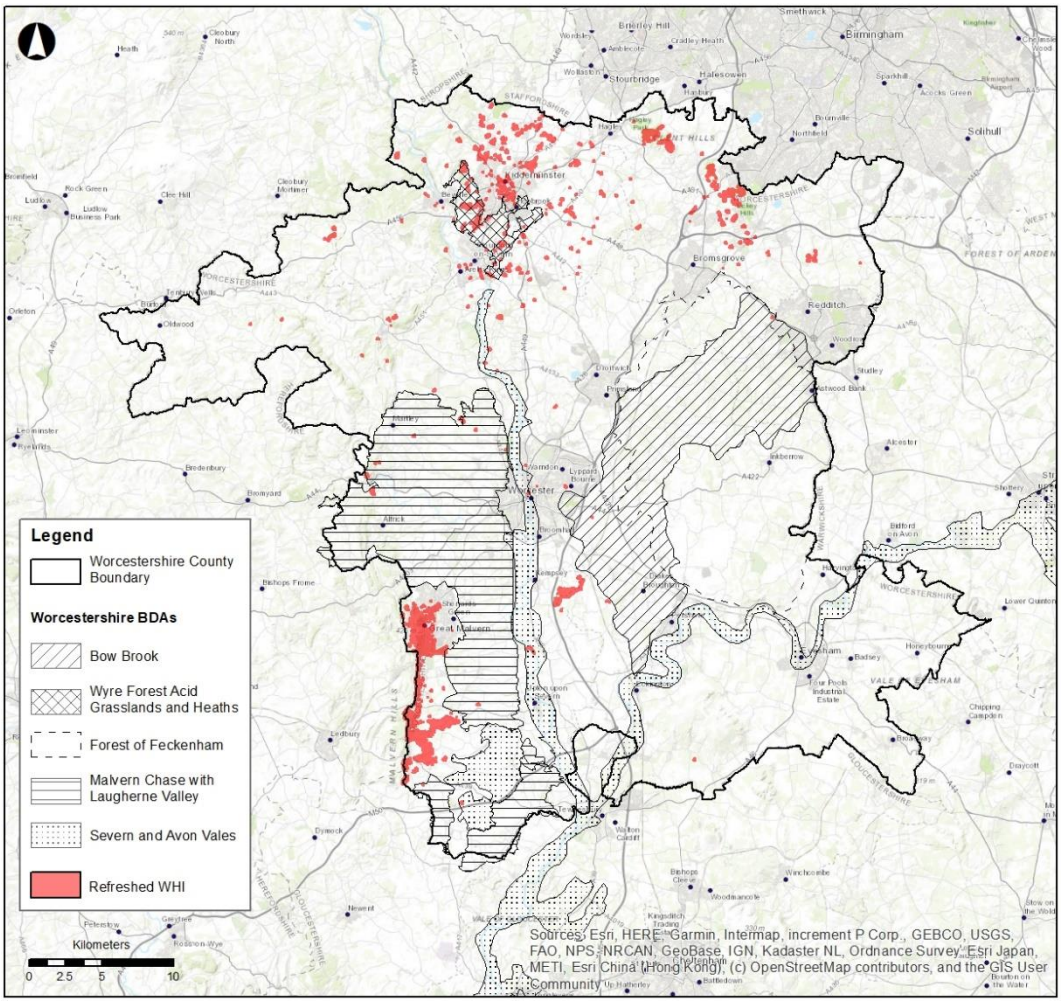
A1.2.1 All grassland habitat



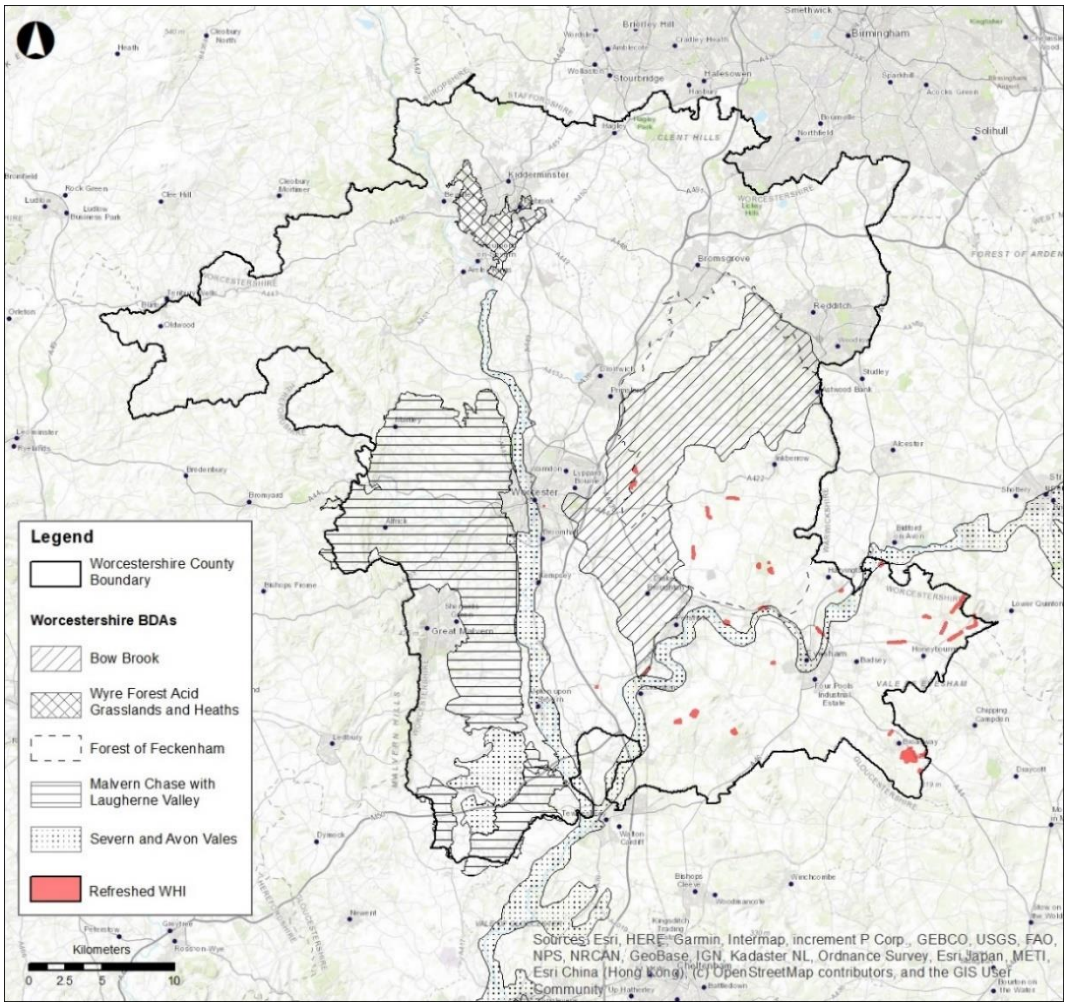
A1.2.2 BAP Acid Grassland (GA1)



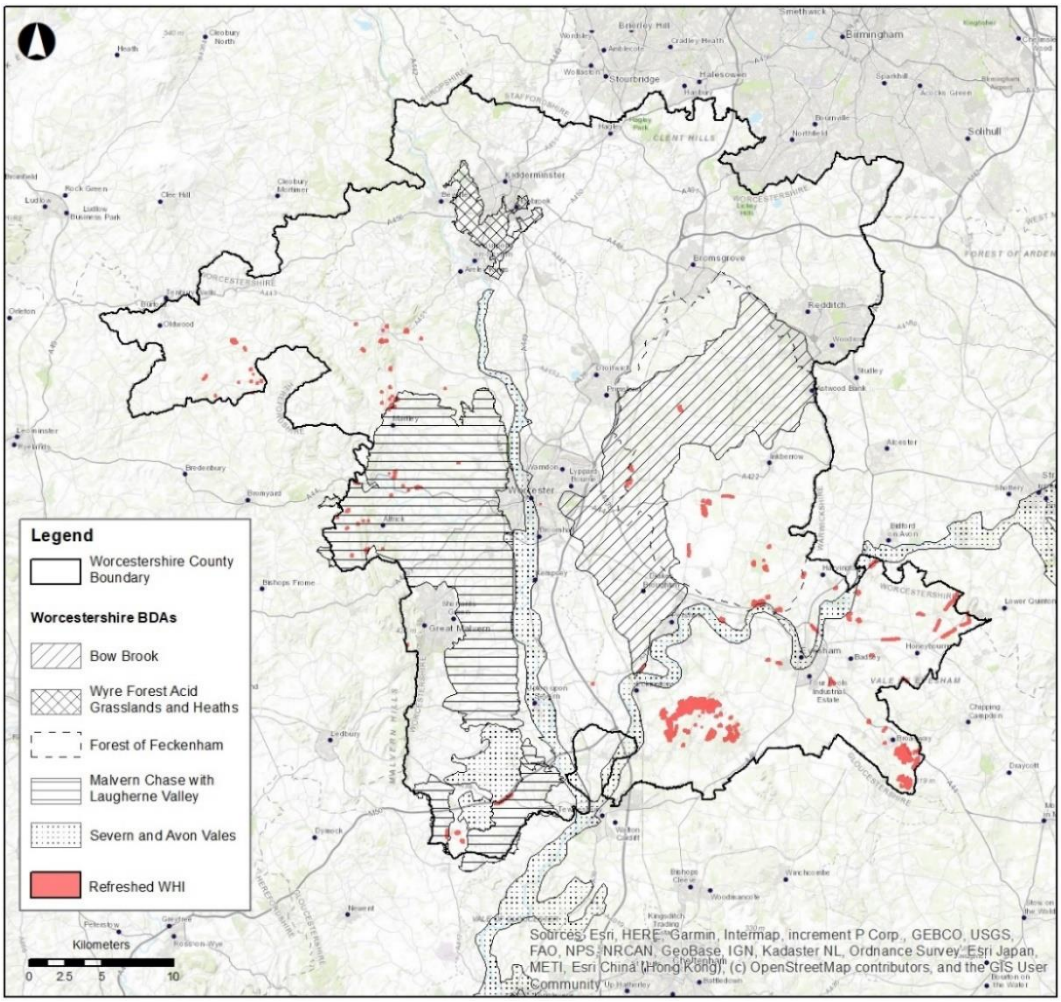
A1.2.3 BAP Acid Grassland (GA0 and GA1)



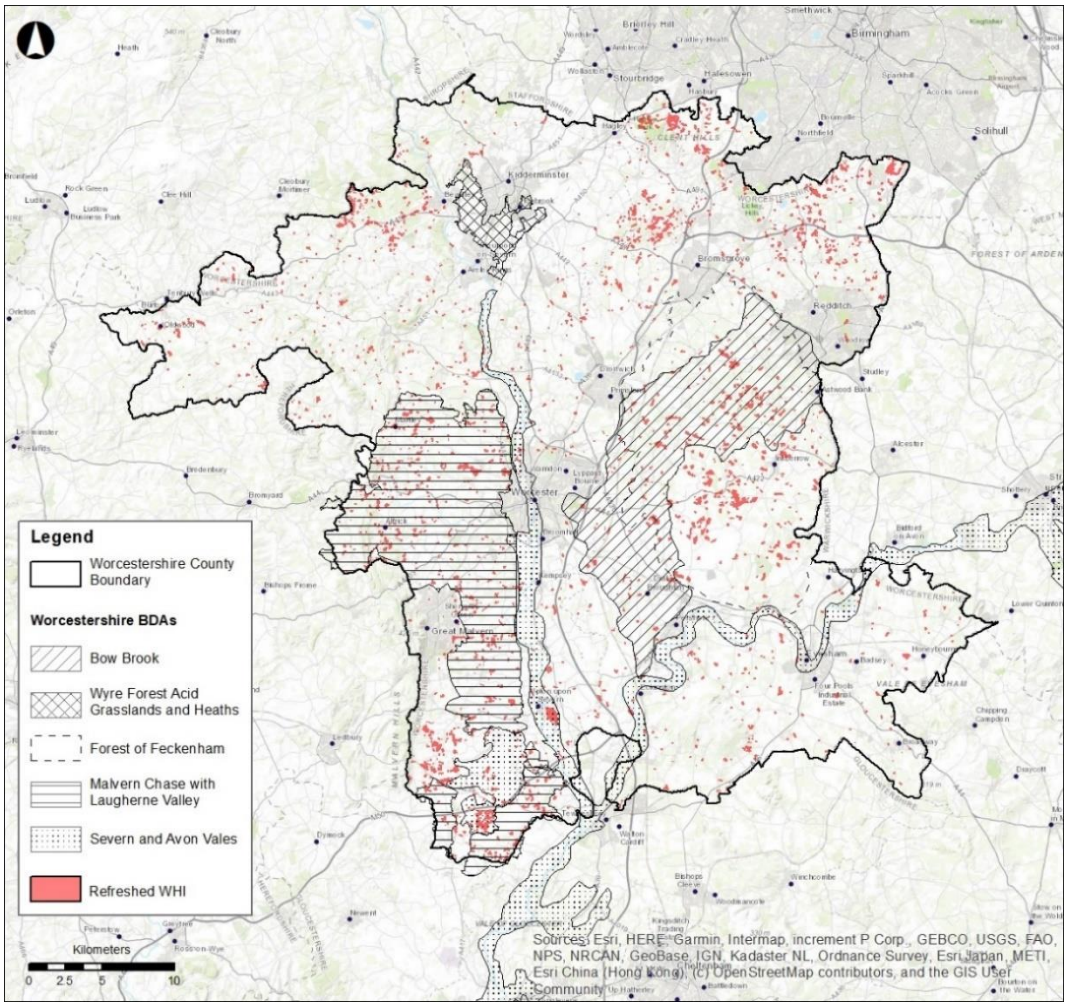
A1.2.4 BAP Calcareous Grassland (GC1)



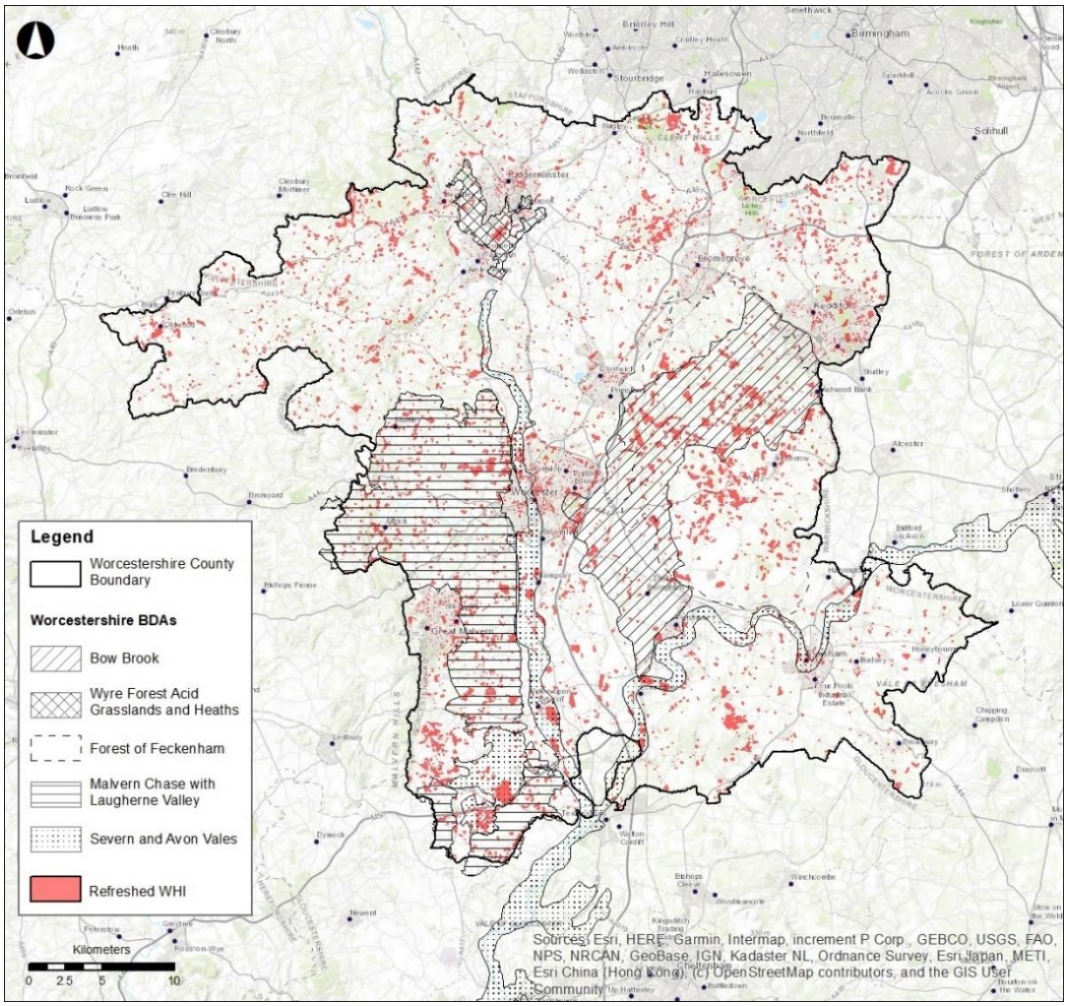
A1.2.5 BAP Calcareous Grassland (GC0 and GC1)



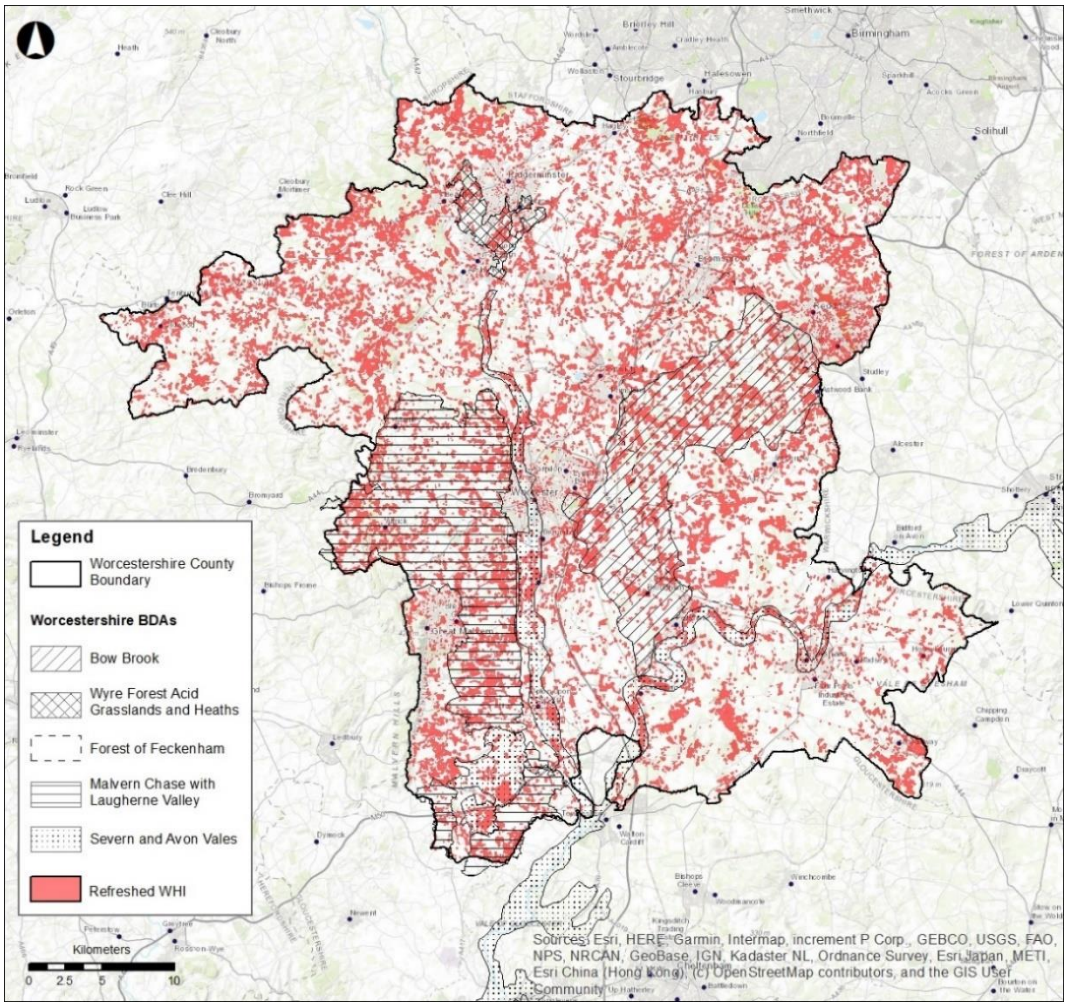
A1.2.6 BAP Neutral Grassland



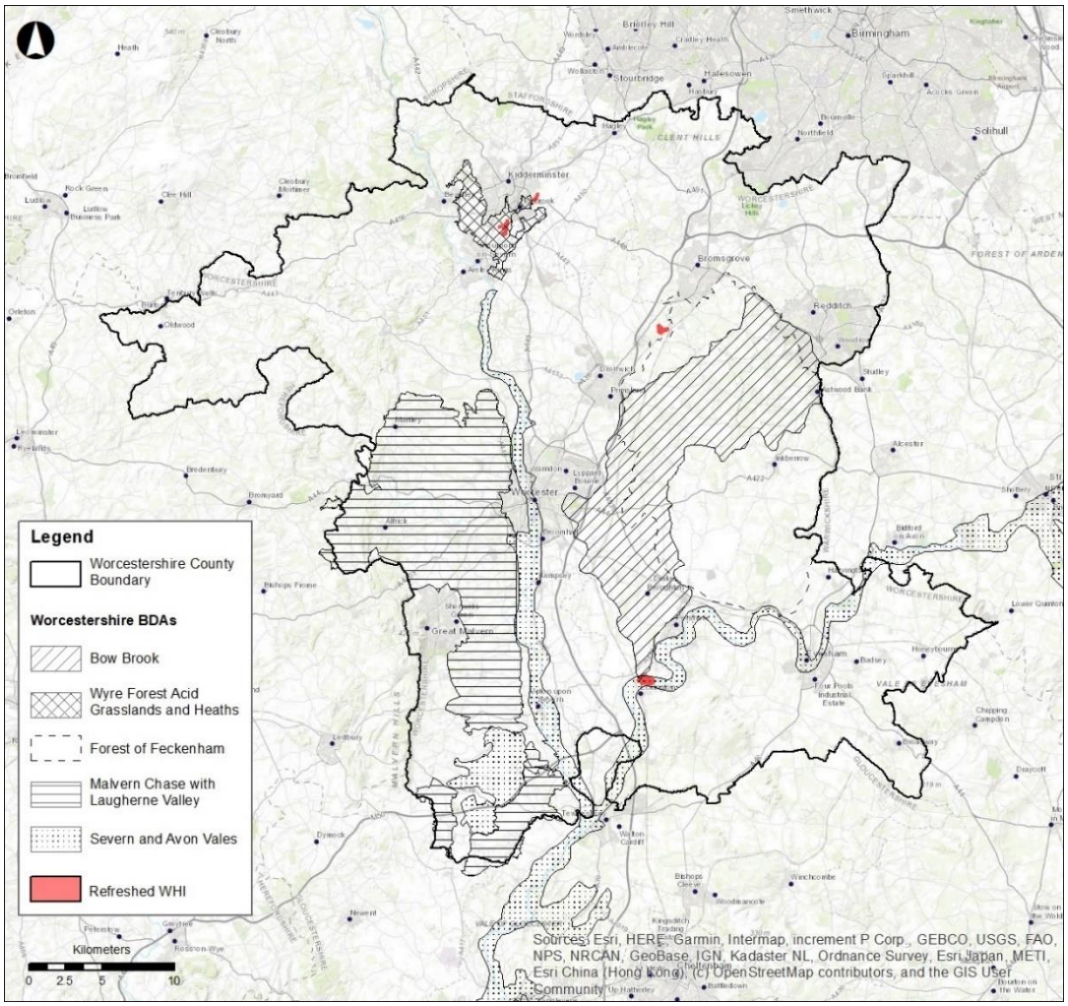
A1.2.7 BAP and Semi-Natural Neutral Grassland



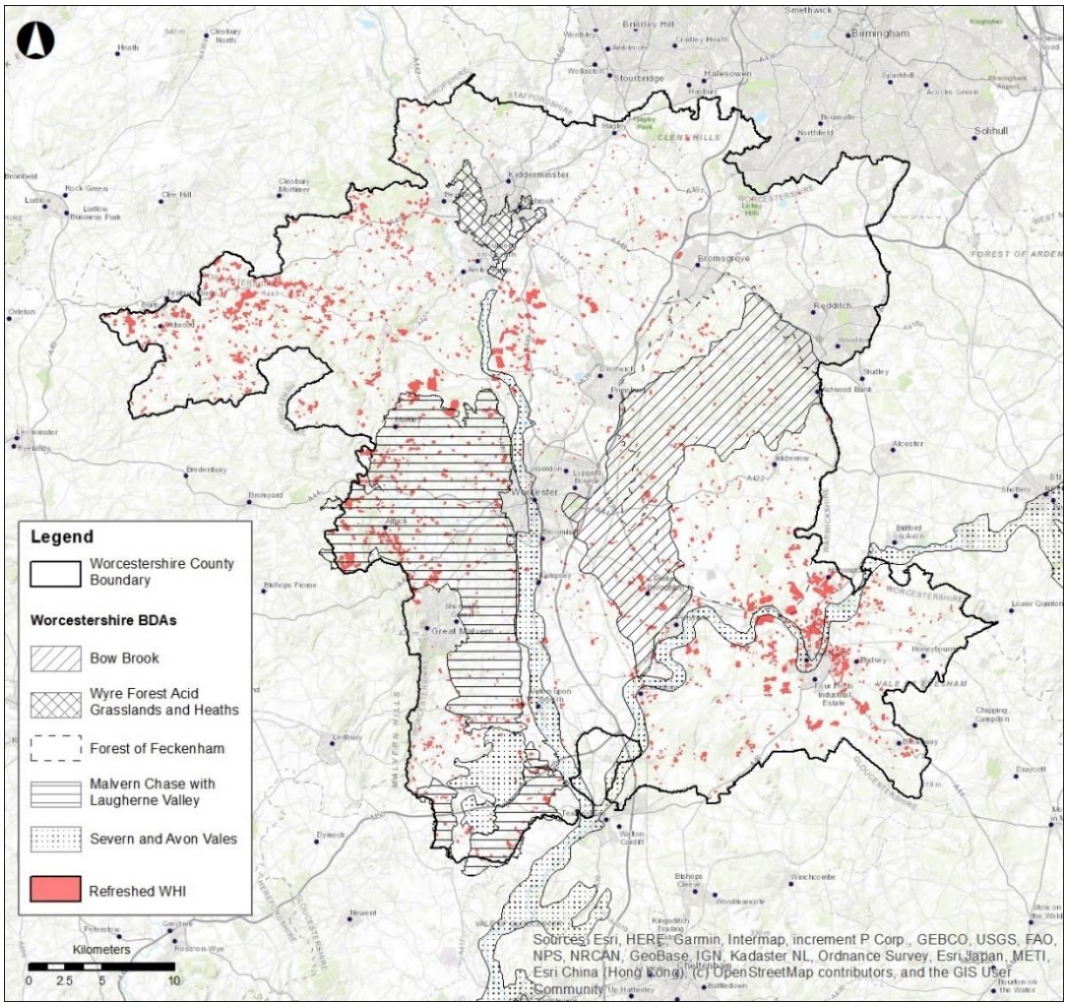
A1.2.8 BAP, Semi-Natural and possibly Unimproved Neutral Grassland



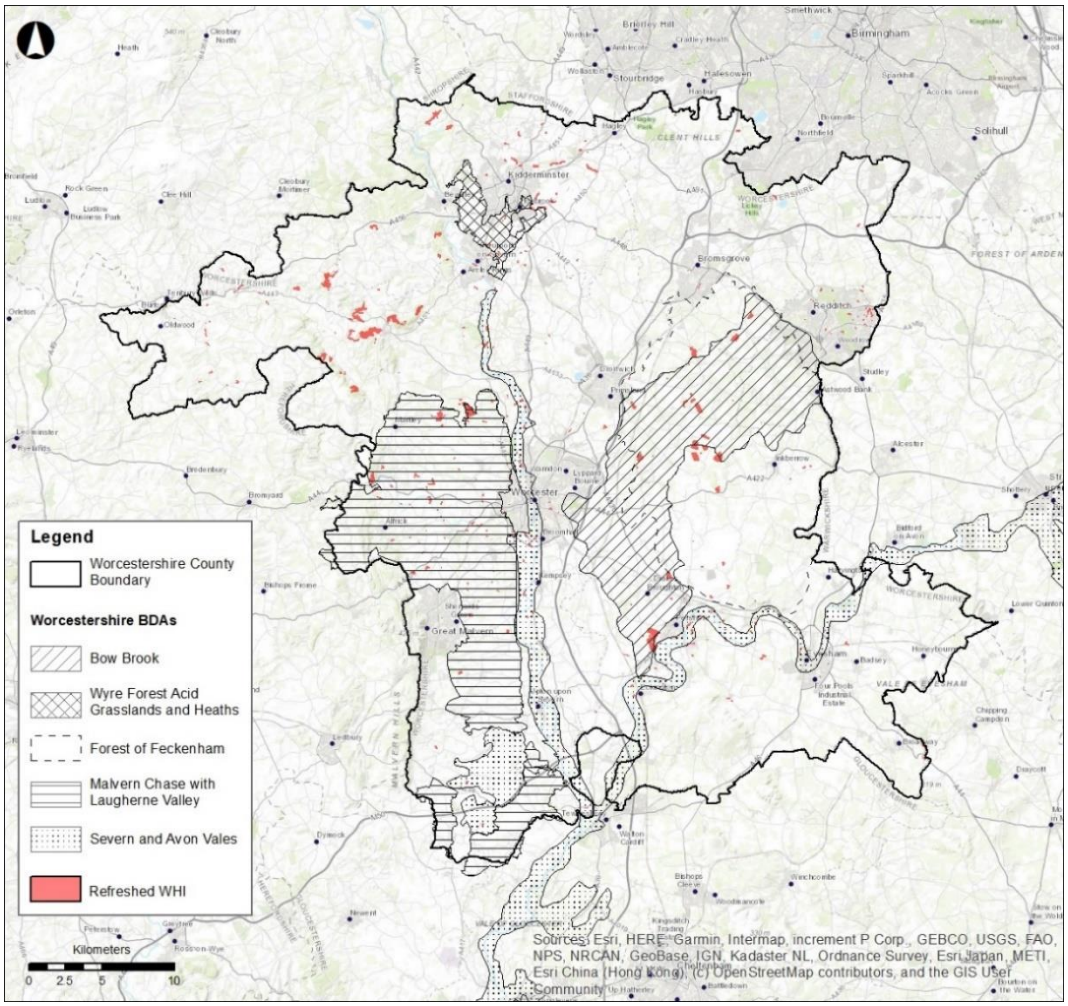
A1.2.9 Floodplain Grazing Marsh



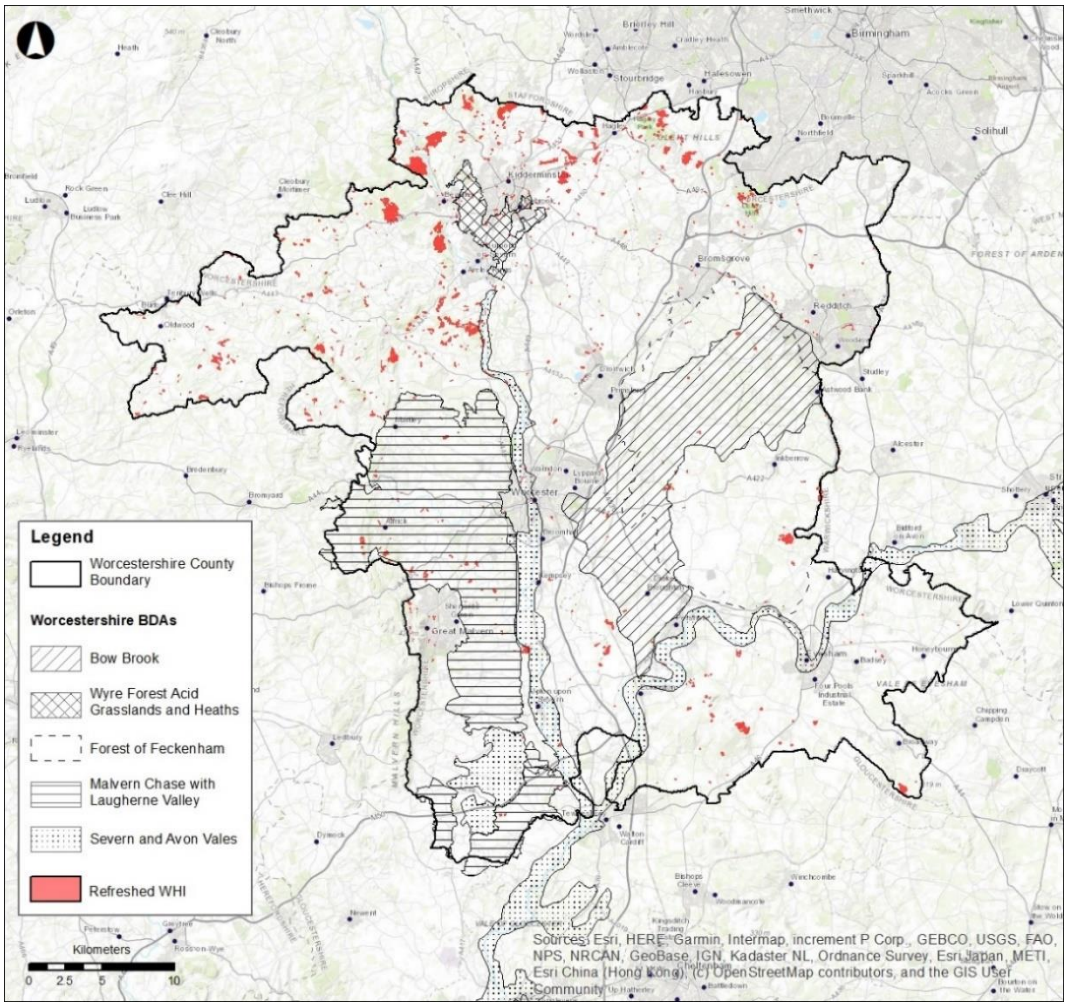
A1.2.10 Standard and Traditional Orchards



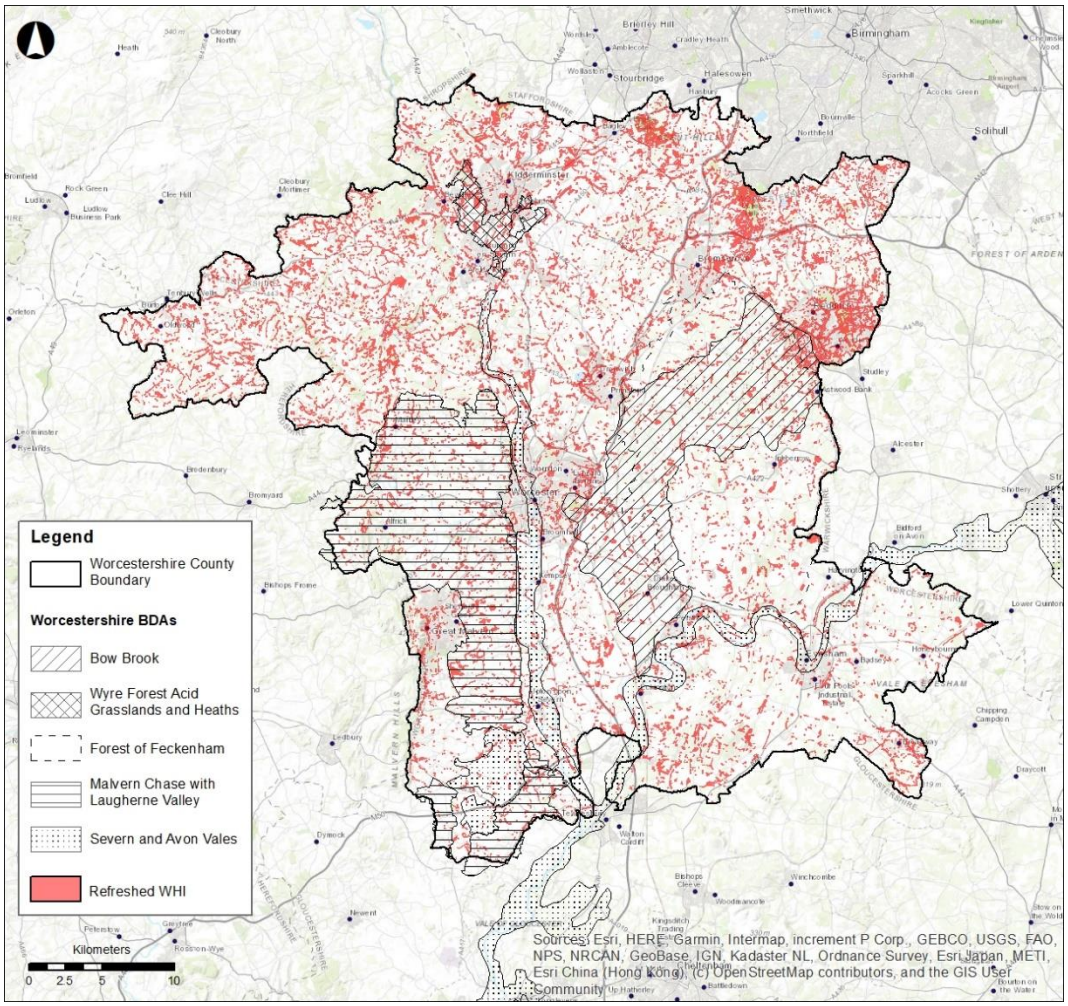
A1.2.11 BAP Woodland



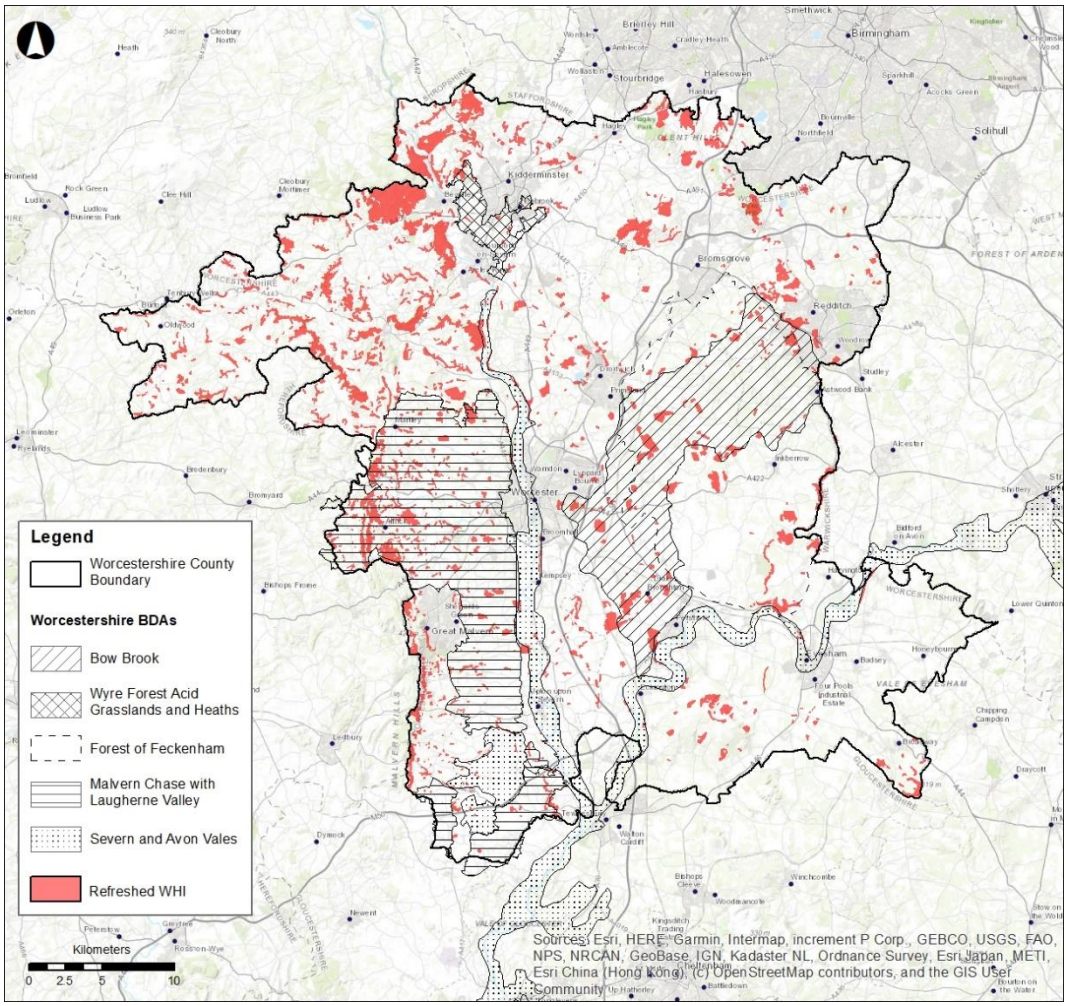
A1.2.12 Coniferous Woodland



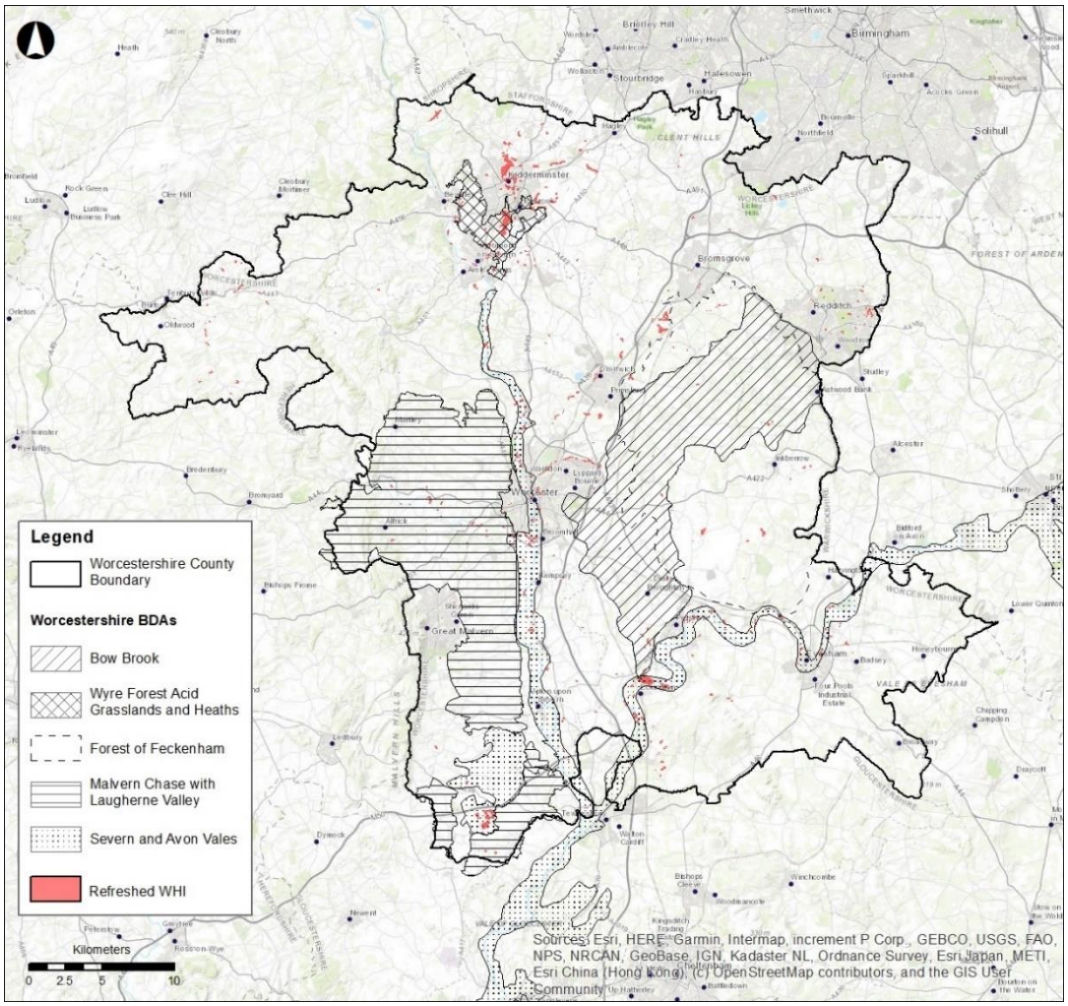
A1.2.13 Broadleaved Woodland excluding recorded BAP or Ancient Woodland



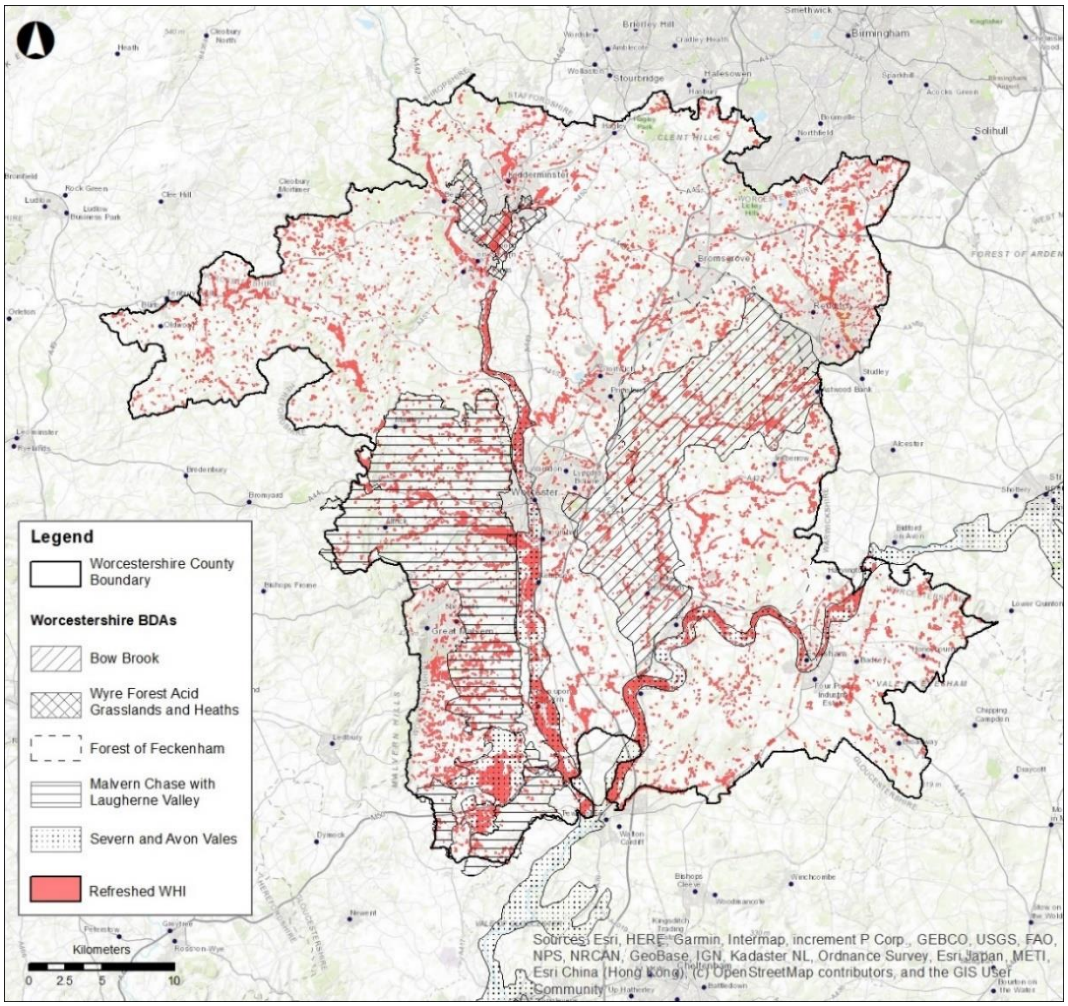
A1.2.14 Ancient Woodland



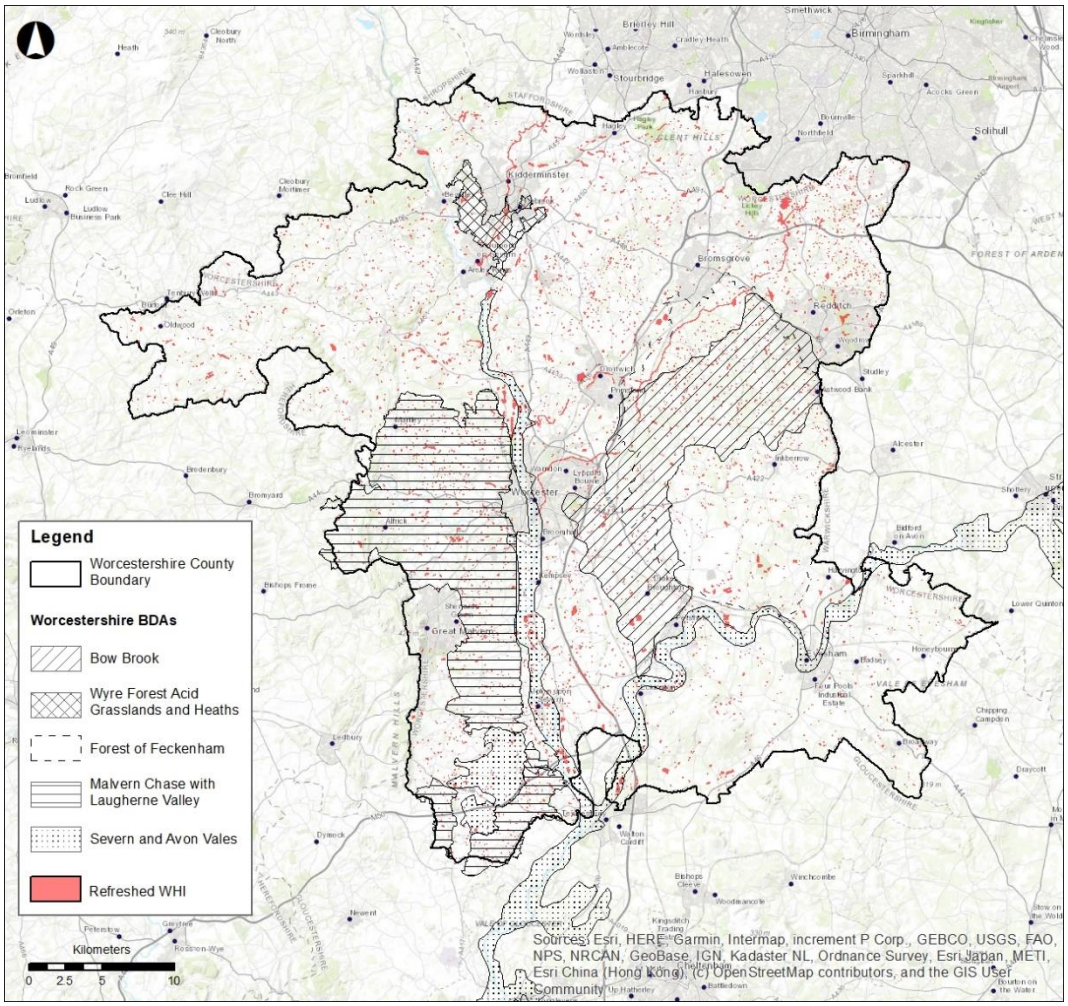
A1.2.15 Wetland



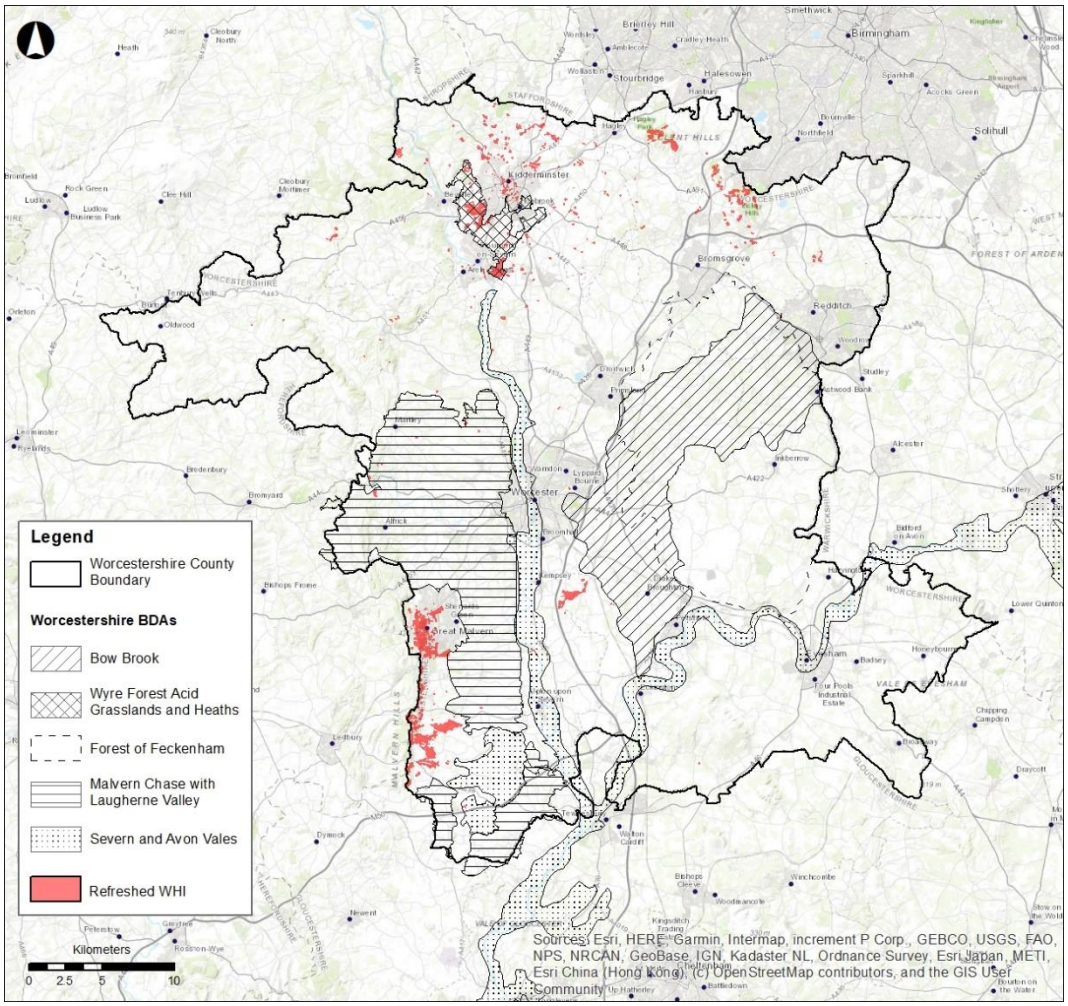
A1.2.16 Wet Grassland



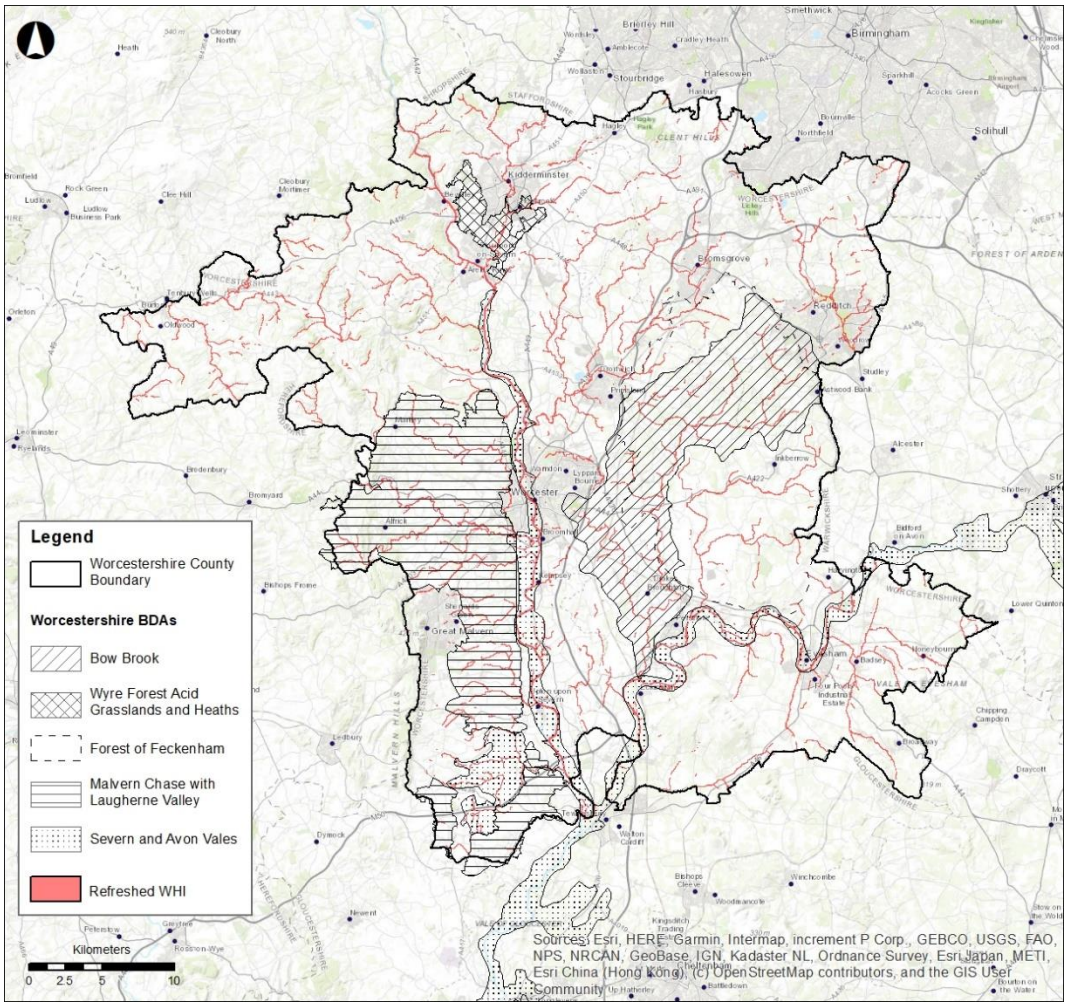
A1.2.17 Ponds, canals and other standing



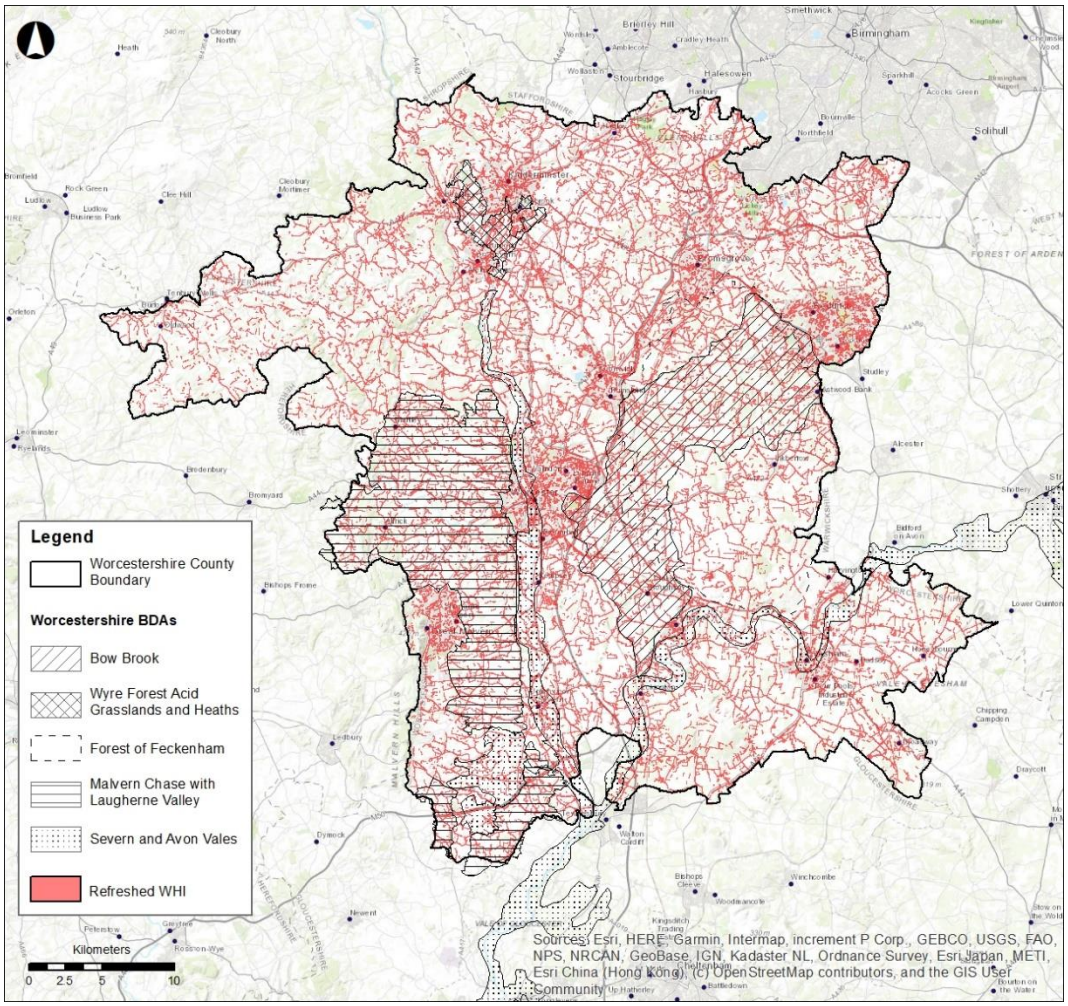
A1.2.18 Heathland and Acid Grassland



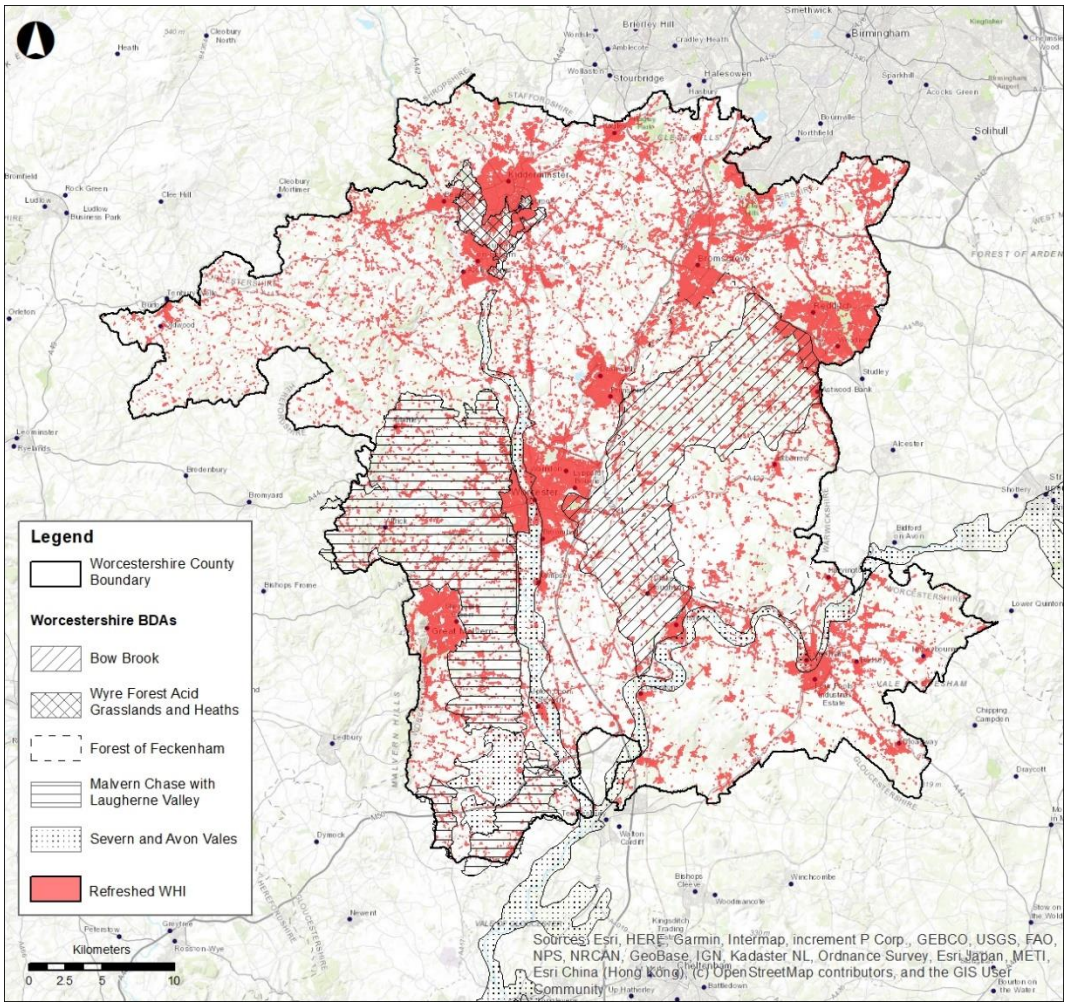
A1.2.19 Rivers and Streams



A1.2.20 Hedgerows and Line of Trees



A1.2.21 Urban Areas



A2 Confusion Matrix

Table 3: Random forest model confusion matrix for the Refreshed WHI.

Habitat code	AS0	AS4	BR0	BR1	BRZ	CR0	CR1	CR2	CR3	CR31	CR3Z	CR4	CR5	CR6	EM0	EM1	EM11	EM21	EM312	GA0	GA1	GC0	GC1	GC112	GI0	GN0	GN1	GN11	GN12	GN3	GN4	HE0	HE1	LF1	OT0	RE0	RE1	RE2	RE21	RE24	RE2Z	SC0	TH1	UR0	WB2	WB3	WB31	WB32	WB3312	WB34	WB36	WB361	WC0	TS0	PA0	BG1
AS0	95	0	0	0	0	3	0	0	0	0	0	0	1	1	4	0	1	0	0	2	0	0	0	1	2	3	1	0	3	0	0	0	0	2	0	0	0	1	0	0	0	0	0	5	14	11	0	0	0	4	1	0	2	4	0	0
AS4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BR0	0	0	12	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	3	0	0	0	0	0	0	0	1	1	0
BR1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BRZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CR0	0	0	0	0	0	96	1	1	2	3	0	1	6	3	0	0	0	0	0	0	0	2	0	0	27	1	1	0	1	2	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	1	0	0	0	0	0	1	0	0	5	0	6
CR1	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
CR2	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
CR3	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CR31	0	0	0	0	0	1	0	0	0	14	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CR3Z	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CR4	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CR5	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CR6	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EM0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	19	2	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
EM1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EM11	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EM21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EM312	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GA0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	18	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	3	1
GA1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GC0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	9	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
GC1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GC112	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GI0	3	0	0	0	0	11	0	0	0	0	0	1	2	0	1	0	0	0	0	1	0	0	0	1	50	8	0	0	3	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	2
GN0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	7	39	1	0	6	0	1	0	0	0	0	0	0	0	0	1	0	0	2	0	2	3	0	0	0	0	0	1	0	0	2	0	2
GN1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	20	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	1
GN11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GN12	2	0	2	0	0	6	0	0	0	1	2	0	2	0	1	0	0	0	0	2	1	1	0	0	0	19	1	1	66	3	0	0	0	0	2	0	0	0	0	0	0	0	3	0	1	2	1	0	0	0	0	0	0	5	4	2
GN3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	13	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GN4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
HE0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	4	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0
HE1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LF1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	10	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1
OT0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
RE0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RE1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RE2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RE21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RE24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RE2Z	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC0	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	1	2	0	0	3	0	0	0	0	0	0	1	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TH1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
UR0	7	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	1	0	2	0	0	1	0	1	0	3	0	0	0	0	0	1	1	0	0	1	2	0	0	7	0	71	11	7	0	0	0	0	1	0	0	4	2	2
WB2	0	0	2	0	1	2	0	0	0	1	0	0	0	1	2	0	1	0	0	3	0	1	1	0	0	1	3	0	2	0	0	0	0	3	2	0	1	0	1	0	0	2	0	3	38	6	0	0	0	0	2	0	1	0	0	1
WB3	14	0	3	0	1	1	0	0	0	5	2	0	0	0	3	1	0	0	0	2	0	1	1	0	1	5	1	0	8	4	0	0	0	4	3	0	1	0	1	0	0	3	0	1	22	235	1	3	0	10	21	0	18	1	1	2
WB31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
WB32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	4	0	0	0	0	0	0	0	0	0
WB3312	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	4	0	0	0	0	0	0	0	0
WB34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	2	0	0	0	17	0	0	0	2	0	0
WB36	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	49	0	0	0	0	0
WB361	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WC0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	41	0	0	0	0
TS0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	16	0	0	0
PA0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
BG1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4	0	0	0	1	0	0	0	0	3	4	0	0	2	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	18

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