Worcestershire Nature Recovery Network Mapping Methodology

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Contents

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1 Introduction

This document provides a brief overview of the Worcestershire Nature Recovery Network (NRN), its purpose and how it has been created. The method is largely the same as that used to create the neighbouring Gloucestershire and Herefordshire NRNs, but the creation of the Habitat base layer was adjusted for the different formats in which the habitat data was supplied.

1.1 The Nature Recovery Network concept

The NRN is a concept put forward by DEFRA in the 25 Year Environment Plan. It is described as a national network of wildlife-rich places, that are well connected and provide natural solutions to environmental issues. In creating such a network, they aim to achieve the following by 2042:

- Restore 75% of protected sites to favourable condition
- Create or restore 500000 hectares of additional wildlife-rich habitat
- Recover threatened and iconic species
- Increase woodland cover
- Achieve a range of other benefits (which broadly speaking fall under the umbrella of ecosystem services)

Here we will treat the term NRN to mean the maps and data underlying the ideas described above. The NRN will be a series of maps that identify where this network should be in a given study area, based on currently available data. Interpretation of these maps will provide targets for nature recovery efforts to help join up existing high-quality habitats.

1.2 Why create a Nature Recovery Network map?

Both humans and nature rely on functioning ecosystems to provide all the services required for survival. Pressure on the environment from humans has resulted in the loss and fragmentation of habitat. Each species has specific requirements for survival which will include obtaining enough food and water, finding a mate, finding shelter etc. Parameters which affect a species ability to fulfil these requirements are the patch sizes of suitable habitat available to them (minimum viable area), the species' ability to disperse (dispersal distance) and the distance between the patches (connectivity). In the assessment of the state of the England's ecological network, the Lawton review 2020 stated that it was not fit for purpose, sites were too far apart and separated by too hostile an environment to support the movement of species for both general survival and in the face of migration required to mitigate for climate change. The phrase Better, Bigger, More and More Joined was coined in the review, and are the principles held to for expanding ecological networks in the UK.

In order to create a functional ecological network, i.e. one where the suitable patches of habitat are not necessarily physically connected, but are close enough and separated by a permeable enough matrix to enable species movement between patches, we need to protect and maintain (Better) and restore outwards (Bigger, More, More Joined) from the existing good quality semi-natural habitat that we still have. The Nature Recovery Network (NRN) mapping presented here, follows these principles.

1.3 The principles behind the mapping

Step 1: understand what we already have, core patches and surrounding habitat/land use (produce complete cover habitat/land use map and identify core habitat patches).

Step 2: understand how connected the core patches of the network currently are at a range of dispersal distances to cover a number of species groups (connectivity mapping).

Step 3: look at how resilient and coherent individual core patches and networks of functionally connected patches are (informs step 5) (network resilience map layers).

Step 4: map network expansion that would reinforce the core networks i.e., the area close to existing good habitat (NRN mapping layers).

Step 5: map strategic restoration areas; these are the bigger gaps between networks that need bigger investment in larger projects to deliver restoration across a large area.

Data modelling can only take you so far and the modelling detailed below takes you up to Step 4, Step 5 requires human interpretation of the mapping and a Local Nature Partnership is suggested as the most likely forum through which Step 5 can be delivered.

1.4 Urban areas

Urban areas are included in the network (there is no "White Space"). If the ability of land to support biodiversity is considered along a continuum from low biodiversity benefit (e.g. concrete, or a highly modified ryegrass ley) to high biodiversity benefit (e.g. ancient semi-natural woodland or unimproved species rich grassland), then there is always the potential to move those at the lower end of the scale, up the scale a notch. Whether that is incorporating planters or street trees or green roofs into an urban landscape, or moving from ryegrass up to a ryegrass and clover ley or further again up to mixed herbal ley in the farmed environment. All actions add up to an improvement on the current situation.

Within the NRN mapping methodology, urban areas are not separated out in any way, other than that they will be scored as less permeable to species movement in the cost distance analysis. Therefore, for example, where the Woodland Network is shown as a high or medium priority across an urban area, is prioritising effective locations for tree planting of any kind to occur to increase canopy cover and so contribute towards woodland connectivity across the landscape. Appropriate tree planting solutions (in gardens, public open space, along highways etc) can all be delivered within green infrastructure inside settlement boundaries/urban extensions.

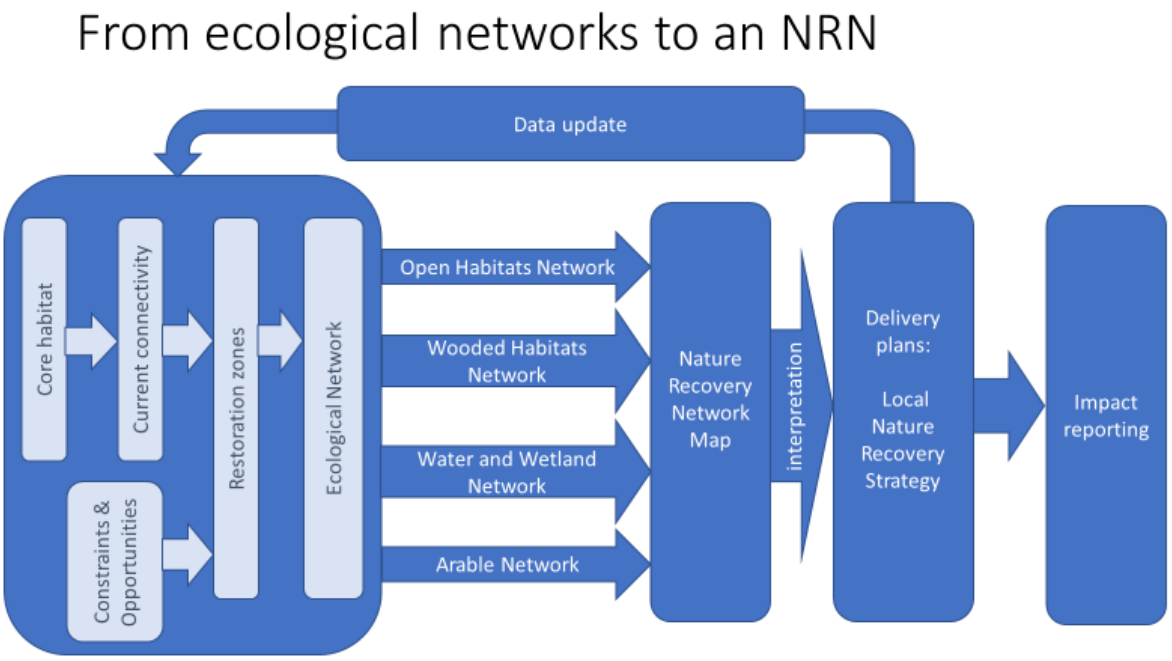


Figure 1: Flow chart showing the larger context and use of NRNs

1.5 Caveats for use, and spatial scales

The Nature Recovery Network should be considered as an indicative aid to decision making. A guide to the areas where habitat restoration or enhancement would create the greatest benefit to increase the connectivity and resilience of the existing network. It is generated from modelling of best available data and may not always reflect the true picture on the ground, therefore advice on interventions should always be sought from suitably qualified experts. Care should always be taken to prevent degradation or further isolation of any existing valued habitat.

The NRN mapping is based on ecological needs, therefore there will be other constraints that need to be considered alongside the NRN when site interventions or projects are being planned, such as the local historic environment record, strategic infrastructure and obviously landowner and occupier engagement and permission.

The NRN has been mapped with a view to balancing the need to view it at a county scale while still being useful to guide project planning at a site level. If each individual priority habitat type (up to 56 in England) is mapped as a separate network and overlayed, it is so complicated a map that it makes interpretation and decision making extremely difficult. In order to achieve a better balance of information and ease of interpretation, habitats have been grouped into different functional systems (Ecological Networks) based on the National Ecosystem Assessment groupings. The four Ecological Networks and the habitats considered core habitat for each network are given in table 1.

Table 1. Habitats considered as core for each Ecological Network

Ecological Networks	**Core habitats**
Open Habitat Network	All priority* habitat grasslands and heathlands
Woodland Network	All broadleaved semi-natural or mixed mainly broadleaved seminatural or broadleaved ancient woodland
Wetland Network	All priority* freshwater wetland habitats

Arable Network	Core habitats not used for this network, it is an assessment of the use of Agri-environment options, important arable plant areas and opportunities for locating arable options.

**Priority habitats are those listed in Section 41 of the Natural environment and Rural Communities Act 2006.*

In the modelling, Open habitat and Woodland are presented as a single continuous layer by using a conditional decision tree to decide whether a location is a higher priority for Open habitat or Woodland or of equal priority in which case a matrix habitat may be of benefit. The Open or Woodland equal priority areas are an indication of where the Open and Woodland networks cross and care should be taken not to cut off the connectivity of one network with the other, e.g. dense woodland planting could cut off the Open habitat network, but Traditional Orchard or Wood Pasture or grassland with scattered scrub or woodland with wide rides and glades could provide benefits for both networks at the crossing point.

Traditional Orchard, and Wood Pasture and Parkland, though priority habitats in their own right, are not considered core habitats, but they are important elements in the Open and Woodland networks due to their very high assigned permeability for those networks.

The Wetland Network layer is provided as a transparent overlay. Where it crosses the Open habitat network there could be opportunities for fen type habitats. Where it crosses the Woodland network there could be opportunities for wet woodland.

The Arable network examines opportunities for increasing the wildlife value of existing arable land to the specific species groups which are most dependant on arable land use, the arable plants and farmland birds. The needs of these groups are considered in separate layers which can help inform the use of relevant agri-environment scheme options. They are then brought together into a series of overall arable network high medium and low opportunity layers for simpler public presentation.

2 Complete cover, habitat base layer

2.1 Creating the Worcestershire, plus 3km buffer, habitat layer

The Worcestershire Habitat Inventory (WHI-2) was supplied by Worcestershire County Council containing UK Habitat Classification system (UKHabs) codes (Butcher et al. 2018). Any habitat survey data covering a 3km buffer around Worcestershire was obtained from organisations in adjacent counties (data sources are in Table 2). The buffer ensures that the cost distance model can look for connectivity outside of the county so that the connectivity is correct at the border.

For the Gloucestershire and Herefordshire NRN mapping, we had used the Ordnance Survey Master Map (OSMM) topographical (polygon) layer as the base polygons into which to attribute the best available habitat data. However, the WHI-2 has been created from interpretation of remote sensing (satellite) imagery using a polygon geometry of watershed segmentation rather than OSMM. Therefore, the WHI-2 data was kept in this format, but the surrounding buffer data was created by attributing the various supplied habitat data sets into the OSMM polygons. The two were then joined by clipping the inside edge of the buffer to the WHI-2 data.

Data processing

Some data clean-up was initially required to remove any overlaps and invalid geometries.

The source datasets used different habitat classification systems. To standardise these differing classification systems, all habitat classifications were converted to UKHabs, adding a primary code and secondary code(s) (if applicable) to each polygon in all data sources.

Once coded to UKHabs, the Worcs and buffer data sets were merged. Roads and buildings were added back in from OS Mastermap (as these were not included in the WHI-2 layer) and any areas of missing habitat/land use were extracted from UK CEH Landcover map 2022 20m open data Raster version.

Table 2. Habitat data sources

Data Source	UKHabs translation
Worcestershire Habitat Inventory 2	Already coded to UKHabs but required some tidying to ensure consistency
Warwickshire 3km buffer	Converted Phase 1 to UK Habs
Gloucestershire 3km buffer	Already coded to UKHabs
Herefordshire 3km Buffer	Already coded to UKHabs
Shropshire 3km buffer	Convert IHS to UKHabs
Staffordshire 3km Buffer	Converted Phase 1 to UK Habs
Birmingham and Black Country 3km Buffer	Used CEH LCM as more reliable than satellite interpretations supplied.
UK CEH Landcover Map 2022	Broad habitats were coded into UK Habs

3 Ecological network connectivity

3.1 Open habitat, woodland and wetland ecological networks connectivity

As mentioned above, the multitude of habitats were grouped into four ecological networks to enable easier interpretation of the maps. Connectivity for three of the networks (open, woodland and wetland) was modelled using cost distance analysis.

The original Forest Research methodology (Watts et al 2021) upon which this was based used generic focal species. A generic focal species is described in Eycott et al (2007) as "a conceptual species, whose profile consists of a set of ecological requirements reflecting the likely needs of real species …… should encompass the needs of most (but not all) real species that need to be considered in the landscape plan or evaluation". These are model species for which you set parameters of minimum viable patch area and dispersal distance.

Invertebrate and vascular plants have been shown to show the most significant responses to patch size and dispersal distance (box 1).

Box 1

Humphrey et al 2015 – carried out a research review, grouped studies on organisms into 4 groups: vertebrates, invertebrates, vascular plants and cryptograms (lichens, bryophytes, fungi).

- Significant response to patch area was highest in studies of invertebrates 69% and lowest in vascular plants 57%.
- Patch characteristics (structure/condition) important for all groups.
- Ecological continuity (connectivity) most sig for vascular plants 88% > Inverts 67% > vertebrates 60% > cryptograms 38%.

However, the data available in the research literature for minimum viable areas (MVA) (and dispersal distances for that matter) is very sparce. Rather than guessing at MVAs, we took the approach that using incremental dispersal distances in 500m bands outwards from the existing habitat patches would be a proxy for different levels of connectivity for different mobilities of species. This also reflects the Lawton principles, i.e., expanding outwards from existing good quality habitat.

The principle of examining connectivity by cost distance modelling is that each habitat category on the habitat layer is given a cost (permeability) score, this is an estimated cost to movement for the model species moving across that habitat or land use. For example, a high cost of 50, which we would give to buildings and sealed surfaces, means it has very low permeability to species movement. A low cost of 1 has a high permeability to species movement. The core habitats are given a cost equivalent to zero as they provide all the needs for the species. The cost is used to adjust how far the generic species would move into the landscape from a core habitat patch, so for a model species with a maximum dispersal distance of 500m, the distance it will actually move out into the landscape is calculated as dispersal distance divided by cost. This means that for a high cost habitat like concrete, we divide 500m by 50 = movement distance of only 10m across that surface.

3.2 Assigning core habitats and cost (permeability) scores

Priority habitats were grouped into three ecological networks: open habitats (grassland and heathland), woodland habitats and wetland habitats (the 4th network, arable was generated differently using stewardship options rather than core habitats, see below).

Least cost distance analysis (in ArcGIS) was used to model current network connectivity. Each UKHabs code present in the habitat layer was assigned a cost (permeability) value (see table 3a - c) for each of the 3 networks and for each network the UKHabs code classed as core habitats were identified. Cost (permeability) scores were based on work done by West of England Nature Partnership (WENP) and Somerset Wildlife Trust with Kevin Watts at Forest Research. The assignment of the relevant UKHabs codes to each ecological networks and their associated cost/permeability can be found in the file "Permeability v1.8 Worcs"

For the least cost distance analysis, core habitat patches 10m or less apart were considered to be contiguous and were merged into a single patch.

Table 3a*. Permeability scores assigned to habitat/land-use for ecological networks: Open habitat network

Permeability level		cost score	**Open Habitats network**
Full permeability (core habitat)		0	Unimproved neutral/Calc/acid grassland (g1a, g2a, g3a), lowland/upland heathland, moor, PMGRP
High permeability	semi-improved grasslands; high floral species richness, relatively unmodified with strong vertical structure and known to readily accommodate grassland/heathland species, largely unshaded	1	Semi-improved neutral/calc/acid grasslands including other neutral grasslands (g3c), g2 and non priority habitat heathland h1.
Medium permeability	semi-natural habitats; little modification with some vertical structure, lower floral species richness narrow species rich strips or open treed habitats	5	conservation road verges, traditional orchards, WP&P, Allotments, bracken, Hedgerows, line of trees, poor quality other neutral grasslands g3c5, g3c7, g3c8, unknown quality acid or neutral grasslands (g3, g1 - g2 is covered above because handled differently in UK hab)
	little modification but with limited vertical structure, wet conditions, very dry or heavy shading	7	Fen marsh & swamp, mire, bog (any f) broadleaved woodland, mixed woodland (unless specified w1h6 or w1 newlyplanted/felled), dense scrub, tall herb,

	moderate modification, limited structure and limited floral species richness, heavy shading	10	Coniferous woodland (any w2), mixed mainly coniferous woodland w1h6 or w1 newly planted/felled, fields with arable margins
Low permeability	Heavily modified habitats with very little structure	20	Modified (g4) and amenity grassland; leys; unknown grassland type not already assigned (g) ; arable and horticulture (without margin specified); intensive orchards, open water; gardens, non native scrub, Landfill, rock, sparsely veg land; bare ground; winter stubble; u1d or u1 with 20 or 230
	Artificial and hostile habitats	50	Roads; buildings

Table 3b*. Permeability scores assigned to habitat/land-use for ecological networks: Woodland habitat network.

Permeability level		cost score	**Woodland network**
Full permeability (core habitat)		0	Broadleaved ASNW (from national inventory) including broadleaved PAWS (from national inventory), All broadleaved semi-natural woodland: all w1_33, w1_37 or w1_33, 37 or w1_33,36 (broadleaved plantation on ancient woodland site) - but not g_33 (incorrect assignment of codes)
High permeability	Secondary woodland and woodland-like habitats; relatively unmodified with strong vertical structure and known to readily accommodate woodland species	1	new planted/felled semi-nat broadleaved and mixed woodland; Traditional orchard; wood pasture & parkland - w1 (with no 33 or 37), w1h, WPP (g_20 plus woodland code) or (w_20) or 20, 11 otherwise could just be historic parkland boundary looking at way codes have been applied. u1 with 33,37 or 37 or 33,36.
Medium permeability	Unimproved semi-natural habitats; little modification with some vertical structure	3	hedgerows; heathland; dense scrub; scattered trees; remnant traditional orchards, Line of trees. Includes h1
	Unimproved semi-natural habitats; little modification but with limited vertical structure	5	Unimproved grassland (g1a, g2a, g3a), bracken (g1c), marshy grassland (g+ plus 119 or 120 or14 or 15,, swamp, fen, bog, mire (f), tall herb (16), scattered scrub (10)
	Semi-improved habitats; moderate modification and limited structure	10	unknown or coniferous woodlands inc planted/felled (all "w" or w2), semi-improved grassland (above just g but not unimproved), bush orchards, allotments
Low permeability	Heavily modified habitats with very little structure	20	unknown (g), modified and amenity grassland, arable and horticulture (and c), water, gardens, rock, field with arable margins; ruderal; landfill; bare ground, u1d or u1 with 20 or 230
	Artificial and hostile habitats	50	Roads; buildings,

*Reproduced and modified from work done by West of England Nature Partnership (WENP) and Somerset Wildlife Trust (SWT) with Kevin Watts at Forest Research (FR). Wetland was not included in work done by WENP and SWT/FR. The Wetland costs have been developed using the principles of structural complexity used above.

Table 3c. Permeability scores assigned to habitat/land-use for ecological networks: Wetland habitat network.

Permeability level		cost score	Wetland Network
Full permeability (core habitat)		0	wetland habitats (NERC duty priority habitats)
High permeability	Flood zone 2	1	any semi imp grassland (g1,g2,g3 or above) or heath (h1 or above) or other priority habitats within flood zone or wet (must have one of these secondary codes 25 or 119 or 120 or 129), wet woodland, other wet habitats (non priority f habitats and r habitats)
	semi-improved grasslands; high floral species richness, relatively unmodified with some vertical structure and shading/damp areas ; semi-natural habitats;	5	Semi-improved neutral/calc/acid grassland including other neutral grassland (g1d, g2, g3c), dwarf shrub heath (h1), other (non water/wetland) priority habitats without the wet secondary codes above (excluding woodland)
	lower floral species richness narrow species rich strips or open treed habitats	7	conservation road verges, traditional orchards, WP&P, Allotments, bracken, tall herb, Hedgerows, line of trees, unknown quality grasslands (g3, g1), unknown grassland (g) with wet secondary code as above.
Medium permeability	moderate modification, limited structure and limited floral species richness, heavy shading	10	non-wet broadleaved woodland or mixed mainly broadleaved, dense scrub, bracken
	Heavily modified habitats with very little structure, very dry	20	arable and horticulture (all c incl any parkland or trad orchards on cropland), modified grassland (g4), coniferous woods, coastal veg shingle, gardens, u1d or u1 with 20 or 230
Low permeability	Artificial and hostile habitats	50	hard surface, built env,bare ground

3.3 Open habitat network and woodland network restoration zones

3.3.1 Assigning Open Network and Woodland Network opportunities and constraints

Opportunities and constraints were identified for each of the open habitat and the woodland ecological networks (Table 4a-b) and spatial layers produced for each of these. Weightings were applied to each layer and the layers combined to produce two network opportunity scoring layers, one for open habitat and the other for woodland.

Table 4a. Opportunity and constraints layers for the open habitat networks.

Layer	**Rationale**	**Constraint or opportunity**	**Weightings**
Open habitat cost distance output	Weighting of least cost pathway distance from core habitat patches	opportunity	1 through 500 = 10 501 through 1000 = 8 1001 through 1500 = 6 1501 through 2000 = 4 2001 through 2500 = 2 All other values = 0
Agri land classification	Grade 1 and 2 land prioritised for food production	opportunity	Grade 1 = 1 Grade 2 = 2 Grade 3 = 3 Grade 4 = 4 Grade 5 = 5 Unclassified = 5
All semi natural open habitats (all g1,g2,g3,h1 and h3 UKHAB codes from habitat layer)	Restoration opportunity of permanent grassland not currently priority habitat quality	opportunity	5
Land within 500m of existing core open habitat	Open habitat smaller and more fragmented patches so need to concentrate high priority very close to existing patches	opportunity	5
Heritage sites – Scheduled ancient monuments and battlefields	Heritage sites can be protected with grassland habitat, do not want woodland	opportunity	5
PAWS (from Ancient Woodland Inventory)	PAWS should be restored to seminatural broadleaf	constraint	0
Existing priority habitats extracted from habitat layer using codes in PriorityHabs.csv	Existing priority habitat should remain as is	constraint	0

Table 4b. Opportunity and constraints layers for the woodland habitat networks.

Layer	**Rationale**	**Constraint or opportunity**	**Weightings**

Woodland cost distance output	Weighting of least cost pathway distance from core habitat patches	opportunity	1 through 500 = 10 501 through 1000 = 8 1001 through 1500 = 6 1501 through 2000 = 4 2001 through 2500 = 2 All other values = 0
Agri land classification	Grade 1 and 2 land prioritised for food production	Graded opportunity	Grade 1 = 1 Grade 2 = 2 Grade 3 = 3 Grade 4 = 4 Grade 5 = 5 Unclassified = 5
Land within 1000m of existing semi natural woodland	There are more larger woodland patches than open habitat patches so 1000m means woodland restoration is slightly more widely spread than open restoration.	opportunity	5
PAWS (from Ancient Woodland Inventory)	PAWS should be restored to seminatural broadleaf, some may already be broadleaf plantation	opportunity	1
Heritage sites – Scheduled ancient monuments and battlefields	Woodland likely to damage heritage sites	constraint	0
Existing priority habitats. Extracted from habitat layer using codes in PriorityHabs.csv	Should not create woodland on existing priority habitat, should remain as is	constraint	0

3.4 Open network and woodland network combined opportunity/priority layer

Having created separate open habitat network opportunity scoring and woodland network opportunity scoring layers as set out above, a combined open & woodland network restoration zone prioritization layer was then created by using conditional statements to decide which of the two networks took priority or whether they were of equal priority and some form of matrix habitat was more appropriate. This helps the user consider where open and woodland networks intersect and should reduce the risk of cutting one network off with the other.

The individual ecological network scoring layers were divided into 3 categories (High, Med, Low) by identifying the 2 break points in the opportunity scores that sit at the threshold between high and med, and med and low, as follows. The percentage areas are approximate as the opportunity layer is discrete not continuous, the algorithm pick the closest break point in the scores once the target area has been reached:

- High opportunity/priority - The High opportunity/priority category comprises approximately 20% of the area of the opportunity layer (starting at the maximum opportunity score and adding lower scores in turn).
- Medium opportunity/priority - are the opportunity scores that comprise approximately the next 10% of area, starting at the high opportunity category minimum and working lower.
- Low opportunities comprise all other categories (approximately the remaining 70% of the area).

The core habitat plus high and medium categories therefore add up to 30% cover. This target value is based upon research which suggests that once 30% cover is reached most habitat patches are in close proximity to another (Buckley and Fraser 1998, Andren 1994).

This combined layer shows potential opportunities with prioritization based on working outwards from existing habitat patches. It also helps to ensure that existing priority habitat is not inadvertently destroyed by for example woodland creation on priority grassland.

The output raster categories are defined in Table 5.

Table 5. Classification of opportunities for combined opportunity layer.

Open and woodland opportunity category	**Raster category**
Open or woodland network high priority	11
Open network high priority	10
Woodland network high priority	9
Open or woodland network medium priority	8
Open or woodland network low priority	7
Woodland network medium priority	6
Woodland network low priority	5
Open network medium priority	4
Open network low priority	3
No opportunities (other priority habitats)	2

3.5 The Wetland Network

The Wetland Network has been modelled differently and is largely based on topography and soil drainage type. The following data sources, with weightings as show in table 6, were applied to the raster layers, and opportunity score was calculated using raster calculation by adding the opportunities and multiplying by the constraints. The wetland network opportunities scoring 12 or higher were extracted from the output and presented as a transparent overlay for the NRN mapping. The threshold of 12 was used based upon comparing the scoring to known opportunities on the ground.

Table 6. Constraint and opportunity scoring for layers used in wet habitat network.

Input layer	**Constraint or opportunity**	**Scoring**

Wetland cost distance raster	opportunity	1 through 500 = 5 501 through 1000 = 4 1001 through 5000 = 2 All other values = 0
Topographical wetness index (see more detail below)	opportunity	1 to 5 with equal categories across the dataset's range (5 is highest)
Environment Agency Flood zone 3 (1:100 or greater probability)	opportunity	1
Soil drainage interpreted from Soil Parent Material V1 (British Geographic Society	opportunity	Impeded drainage and naturally wet = 5 Slightly impeded drainage = 2 Free draining = 0
Slope (degrees) calculate from Terrain50_OSOpendata DEM in degrees	opportunity	<=1 degree = 10 1-2 degrees = 5 2-4 degrees = 4 4-6 degrees = 3 6-8 degrees = 2 8-10 degrees = 1 >10 degrees = 0
Slope (>10 degrees)	Constraint	0

Topographical wetness Index is a useful indicator of soil moisture (Raduła et al 2018) and is a function of both the slope and upstream contributing area.

Method used to Calculate topographical wetness index (now incorporated into the Python code), but in summary:

- Calculate slope from DEM in degrees
- Correct to remove zeros using raster calculator ("slope_degrees@1" <=0)*1+("slope_degrees@1" >0)* "slope_degrees@1"
- Save as slope_degrees_modified
- Convert to radians – raster calculator "slope_degrees_modified@1"*0.01745
- Save as slope_radians
- Calculate upslope contributing area – using SAGA flow accumulation tool. Use the DEM file.
- Save as upslope_area
- Calculate topographic wetness – raster calculator ln((upslope area +1*(50*50)/tan(slope radians))

3.6 Future improvements to the wetland network method

The following methodology was discussed with staff at the Wildfowl and Wetlands Trust, Slimbridge. If a license for NATMAP soil data (Cranfield University) were obtained, the following alternative method for the wetland network could be tested.

Table 7. Data layers for alternative Wetland network method

Data Layer	**Constraint or opportunity**	**Raster categories to apply**
EA Floodzone 3	Opportunity	Inclusion if in floodzone

Topographical wetness index	Opportunity/constraint	High TWI (10) and poorly drained soil then inclusion
Soil type = peat (NATMAP)	Opportunity	Inclusion of all peat
Soil drainage (NATMAP)	Opportunity/constraint	(See TWI)
Slope	Constraint	If slope >10 = 0 (exclusion)
Wetland connectivity	Prioritization	500m 1000m 3000m

Combine the data layers in table 7 using a raster calculation (add opportunities and multiply by constraint) so that anything in Floodzone 3 is included as an opportunity. For the areas outside of Floodzone 3, areas of impeded drainage or naturally wet soils plus high (>6) TWI are included as an opportunity. Any areas of peat are included as an opportunity, but any slopes >10 degrees are excluded.

Prioritization could then be assigned by incorporating the Wet Network connectivity at 500m, 1000m and 3000m cost distance.

3.7 Watercourses and open water bodies

Running and open water were not incorporated into the wetland network as different suits of species use them. We have not yet created layers for watercourses and open water and they were not included as part of this contract, but we have the following suggestions formed in discussion with the Wildfowl and Wetland Trust research staff at Slimbridge. It was suggested that a pond density heatmap would be useful to inform pond opportunities. Depending on what you want to achieve for what suit of species, you might target areas of low density to increase connectivity across the landscape, or areas of high density to create a larger surface area of water to support bigger more resilient populations.

Physical river connectivity is reliant on the removal of barriers. The Environment Agency have a barrier layer which incorporates prioritization for removal. This layer could be used in the first instance and local upstream prioritization could be added to it. Alternatively you could take the policy that any opportunity to remove a barrier should be taken as removal of any barrier will help internal river system movement even if it does not enable source to sea movement.

3.8 The Arable network

While the Open, Woodland and Wetland networks support a wide range of species, they don't cover the needs of species that use arable farmland e.g. arable plants and some of the farmland birds, particularly those relying on seed for food and those that nest in cropland. Having examined the farmland bird species they distilled down into two groups: ground nesting species and Hedge/scrub/tree nesting species. In general the adults utilise seed as their main food resource and an insect resource is required for the chicks. The Arable Network looks at the availability of options to meet the nesting, adult and chick food requirements of these two groups of farmland birds. In addition, Important Arable Plant Area tetrad data is available from plantlife, to provide information on areas which are important for these plant species. Worcestershire also specifically requested that the Buglife B-lines network be included as opportunity areas in the arable network.

3.8.1 Farmland bird data extraction and interpretation

All live Environmental Stewardship Scheme (ESS) options and Countryside Stewardship (CS) options for Worcestershire plus 3km buffer were downloaded from MAGIC Maps. Natural England ESS farmland birds advisory note (Delivering the HLS Package for Farmland Birds 2013) and RSPB farming advice guidance was used to identify which options contributed to the following Arable Network benefits:

- Ground nesting sites
- Hedge/scrub/tree nesting sites
- Seed food source (adult food)
- Insect food source (chick food)

The ESS and CS point data was merged, irrelevant fields were deleted and the four Arable Network benefits were assigned to each option.

Ground nesting options and hedge/scrub/tree nesting options were extracted into two separate point data sets. A 1000m radius buffer was added to each of these data sets (based on foraging distances for birds e.g. Evens et al 2018).

Two layers were then extracted, adult food options points and chick food option points from the ESS, CS merged options layer.

For each nest buffer, the QGIS tool "Count points within polygons" was run for adult and then chick food.

The output from the above step was run through the QGIS tool "join by location summary" (apply sum of the "quantity" field) to get total area of adult food (af) and chick food (cf) options in each buffer.

Next the % area that the options cover per buffer was calculated. 7% of buffer area was used as the threshold for meeting the requirements (7% per holding was requirement under NE Farmland Birds: Advisory Note). Fields were then added to the attribute table for: percent af options, percent cf options (314.16ha total area of 1000m buffer so 100/314.16 x option hectarage = % area of the 1000m radius circle). Also added fields for af requirements met; cf requirement met; both af and cf requirement met; no requirements met (i.e., % area >=7), if met then coded to 1 if not met coded to 0.

The resultant output can then be separated into the following layers:

- Ground nesting birds – adult and chick food requirements met
- Ground nesting birds – adult food requirements met
- Ground nesting birds –chick food requirements met
- Ground nesting birds – no food requirements met
- Tree/Scrub/Hedge nesting birds – adult and chick food requirements met
- Tree/Scrub/Hedge nesting birds – adult food requirements met
- Tree/Scrub/Hedge nesting birds –chick food requirements met
- Tree/Scrub/Hedge nesting birds – no food requirements met

The areas where only one food requirement has been met are a high opportunity for enhancing the arable network.

3.8.2 Important arable plants

Plantlife important arable plant tetrads of national/European and county importance can also be displayed as a layer to highlight the potential for applying options relevant to promoting arable plant species.

All arable and horticulture landuse was extracted from the habitat layer and can be displayed underneath the Arable network to show where further opportunities exist to enhance the contribution of the arable network to nature recovery.

3.8.3 Combine prioritised arable network

Worcestershire specifically requested that the arable layers be combined (merged vector files) to simplify into a series of high, medium and low priority restoration opportunities. To achieve this, layers above were combined as set out in table 8.

Table 8. Data layers combined into arable network restoration opportunities

Data Layer	**Prioritised restoration opportunities**
• Ground nesting birds – adult and chick food requirements met • Tree/Scrub/Hedge nesting birds – adult and chick food requirements met • Important arable plant tetrads of national/European importance	High
• Ground nesting birds – adult food requirements met • Ground nesting birds –chick food requirements met • Tree/Scrub/Hedge nesting birds – adult food requirements met • Tree/Scrub/Hedge nesting birds –chick food requirements met • Important arable plant tetrads of county importance • Buglife's B-lines	Medium
All other arable and horticulture landuse	Low

4 Metrics to assess coherence and resilience

4.1 Patch Viability

Note that on the Gloucestershire Mapping website we have used the terms Patch Viability and Network Viability rather than talking about resilience and coherence and metrics as we think that viability is a more understandable term/concept for the layperson.

Open or Woodland Network Patch Viability - this is the area in hectares of each core habitat patch and can be used to consider whether patches meet minimum viable patch size requirements to support particular species or groups of species. In general terms you do not want core patches below the minimum threshold for the network and these are a priority to expand in size.

The Open Network Patch Viability patch size categories used are estimated from various studies:

- 1ha (invertebrates e.g. Hesperia comma, Hill et al 1996)
- 3ha (Somerset Ecological Networks Report 2016, estimate based on a range of species data)
- 5ha (large blue butterfly in Somerset Ecological Networks Report 2016 and Pe'er et al 2014)
- 30ha NERR081 for invertebrates of heathland

Many patches are below the 1ha minimum threshold and so will support a much reduced suite of species.

The Woodland Network Patch Viability patch size categories are taken from the Natural England Nature Networks Handbook (NERR081) which lists various examples of viable patch sizes for different species/groups associated with woodland (Box 2). The woodland core habitat patch size categories used in this layer illustrate those suggested thresholds:

- <1.5Ha
- 1.5 - 5Ha
- 5 - 10Ha
- 10 - 20Ha
- 20 - 100Ha
- >100Ha

Many patches are below the lower 1.5ha threshold and so will support a much reduced suite of species.

Box 2.
From NERR081 Nature Networks Evidence Handbook

How big should a wildlife site be? Studies that have suggested minimum areas to support populations of different taxa in woodland habitats.
• Herbaceous species: require > 1.5 ha and preferably > 5 ha to support typical woodland species (Usher et al. 1992); species richness increases to 40 ha (Humphrey et al. 2013)
• Bryophytes: require > 3.5 ha to support a diverse array of bryophyte functional groups (Humphrey et al. 2013)
• Saproxylic Beetles: with low dispersal abilities require > 100 ha (Humphrey et al. 2013)

- Birds: the species richness of woodland birds is maximised at > 10 ha (Bennett & Saunders 2010), but Marsh Tit Poecile palustris requires >25 ha and Great Spotted woodpecker Dendrocopos major > 100 ha (Peterken 2002)
    - if < 1.5 ha, some woodland bird species will not breed (Hinsley et al. 1995)
- Mammals: the likelihood of dormice occupying a suitable woodland is maximised if the woodland is > 20 ha (Bright et al. 1994; Bennett & Saunders 2010)
    - Red squirrels Sciurus vulgaris require > 10 ha (Peterken 2002)
- General: > 3 ha is required to provide some internal habitat heterogeneity, but >25 ha is required if the rides are to be open enough for open-habitat species (Peterken 2002).

4.2 Network Viability

Woodland or Open habitat network viability - This shows the summed area of core patches within each functionally connected wooded habitat network within a 500m cost distance (dispersal distance). If you have core patches that are part of a network within these layers, you can look at how resilient that network currently is. Does it meet the minimum threshold or is it below the threshold. If below the minimum threshold, this is a priority; you could increase the number of patches within this network (ensuring they are greater than the minimum viable patch area) or expand the area of existing patches. The NRN layer can help to show where expansion could take place to increase the overall resilience of the ecological network.

Open Network viability thresholds: The Southwest Naturemap methodology states that a viable metapopulation needs 10 x minimum viable patch area (from Cox et al (1994)), therefore the core patch area categories used in "Open habitat network core patch sizes" are multiplied by 10 to provide the categories used in this layer, except for 70ha which is the lower estimate for marsh fritillary butterfly given in the Somerset Wildlife Trust Ecological Networks Report 2016). The lowest category (<10Ha) are considered to be unviable networks.

- under 10ha of core open habitat
- 10-30ha of core open habitat
- 30-50ha of core open habitat
- 50-70ha of core open habitat
- over 70ha of core open habitat

Woodland Network viability thresholds: The NE Nature Networks Handbook (NERR081) recommends woodland wildlife sites should be at least 40ha and preferably 100ha in size. Here that is interpreted as total woodland core habitat within a functionally connected woodland network at 500m cost distance. Many of the networks are below the 40ha minimum threshold given for maximising the species richness of lower and higher woodland plants and vertebrates. 100ha is given as the threshold to support wider ranging species and those with specialist requirements.

- under 40ha of core woodland
- 40-100ha of core woodland
- over 100ha of core woodland

5 Identifying strategic restoration areas

The networks above concentrate on prioritizing work around the bigger, better principles of network restoration. I.e., the focus on expanding outwards from core habitat patches and reinforcing the core networks. The modelling does not prioritize connections across large gaps in the networks. These large gaps require a more strategic approach as they will require a lot more work and investment to bridge them. However, Local Nature Partnerships or other groups of partners may want to develop large projects to bridge such gaps. The following is a suggested way to approach this:

- Local expertise is required to identify strategic restoration areas as you need to consider things such as climate corridors that may go well beyond the county map. Decisions can be aided by looking at the NRN map which shows the bigger, better opportunities for the network.
- Identify extensive low opportunity areas between areas of high/medium opportunity.
- Overlay with the relevant network 5 or 10km connectivity layer, this will indicate least cost pathways.
- Overlay the relevant network patch and network viability layers to see whether there are stepping stones that could be enhanced within the gaps.
- Look for areas where the patch metrics fall below the lower thresholds.
- The needs of key species in particular locations may guide the identification of some strategic gaps.
- You may want to consider the location of local, national and European designations in relation to gaps.

ANNEX 1 – Python packages and GCER?/GWT python scripts

Python scripts developed by GCER for running the NRN were created using Python 3.9.2 and the following packages:

Package	Version used (if available)	Description
numpy	1.20.2	Numerical python. This package is used primarily for array handling (particularly for raster data) but also some mathematical functions.
pandas	1.2.3	Python data analysis library. This package is used for handling data tables (particularly for the input and use of csv tables).
geopandas	0.9.0	A version of pandas that handles spatial data. Used for handling vector data.
rasterio	1.2.1	Raster input output. This package is used for handling raster data.
rasterstats	0.14.0	This package is used to carry out zonal statistics.
richdem		This package is used to carry out hydrological analysis and operations (slope and flow accumulation in particular).

Input files and python scripts used to produce the Worcestershire NRN are briefly described below. More detail on each output layer can be found in the associated metadata files:

GCER Location: D:\Dropbox\NRN\Other NRNs\Worcestershire

Permeability v1.8 Worcs.csv
Description: A list (flat table) of all the UKHAB codes produced from the habitat layer creation of the NRN, their permeability score for each ecological network and their status (core habitat or not) within each network
Location at GWT: D:\Dropbox\NRN\Other NRNs\Worcestershire\Codes\

PriorityHabs.csv
Description: A list (flat table) of all the priority habitat UKHAB

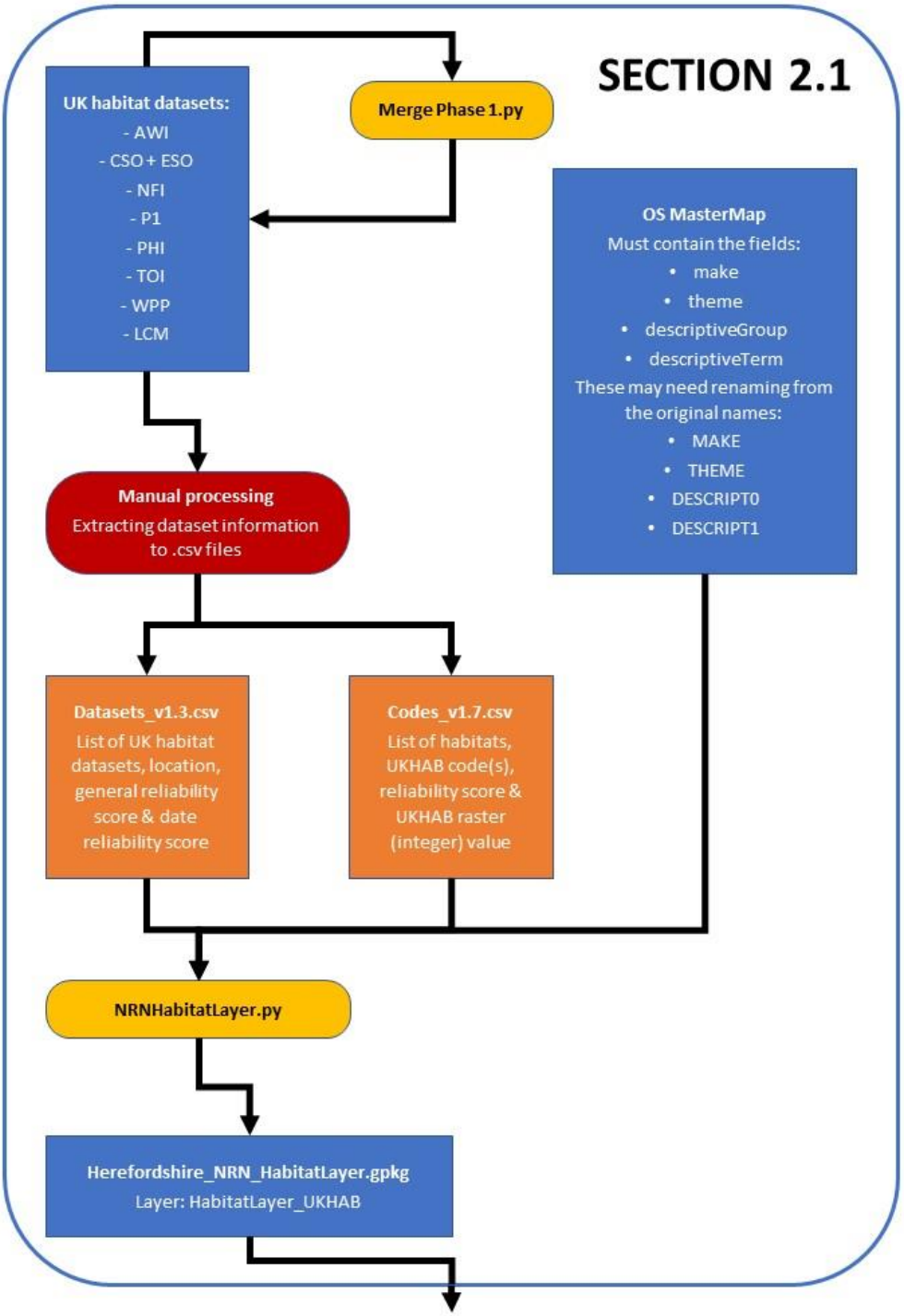
NRNEcoNetAssign.py
Description: A python script that takes the habitat layer and assigns each polygon a permeability value for each of 3 ecological networks, and whether it is core habitat for that network. It also produces rasters of this information.

NRNExtractOpportunities.py
Description: A python script that rasterises (2m resolution) all opportunity and constraint layers (resamples rasters to 2m where inputs are rasters).

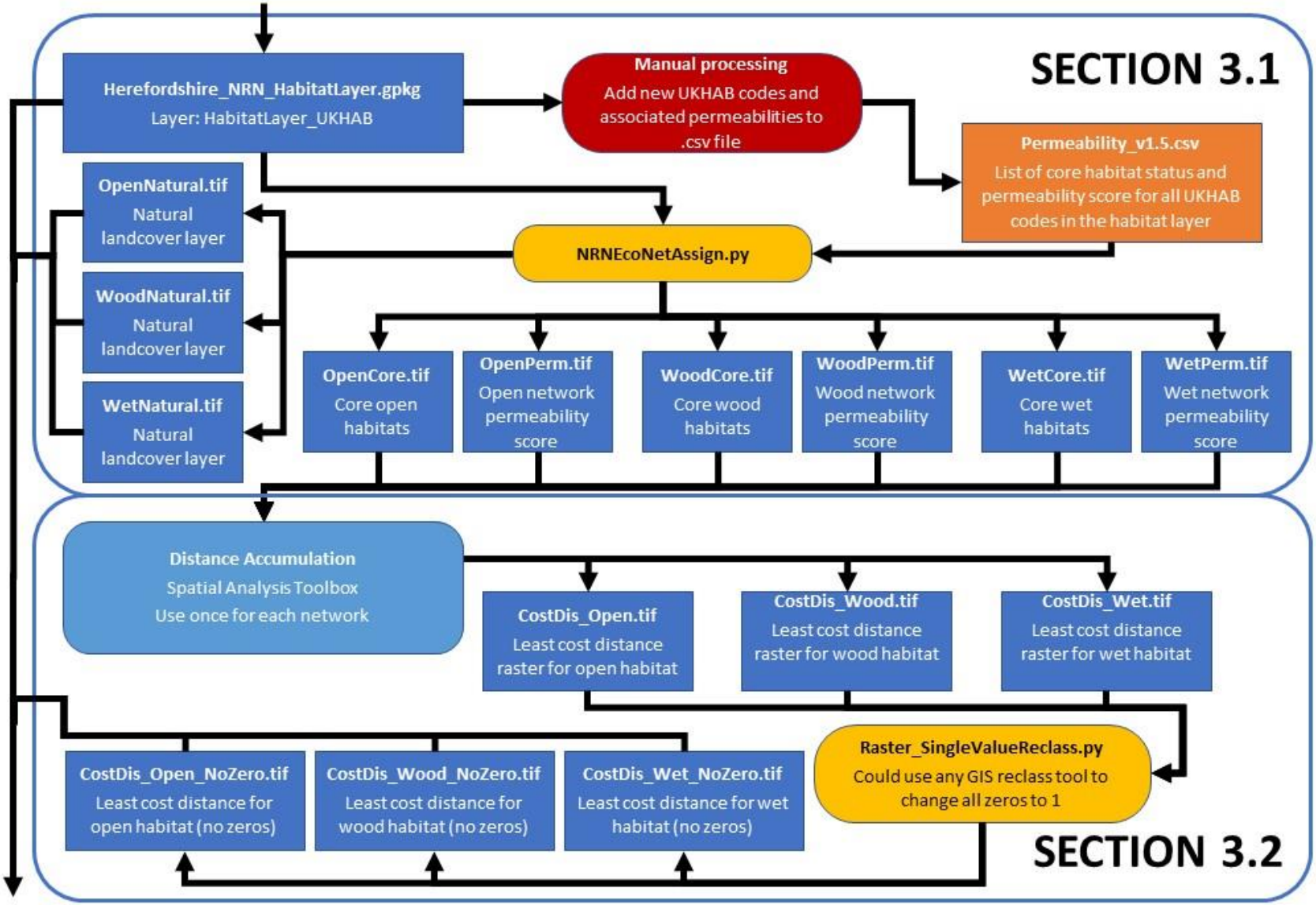
NRNCalcCombOpps.py
Description: A python script that calculates opportunities for open and woodland networks, and the two combined.

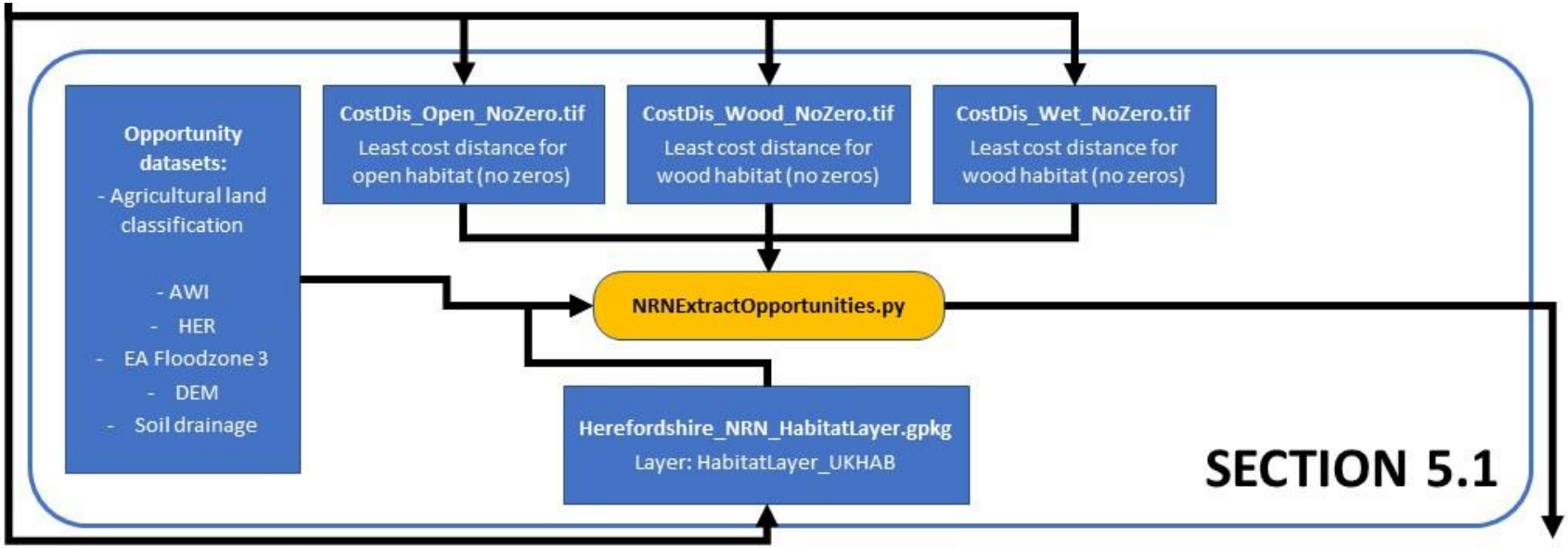
ANNEX 2 – Flowchart of NRN modelling methodology

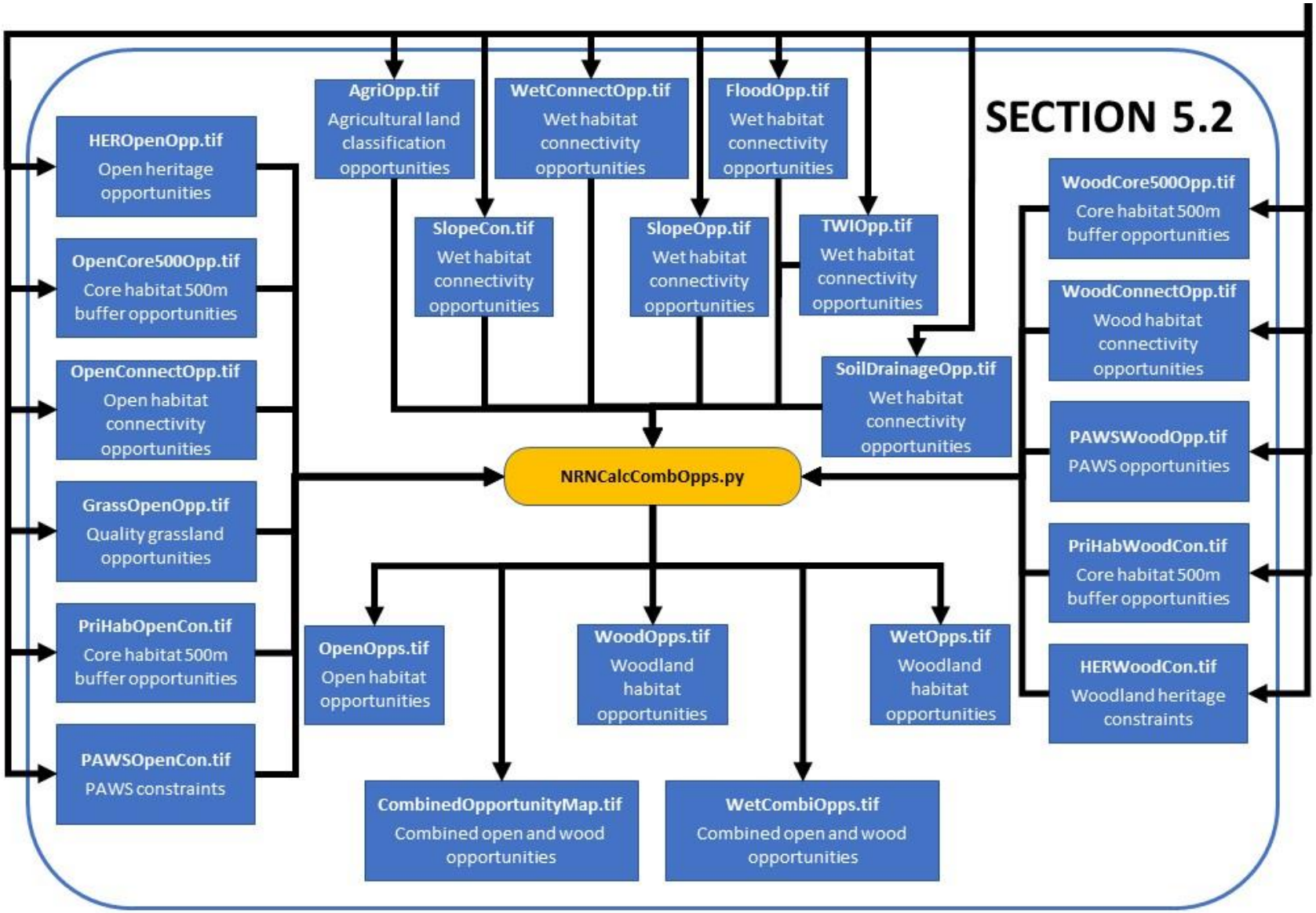
Same as methodology used for Gloucestershire and Herefordshire. Note that the Worcs process started at section 3.1 as Worcs supplied a habitat inventory.



Version 1: 25/10/2022




Opportunity datasets:
- Agricultural land classification
- AWI
- HER
- EA Floodzone 3
- DEM
- Soil drainage
CostDis_Open_NoZero.tif
Least cost distance for open habitat (no zeros)
CostDis_Wood_NoZero.tif
Least cost distance for wood habitat (no zeros)
CostDis_Wet_NoZero.tif
Least cost distance for wood habitat (no zeros)
NRNExtractOpportunities.py
Herefordshire_NRN_HabitatLayer.gpkg
Layer: HabitatLayer_UKHAB
SECTION 5.1


SECTION 5.2
HEROpenOpp.tif
Open heritage opportunities
OpenCore500Opp.tif
Core habitat 500m buffer opportunities
OpenConnectOpp.tif
Open habitat connectivity opportunities
GrassOpenOpp.tif
Quality grassland opportunities
PriHabOpenCon.tif
Core habitat 500m buffer opportunities
PAWSOpenCon.tif
PAWS constraints
AgriOpp.tif
Agricultural land classification opportunities
WetConnectOpp.tif
Wet habitat connectivity opportunities
FloodOpp.tif
Wet habitat connectivity opportunities
SlopeCon.tif
Wet habitat connectivity opportunities
SlopeOpp.tif
Wet habitat connectivity opportunities
TWIOpp.tif
Wet habitat connectivity opportunities
SoilDrainageOpp.tif
Wet habitat connectivity opportunities
NRNCalcCombOpps.py
WoodCore500Opp.tif
Core habitat 500m buffer opportunities
WoodConnectOpp.tif
Wood habitat connectivity opportunities
PAWSWoodOpp.tif
PAWS opportunities
PriHabWoodCon.tif
Core habitat 500m buffer opportunities
HERWoodCon.tif
Woodland heritage constraints
OpenOpps.tif
Open habitat opportunities
WoodOpps.tif
Woodland habitat opportunities
WetOpps.tif
Woodland habitat opportunities
CombinedOpportunityMap.tif
Combined open and wood opportunities
WetCombiOpps.tif
Combined open and wood opportunities

References

Andren, H. (1994), Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review, OIKOS 71: 355-366.
Barnes, R. (2016) *RichDEM: Terrain Analysis Software.* http://github.com/r-barnes/richdem

Bennett, A. F. & Saunders, D. A. (2010). Habitat fragmentation and landscape change. In Conservation Biology for All (eds N. S. Sodhi and P. R. Ehrlich), pp. 88–106. Oxford University Press, Oxford

Buckley, G.P. & Fraser, S. (1998), Locating new lowland woods, English Nature Research Report ENRR283.

Butcher, B., Edmonds, B., Treweek, J., Carey, P. and Norton, L. (2018) Introducing the UK Habitat Classification – Updating Our Approach to Habitat Survey, Monitoring and Assessment. InPractice, **100**.

Cox et al. (1994), Closing the gaps in Florida's wildlife habitat conservation system. Forida Game and Fresh Water Fish Commission

Crick, H. et al (2020) Nature Networks Evidence Handbook, Natural England Research Report NERR081.

Evens, R., Beenaerts, N., Neyens, T. *et al.* (2018) Proximity of breeding and foraging areas affects foraging effort of a crepuscular, insectivorous bird. Sci Rep **8**, 3008

Harris, C.R., Millman, K.J., van der Walt, S.J. et al. (2020) Array programming with NumPy. Nature **585**, p357–362. DOI: 0.1038/s41586-020-2649-2.

Hill, C.D. et al, (1996), Effects of Habitat Patch Size and Isolation on Dispersal by Hesperia comma Butterflies: Implications for Metapopulation Structure, Journal of Animal Ecology, 65: 725-735.

Hinsley, S. A., Bellamy, P. E., Newton, I., & Sparks, T. H. (1995). Habitat and landscape factors influencing the presence of individual breeding bird species in woodland fragments. Journal of Avian Biology 26: 94-104.

Humphrey, J., Watts, K., Fuentes-Montemayor, E., Macgregor, N. & Park, K. (2013) The evidence base for ecological networks: lessons from studies of woodland fragmentation and creation. Forest Research, Roslin.

Humphrey, J. W., Watts, K., Fuentes-Montemayor, E., Macgregor, N. A., Peace, A. J., & Park, K. J. (2015). What can studies of woodland fragmentation and creation tell us about ecological networks? A literature review and synthesis. Landscape ecology 30: 21-50.

Pe'er, G. et al (2014), Toward better application of minimum area requirements in conservation planning, Biological Conservation 170: 92-102

Peterken, G. (2002) Reversing the habitat fragmentation of British Woodlands. WWF-UK, Godalming.

Phillips, J., Willmott, M. and Grice, P., (March 2013)Delivering the HLS Package for Farmland Birds: Advisory Note for Natural England advisers
Radula, M.W. et al (2018) Topographic wetness index explains soil moisture better than bioindication with Ellenberg's indicator values, Ecological Indicators, 85: 172-179

RSPB farming advice guidance https://www.rspb.org.uk/our-work/conservation/conservation-and-sustainability/farming/advice/helping-species/

Somerset's Ecological Network: Mapping the components of the ecological network in Somerset 2016, Somerset Wildlife Trust, Somerset County Council, Forest Research & Somerset Environmental Records Centre https://www.somerset.gov.uk/waste-planning-and-land/ecological-networks/

Southwest Naturemap Appendix 4: Stand-alone summary Primer on the Rebuilding Biodiversity methodology.

The pandas development team. (2020, March 18). *pandas-dev/pandas: Pandas 1.20.2 (Version v1.20.2)*. Zenodo. http://doi.org/10.5281/zenodo.3715232

Usher, M.B., Brown, A.C. and Bedford, S.E. (1992) Plant-species richness in farm woodlands. Forestry 65: 1-13.