SM1: Additional Methods

1.1 Our focal landscapes and their location in the UK, Syder et al., *in prep*

1.2 Ecosystem service valuation (workshop 1)

We asked stakeholders to list Ecosystem Services (ES) currently provided by the landscapes, introducing the terms 'ecosystem services' and 'nature's benefits to people' as interchangeable for our purposes (Pascual et al., 2017). The facilitator gave examples of the range of ES which they could consider, including through material benefits such as food and water provisioning, the value of the land for aesthetic or recreational purposes, or the wider cultural services it may offer. We coded ES themes from audio-recorded discussions by themes, and quantified presence or absence within each group using NVivo software (Lumivero, 2023). We grouped these themes into provisioning, regulatory and cultural services, following the Millenium Ecosystem Assessment's framework. We only included codes if a positive attribute was used by the speaker to assign some level of value of that ES; this was defined as a reference to a personal experience, use of positive adjectives when describing the ES, or a detailed description and connection to place offered. Any codes were discounted if they were instead spoken as a statement with little detail, importance or feeling attached, or referenced in terms of benefiting another interest group. We do not present ES valuation results for farmers in the Elenydd as this activity was not completed during the shorter focus group session, however we do still show their top 5 future ES.

1.3 Spatial data methods

1.3.1 Tree canopy and height

In order to map tree cover and height across the two landscapes, we used LiDAR-derived digital elevation models (DTM) and digital surface models (DSM) to create canopy height models (CHM). English DTMs and DSMs were downloaded from Environment Agency National LIDAR Programme using the R package “gblidar” (Environment Agency, 2023; Graham, 2023). For Wales DTMs and DSMs (Welsh Government 2020-22 LiDAR Cloud Optimized GeoTIFFs, (Welsh Government, 2023)) were imported into QGIS and then clipped to the Elenydd landscape boundary. We calculated dominant treetops, height values and tree crowns from CHM files using the ‘vwf’ and ‘mcws’ functions in the ForestTools R package (Plowright, 2023) using a height threshold of 1.5m. This threshold was selected to capture shorter vegetation including shrub/scrub whilst excluding built structures including dry stone walls. We removed buildings from the tree tops and tree crowns data using the OS local buildings data (Ordnance Survey, 2023). We created raster layers of mean canopy cover and mean tree height in each landscape at 10m resolution.

1.3.2 Bracken

In order to identify potential areas of bracken cover in the landscapes, we used Your Maps Your Way (Morton & Schmucki, 2023) in Google Earth Engine (Gorelick et al., 2017). We created a training data set (1304 and 454 points in North Pennines and Elenydd, respectfully) within each landscape, ensuring coverage within every 10 x 10 km square. For each training point location, we manually identified land cover (heather/bog, water, improved grassland, arable, sparse vegetation, rough grassland, deciduous woodland, coniferous woodland and bracken) using satellite imagery. We then used Sentinel-2 data and the default options to create the classification, which includes 30% cloud tolerance, 100 trees, and uses 70% of the training data. The producer accuracy for bracken was 0.7 and 0.9 for the North Pennines and Elenydd, respectfully.

1.3.3 Land cover

The 10-m resolution 2020 land cover map (LCM2020) formed the basis of all spatially explicit scenarios. We modified the land cover with the following changes. Firstly, we identified scrub using the tree canopy and height data and thresholds of < 3.5m height and > 30% canopy cover. This height threshold was chosen as the mean value of cell heights within areas defined as ‘shrub’ in the National Forest Inventory (Forestry Commission, 2018) in the North Pennines, as no shrub data was available in the Elenydd. The canopy cover threshold was taken from scrub related habitats including ‘Juniper’ and ‘Mixed montane scrub’ (Fletcher et al., 2021). Next, we identified additional broadleaved woodland using areas classed as ‘Broadleaved’, ‘Coppice with standards’, ‘Coppice’; additional coniferous woodland using areas classed as ‘Conifer’; and mixed woodland using areas classed as ‘Mixed mainly broadleaved’ and ‘Mixed mainly conifer’ in the National Forest Inventory (Forestry Commission, 2018). In the North Pennines, we additionally assigned broadleaved woodland to pixels classed as ‘Ancient & Semi-Natural Woodland’ and coniferous woodland to pixels classed as ‘Ancient Replanted Woodland’ in the Ancient Woodland Inventory (Natural England, 2020). In the Elenydd, we assigned broadleaved woodland to pixels classed as ‘Ancient Semi-Natural Woodland’ and ‘Restored Ancient Woodland Site’, and coniferous woodland to pixels classed as ‘Plantation on Ancient Woodland Site’ Woodland’ in the Ancient Woodland Inventory (Natural Resources Wales, 2021). We also assigned to broadleaved woodland, coniferous woodland, acid grassland, neutral grassland, calcareous grassland, bog, fen, heathland to any pixels classed as such in national priority habitat inventories (Natural England, 2021; Welsh Government, 2014). We classed pixels as degraded bog if they have been subject to muirburn in the last 5 years (Shewring et al., 2024) or, for North Pennines only, areas classed as ‘Burned’, ‘Hagged, Gripped and Burned’, ‘Gripped and Burned’ and ‘Hagged and Burned’ in the Moorland Deep Peat Status map (Natural England et al, 2023). Finally, we assigned pixels as bracken in Elenydd only (where interventions included bracken removal) using the bracken layer derived above (see 1.2.2 Bracken).

1.4 Spatially explicit future land use scenarios

We converted the qualitative land use visions from the participatory workshops into quantitative spatially explicit future land use scenarios by editing the 10m resolution land cover and tree cover rasters to reflect the deployment of specific interventions according to predefined spatial criteria. Firstly, we listed the land use interventions chosen by each workshop group (e.g. woodland creation, peatland restoration, semi-natural grassland creation) and extracted the criteria given by each group related to where the intervention should or should not be placed. Some rules were given specifically for one intervention, (e.g. woodland creation in upland gills), some rules were given to all interventions which involved tree planting (e.g. no tree planting in wader zones), and some rules were given to all interventions (e.g. no new interventions on priority semi-natural grassland). For each group's set of interventions, we identified all the rules which were applicable, and then identified the most appropriate spatial data which could be used to quantitively map the areas which were applicable (see Table 1.3.1 for all data sources used). We thus identified the unique opportunity area of each intervention, for each group, in each of the two landscapes. Interventions which were characterised by more rules tended to have smaller opportunity areas, and vice versa. Table 1.3.2 shows the criteria which are common across all interventions in both landscapes, including the target tree canopy cover percentage of treescape interventions. For simplicity, scenarios deploy interventions to the entirety of each interventions' opportunity area. We used a ranking system to account for the fact that opportunity areas for different interventions are not necessarily mutually exclusive. For all tree/woodland interventions we ranked pixels by the lowest tree cover first, so areas with the lowest tree cover were prioritised first. For any interventions which included natural colonisation, pixels were also ranked by distance to nearest woodland/scrub, so these interventions were deployed closest to woodland/scrub first. For interventions that involve expansion of current habitat (e.g. hay meadows, semi-natural grassland, woodland), these were also ranked by distance to the habitat. Lastly, some groups gave their preference for where interventions are 'preferred' such as on the least agricultural productive land first, or highest elevation first. All other interventions were ranked randomly. For any rules which related to waders in NP, we created a 'wader hotspot' data layer, which combined the BTO Wader zones 4 and 5 for Curlew, Lapwing, Snipe, Redshank, Dunlin, Golden Plover, and denoted wader hotspots as anything over a score of 10. All external data sources used for scenario creation can be found in Table 1.3.1.

Table 1.4.1: All third-party data used in scenario creation and predicted outcomes.

Type	Data source name	URL
Land cover	Land Cover Map 2020 (10m raster, GB)	https://doi.org/10.5285/35c7d0e5-1121-4381-9940-75f7673c98f7
Hedgerows	Woody Linear Features framework (GB)	https://doi.org/10.5285/d7da6cb9-104b-4dbc-b709-c1f7ba94fb16
Agriculture	Provisional Agricultural Land Classification (ALC) (England)	https://naturalengland-defra.opendata.arcgis.com/datasets/5d2477d8d04b41d4bbc9a8742f858f4d/explore
Agriculture	Predictive Agricultural Land Classification (ALC) Map 2 (Wales)	https://datamap.gov.wales/layers/inspire-wg:wg_predictive_alc2
Land cover	Ancient Woodland (England)	https://naturalengland-defra.opendata.arcgis.com/datasets/ancient-woodland-england/explore

Land cover	Ancient Woodland Inventory 2021 (Wales)	https://datamap.gov.wales/layers/inspire-nrw:NRW_ANCIENT_WOODLAND_INVENTORY_2021
Land cover	National Forest Inventory Woodland GB 2019	https://data-forestry.opendata.arcgis.com/documents/5d694fb04c4f43558f90095a103f4513/explore
Biodiversity	Breeding Bird Survey	https://www.bto.org/our-science/data/data-request-system
Land cover	Priority Habitats (England)	https://naturalengland-defra.opendata.arcgis.com/datasets/Defra::priority-habitats-inventory-england/about
Land cover	WOM21 Priority Habitat - High Sensitivity (Wales)	https://datamap.gov.wales/layers/geonode:gwc21_priority_habitat_high_sensitivity
Land cover	Muirburn	https://doi.org/10.1002/rse2.389
Soil	Peatland	https://naturalengland-defra.opendata.arcgis.com/datasets/8a61459e22fb44a392dd7b10de36f5d8/explore; https://www.mediafire.com/file/sd1jyrx4dvq7gax/NATIONAL_FOREST_ESTATE_SOIL_GB.zip/file; https://www.bgs.ac.uk/datasets/bgs-geology-50k-digmapgb/; https://datamap.gov.wales/layergroups/geonode:nrw_terrestria l_phase_1_habitat_survey; https://datamap.gov.wales/layergroups/geonode:nrw_phase_2_peatland?lang=en (following Bradfer-Lawrence et al. 2021)
Soil	Moorland Deep Peat AP Status (England)	https://naturalengland-defra.opendata.arcgis.com/datasets/Defra::moorland-deep-peat-ap-status-england/about
Soil	Global Hydrologic Soil Groups (HYSOGs250m) for Curve Number-Based Runoff Modelling	https://daac.ornl.gov/SOILS/guides/Global_Hydrologic_Soil_Group.html
LiDAR	National Lidar Programme - Environment Agency (England)	https://www.data.gov.uk/dataset/f0db0249-f17b-4036-9e65-309148c97ce4/national-lidar-programme
LiDAR	National Lidar Programme - Welsh Government (Wales)	https://datamap.gov.wales/maps/lidar-viewer/
Rivers	OS Open Rivers (GB)	https://osdatahub.os.uk/downloads/open/OpenRivers
Biodiversity	Wader Zonal Map (BTO, Forestry Commission and the Cairngorm National Park Authority)	https://data-forestry.opendata.arcgis.com/datasets/a77be003a20748fcbb7b8a484305dc06_0
Roads	OS Open Roads (GB)	https://osdatahub.os.uk/downloads/open/OpenRoads
Forestry	Tree yield class, height and age data	https://www.forestresearch.gov.uk/tools-and-resources/fthr/forest-yield/
Designations	NNR Wales	https://datamap.gov.wales/layers/inspire-nrw:NRW_NNR
Forestry	Ecological Site Classification - Tree Yield Class	http://www.forestdss.org.uk/geoforestdss/
Land cover	Moorline (England)	https://magic.defra.gov.uk/Datasets/Dataset_Download_MoorlandLine.htm
Land cover	Upland boundary - upper limit of enclosure (Wales)	https://datamap.gov.wales/layers/geonode:phase1_upland_boundary
Opportunity maps	Non-habitat woodland planting sensitivity ecological score (Wales)	https://datamap.gov.wales/layers/geonode:GWC21_Less_Biodiverse_Habitat_Dissolve_Score/metadata_detail
Opportunity maps	River Wye catchment (Wales) species-rich grassland creation opportunity maps	https://datamap.gov.wales/documents/2646
Buildings	OS open buildings	https://hub.arcgis.com/datasets/esriukcontent::os-openmap-local-buildings-1/explore
Land cover	Grass field boundaries - Land	https://doi.org/10.5285/0e99d57e-1757-451f-ac9d-92fd1256f02a

	Cover Map 2020 (vector, GB)	
Livestock	AgCencus 2016 5km (England)	https://agcensus.edina.ac.uk/
Livestock	AgCencus 2018 2km (Wales)	https://agcensus.edina.ac.uk/
Soil	National Soil Map	https://www.landis.org.uk/data/nmvector.cfm
Other	Lead mines (Wales)	https://elanvalley.org.uk/heritage/history/mining/
Climate	UK climate data (for run-off storm depth calculation)	https://www.metoffice.gov.uk/hadobs/hadukp/data/download.html

Table 1.4.2: Generic spatial criteria applied to different intervention types, these do not include the spatial criteria selected by stakeholder groups

Intervention	Land cover change	Tree cover change	General opportunity area
Broadleaved woodland (planting)	To broadleaved woodland	Increase to 80%	Grassland/heather land cover pixels
Broadleaved woodland (natural colonisation)	To broadleaved woodland	Increase to 10%	Grassland/heather land cover pixels within 100m buffer
Broadleaved woodland (expansion from existing)	To broadleaved woodland	Increase to 80%	Grassland/heather land cover pixels within 200m buffer
Riparian woodland	To broadleaved woodland	Increase to 80%	Grassland/heather land cover pixels within 50m buffer of watercourses
Upland gill planting - **Woodland** - **Scrub**	 To broadleaved woodland To scrub	 Increase to 80% Increase to 30%	Grassland/heather land cover pixels, within 50m buffer around watercourses, above the moorline, and above 5 degrees slope
Mixed woodland	To mixed woodland	Increase to 80%	Grassland/heather or conifer pixels (if specified)
Wood pasture	To wood pasture	Increase to 10%	Semi-natural grassland pixels
Wood meadow	To wood meadow	Increase to 10%	Semi-natural grassland pixels
Orchard (silvopastoral)	To orchard	Increase to 10%	Improved grassland pixels
Semi-natural grassland	To semi-natural grassland	No change	Improved grassland pixels
Semi-natural grassland (expansion from existing)	To semi-natural grassland	No change	Improved grassland pixels within 1km buffer from existing
Peatland restoration	To bog	No change	On peat soils
Scattered/field trees/tree standards	No change	Increase to 10%	Grassland/heather pixels
Scrub/Ffridd (planting)	To scrub	Increase to 30%	Grassland/heather pixels
Scrub/ Ffridd (natural colonisation)	To scrub	Increase to 10%	Grassland/heather pixels within 100m buffer
Conifer removal (on peat)	To bog	Decrease to 0%	Conifer pixels on peat soils
Conifer removal (not peat)	To broadleaved woodland	Change to 80%	Conifer pixels not on peat soil

1.5 Impacts on livestock units

We estimated changes in livestock numbers by multiplying the area of each land cover by the recommended stocking rate and summing across the landscape. We treated wood pasture and wood meadows as ‘Semi-natural grassland’, except for the NP Farming group who specifically requested wood pasture in the lower valleys, and for whom we assumed the same stocking density as ‘Improved grassland’. We treated silvopastoral Orchard (NP Land) as ‘Improved grassland’.

Table 1.5: Habitat specific livestock stocking rates, including upper and lower estimates. Stocking rates taken from Chapman (2007).

Habitat	**Stocking rate (mid)**	**Stocking rate (upper)**	**Stocking rate (lower)**	**Calculated from (Chapman, 2007)**
Improved grassland	1	1.3	0.7	Improved grassland (mid) and ±30% for upper/lower
Semi-natural grassland	0.3	0.4	0.15	Unimproved upland grassland (lower), Unimproved lowland grassland (mid), rush pasture (upper)
Intermediate heather	0.05	0.2	0.02	Young heather (upper), intermediate heather (mid), old heath (lower)
Blanket bog	0.06	0.078	0.042	Blanket bog (mid) and ±30% for upper/lower
Woodland	0.07	0.15	0.03	High fertility (upper), moderated fertility (mid) and low fertility (lower)

1.6 Impacts on greenhouse gas emissions

1.6.1 Tree age model

Carbon sequestration by trees varies as a function of their age. To predict current and future GHG emissions under each scenario from trees inside and outside of woodlands, we created a model to predict age of 10m cells based on average tree height (for methods on creating tree height data, see section 1.3.1). To create training data for the model, we download yield tables of Oak, Sycamore (as a proxy for Silver Birch) and Sitka Spruce from ForestYield (ForestryCommission, 2016) which include data of stand age and height for each yield class for the three species. We then created a species-specific nonlinear least-squares models using the R package minpack.lm (Elzhov et al., 2023) with age as the response variable, and yield class and height as the explanatory variables. Models were fitted using the starting parameters a = 1 (a controls the asymptotic growth of height with age), b = 0.01 (b controls the rate of increase with age), c = 1 (c controls the linear effect of yield class (yc) on height) and a_yc = 1 (ac_y represents the interaction between a and yc) following the equation:

$$age = \frac{-1}{b}.\log\left(\frac{1-(height-c.yc)}{a-\ a\_yc.yc}\right)$$

To use this model to predict the age of trees across our landscape, we first estimated the yield cla-ss of each 10m cell. To predict yield class, we created 100 random coordinates in each landscape, and downloaded the expected yield class for Sessile Oak, Sikta Spruce and Silver Birch from the Forest Research Ecological Site Classification tool (Forest Research, 2023), along with accumulated temperature, continentally, exposure, moisture deficit, soil moisture regime and soil nutrient regime (mapped for the entire landscape). We then used random forest model using the R package ‘randomForest’ (Liaw & Wiener, 2002) to predict yield class as a function of these 6 soil and climatic variables. We clipped the mean tree height by areas defined as ‘Coniferous woodland’ in the LCM2020, and assumed everything else was deciduous (which includes deciduous woodland and trees outside of woodland). We assumed that the Sitka Spruce yield class model was representative of coniferous woodland, and that all broadleaved woodland and trees outside woodland were represented by the mean of the Sycamore and Oak age models.

1.6.2 Carbon in woodlands and trees

Firstly, the we extracted 5-yearly biomass estimates for Sycamore-Ash-Birch (SAB), Oak and Sitka Spruce from the Woodland Carbon Code Carbon Calculator Spreadsheet (WWC, 2021), and following the methods of (Finch et al., 2023), interpolated values into annual flux estimates. We interpolated values for missing low yield classes and for 'unthinned' Oak and SAB. We also estimated the removed biomass used for timber/fuel arising from clear-felling, and for remaining debris, for SAB, Oak and SS woodlands following the methods of Finch et al., 2023. For current deciduous woodland and trees outside of woodland we used the mean standing flux estimates for Oak and SAB, varying according to the yield class and predicted age of each cell (Table 1.6.2). For current mixed woodland and conifer woodland, we assumed stands were clearfelled on a species and yield class specific rotation length, unless the predicted age of the cell was greater than the clear fell age, in which ase we assumed stands were left unharvested (Table 1.6.2). For mixed woodland we calculated the weighted mean carbon flux of Oak (25%), SAB (25%), and Sikta Spruce (50%), varying according to yield class and age, and for conifer woodland we assumed carbon fluxes were represented by Sitka Spruce (Table 1.6.2). All woodland flux estimates were scaled to the % of canopy cover per cell. For existing trees (in and outside of woodland) in 2050, we increased the predicted age by 28 years (LiDAR data was collected in 2022) and recalculated the net annual flux as described above. New woodland was introduced at an annually constant rate between 2025 and 2040. We treated deciduous woodland and trees outside of woodland (including wood pasture, wood meadows, tree standards, scattered trees, orchards) as above (i.e. unharvested), with age based on the year of intervention implementation. We treated new mixed productive woodland as above (25% Oak, 25% SAB and 50% Sitka Spruce) assuming harvesting occurs on a clearfell rotation. Coniferous woodland was removed (and replaced with either new woodland or restored bog) at an annually constant rate between 2025 and 2040, and we treated the intervention year as a clearfell event. To calculate lower and upper estimates we used yield class +2 and yield class -2 to recalculate the net flux.

Table 1.6.2: Woodland and trees outside of woodland types and assumptions for estimating annual net flux. For current deciduous woodland and trees outside of woodland we used the standing flux estimates for Oak and SAB, using the yield class and predicted age of each cell, and calculated the mean of the two species. For current mixed woodland and conifer woodland, we assumed stands were harvested on a clearfell rotation unless predicted age was greater than the rotation length. For mixed woodland we assumed the proportion was made up of Oak (25%), SAB (25%), and Sikta Spruce (50%), using the predicted yield class and age, and for conifer woodland we used Sikta Spruce flux only.

Woodland Type	Description	Existing or unchanged interventions	New interventions
Standing	Assume standing trees/woodland with no removals but occasional thinning	- Broadleaved woodland - Trees outside of woodland - Mixed woodland (if age > clear fell age) - Conifer woodland (if age > clear fell age)	- Broadleaved woodland - Trees outside of woodland
Clear fell	On clear fell rotation with area felled and replaced	- Mixed woodland (if age < clear fell age) - Conifer woodland (if age < clear fell age)	- Mixed woodland
Removed	Removal with no replacement	NA	- Conifer removal

1.6.3 Soils

We predicted the net flux from soils largely following Finch et al. (2023). Firstly, we calculate the estimated net flux from peat soils under current and future land use using emissions factors reported in national inventories (Evans et al., 2022; Evans et al., 2017). We first mapped the extent of peat soils using the data sources described in Table 1.4.1. Next, we matched each land cover to one or more corresponding peat condition categories from the national inventories, taking an area-weighted average for land covers with multiple corresponding condition categories (Table 1.6.3). Where available, we used reported mid, upper and lower bounds of emissions factors for each land cover type,

For non-peat soils, we assume carbon fluxes were 0 except for land-use transitions from grassland to woodland (including deciduous woodland and mixed woodland, this did not include wood pasture). We applied different emissions factors for mineral and organo-mineral soils (identified using the National Soil Map (https://www.landis.org.uk/data/natmap.cfm). For non-organic soils we use the England and Wales country-specific change in equilibrium soil carbon density (t ha^{-1}) of woodland and grassland (Brown et al., 2023) and used the range to calculate upper and lower estimates. For organo-mineral soils, we assume a mid-estimate of 0 t ha^{-1} (i.e. no soil carbon gain from woodland creation) and use the same range values from non-organic to calculate upper and lower estimates (capturing either both a loss and gain of soil carbon following woodland creation).

Table 1.6.3: Combined total net flux for all GHG source/sink pathways of peat soils based on different land cover classes, expressed in CO_2 ha^{-1} yr^{-1}. Values taken from (Evans et al., 2022; Evans et al., 2017).

LCM category	Peatland activity category	Total flux	Reference
Broadleaved woodland	Forest	9.91	Evans et al 2017
Coniferous Woodland	Forest	9.91	Evans et al 2017
Arable and Horticulture	Cropland	37.17	Evans et al 2022
Arable and Horticulture	Cropland - wasted	26.1	Evans et al 2022
Improved grassland	Intensive grassland	22	Evans et al 2022
Semi natural grassland	Extensive grassland	15.88	Evans et al 2022
Semi natural grassland	Drained grass dominated modified bog	3.32	Evans et al 2022
Semi natural grassland	Undrained grass dominated modified bog	3.32	Evans et al 2022
Fen	Rewetted fen	3.31	Evans et al 2022
Fen	Near natural fen	-0.36	Evans et al 2022
Heather	Drained grass/heather modified bog	3.32	Evans et al 2022
Heather	Undrained grass/heather modified bog	2.51	Evans et al 2022
Bog	Near natural bog	0.32	Evans et al 2022
Bog	Rewetted bog	3.42	Evans et al 2022
Degraded Bog	Extracted domestic (fuel peat)	15.18	Evans et al 2022
Degraded Bog	Extracted industrial (horticultural)	18.86	Evans et al 2022
Degraded Bog	Drained eroded modified bog	18.86	Evans et al 2022
Degraded Bog	Undrained eroded modified bog	17.72	Evans et al 2022
Fen (new)	Rewetted fen	3.31	Evans et al 2022
Bog (new)	Rewetted bog	3.42	Evans et al 2022
Bog (new)	Rewetted modified bog	0.32	Evans et al 2022
Mixed Woodland	Forest	9.91	Evans et al 2017

1.6.4 Agricultural emissions

We first estimated the total number into of cattle, lambs, breeding ewes and other sheep in each landscape. We extracted AgCensus data for Wales including breeding ewes, total sheep, lambs and cattle at 2km resolution from 2018 (WelshGovernment, 2018) and for England including total sheep, lambs, cattle and breeding ewes (further breeding, for slaughter, first time breeding) at 5km resolution from 2016 (DEFRA, 2016), and calculate the total head count across each landscape. We scaled these totals in proportion to the % change in national cattle and sheep numbers for 2016-2021 and 2018-2021 for England and Wales, respectfully (DEFRA, 2023; WelshGovernment, 2022) to give current (2021) estimates of cattle, lambs, ewes and other sheep in both landscapes. We then use the change in livestock units under future scenarios (see section 1.5) to adjust the total number of each livestock type under each scenario. If a group's intervention included 'alter stocking density', we increased cattle and decreased sheep stocking densities in the landscape. For the North Pennines, we increased cattle by 50%, and in the Elenydd (where there are fewer cattle) we increased cattle densities 100%. We then calculated the corresponding decrease in total sheep, lambs and ewes which maintained the total livestock units in the landscape. We calculated this using the animal number to units values, 1 cattle = 1 livestock unit and sheep = 0.08 livestock units (hill ewe and lamb)[1].

Next we took emissions factors (see Table 1.6.4) for manure methane, enteric methane and manure N_2O (all expressed per head of livestock), for fuel and concentrate use (deriving estimates of fuel and concentrate use per calf and per lamb from Williams et al. 2006), for N_2O from inorganic nitrogen (assuming a constant application rate on improved grassland only) and for CO_2 from urea, lime and dolomite (again assuming a constant application rate on improved grassland only). For each scenario, we multiplied emissions factors by the estimated numbers of cattle, lambs, breeding ewes and other sheep, or the area of improved grassland in the landscape to calculate the total net flux of agricultural emissions. For the 'low carbon farming' intervention we assumed electrification of farm vehicles and reduce fuel rate per calf/lamb (see Table 1.5.4) by 50%.

[1] https://www.gov.uk/guidance/countryside-stewardship-mid-tier-and-wildlife-offers-manual-for-agreements-starting-on-1-january-2022/annex-6c-convert-livestock-numbers-into-livestock-units

Table 1.6.4 Published emission factors (per head of livestock or per hectare of agricultural grassland (improved grassland) for emissions from enteric methane, manure management, fuel use and fertiliser use.

Animal	Variable	Value	Min	Max	Units	Gas	Source
Cattle	ef_enteric_ch4	57	39.9	74.1	kg CH4 / head / yr	CH4	IPCC Tier 1, Western Europe (IPCC, 2006); (Edwards-Jones et al., 2009); +- 30%
Sheep	ef_enteric_ch4	8	5.6	10.4	kg CH4 / head / yr	CH4	IPCC Tier 1 (IPCC, 2006), Western Europe; Edward-Jones et al. 2009; +- 30%
Sheep (<1 yr)	ef_enteric_ch4	3.2	2.24	4.16	kg CH4 / head / yr	CH4	Jones et al. 2014; Edward-Jones et al. 2009; +- 30%
Cattle	ef_manure_ch4	10	7	13	kg CH4 / head / yr	CH4	IPCC Tier 1, Western Europe 15C av temp; Edward-Jones et al. 2009; +- 30%
Sheep	ef_manure_ch4	0.19	0.133	0.247	kg CH4 / head / yr	CH4	(Jones et al., 2014); Edward-Jones et al. 2009; +- 30%
Sheep (<1 yr)	ef_manure_ch4	0.076	0.053	0.099	kg CH4 / head / yr	CH4	Jones et al. 2014; Edward-Jones et al. 2009; +- 30%
Cattle	ms_pasturepaddock	0.5			Fraction		Table A 3.3.5 in UK GHGI 1990-2021 Annex (Brown et al., 2023)
Cattle	ms_solid	0.25			Fraction		Table A 3.3.5 in UK GHGI 1990-2021 Annex (Brown et al., 2023)
Cattle	ms_liquid	0.25			Fraction		Table A 3.3.5 in UK GHGI 1990-2021 Annex (Brown et al., 2023)
Cattle	ms_dailyspread	0			Fraction		Table A 3.3.5 in UK GHGI 1990-2021 Annex (Brown et al., 2023)
Sheep	ms_pasturepaddock	0.95			Fraction		Slight simplification of Table A 3.3.5 in UK GHGI 1990-2021 Annex (Brown et al., 2023)
Sheep	ms_solid	0.05			Fraction		Slight simplification of Table A 3.3.5 in UK GHGI 1990-2021 Annex (Brown et al., 2023)
Cattle	ef3_solid	0.02	0.01	0.04	kg N2O-N / kg N	N2O-N	Table A 3.3.6 in UK GHGI 1990-2021 Annex (FYM systems); uncertainty factor of 2 (Brown et al., 2023)
Cattle	ef3_liquid	0.002	0.001	0.004	kg N2O-N / kg N	N2O-N	Table A 3.3.6 in UK GHGI 1990-2021 Annex; uncertainty factor of 2 (Brown et al., 2023)
Sheep	ef3_solid	0.005	0.0025	0.01	kg N2O-N / kg N	N2O-N	Table A 3.3.6 in UK GHGI 1990-2021 Annex; uncertainty factor of 2 (Brown et al., 2023)
Cattle	n_excretion	44.5			kg N / head / yr		Table A 3.3.4 in UK GHGI 1990-2021 Annex (2020 value) (Brown et al., 2023)
Sheep	n_excretion	8.8			kg N / head / yr		Table A 3.3.4 in UK GHGI 1990-2021 Annex (2020 value) (Brown et al., 2023)

Sheep (<1 yr)	n_excretion	4.2			kg N / head / yr		Table A 3.3.4 in UK GHGI 1990-2021 Annex (2020 value) (Brown et al., 2023)
Cattle	ef1_pasturepaddock	0.02	0.007	0.06	kg N2O-N / kg N	N2O-N	IPCC Tier 1 (Table 11.1) (IPCC, 2006)
Sheep	ef1_pasturepaddock	0.01	0.003	0.03	kg N2O-N / kg N	N2O-N	IPCC Tier 1 (Table 11.1) (IPCC, 2006)
	ef1_organic	0.01	0.003	0.03	kg N2O-N / kg organic N	N2O-N	IPCC Tier 1 (Table 11.1) (IPCC, 2006)
	ef1_inorganic	0.01	0.003	0.03	kg N2O-N / kg inorganic N	N2O-N	IPCC Tier 1 (Table 11.1) (IPCC, 2006)
Cattle	frac_loss_solid	0.5			Fraction		IPCC Tier 1 (Table 10.23, Solid storage) (IPCC, 2006)
Cattle	frac_loss_liquid	0.48			Fraction		IPCC Tier 1 (Table 10.23, dairy, liquid/slurry) (IPCC, 2006)
Cattle	frac_loss_dailyspread	0			Fraction		
Sheep	frac_loss_solid	0.15			Fraction		IPCC Tier 1 (Table 10.23, other, Solid storage) (IPCC, 2006)
	n_rate_inorganic	25.5			kg inorganic N / ha improved grass / yr		34 kg N/ha/yr is the average applied to "grass 5 years and over" from GB livestock farms in 2020, Table GB4.4, (DEFRA, 2021). This was revised down by 25% following advice from RSPB staff with knowledge of the landscapes.
	ef4	0.01	0.002	0.05	kg N2O-N / kg N vol	N2O-N	IPCC Tier 1 (Table 11.3) (IPCC, 2006)
	ef5	0.008	0.0005	0.025	kg N2O-N / kg N leach	N2O-N	IPCC Tier 1 (Table 11.3) (IPCC, 2006)
	frac_vol_inorganic	0.1			Fraction		IPCC Tier 1 (Table 11.3) (IPCC, 2006)
	frac_vol_organic	0.2			Fraction		IPCC Tier 1 (Table 11.3) (IPCC, 2006)
Cattle	frac_vol_pasturepaddock	0.2			Fraction		IPCC Tier 1 (Table 11.3) (IPCC, 2006)
Sheep	frac_vol_pasturepaddock	0.2			Fraction		IPCC Tier 1 (Table 11.3) (IPCC, 2006)
	frac_leach_inorganic	0.1			Fraction		(Brown P et al., 2016)
Cattle	frac_leach_pasturepaddock	0.1			Fraction		Brown et al., 2016
Sheep	frac_leach_pasturepaddock	0.1			Fraction		Brown et al., 2016
	frac_leach_organic	0.3			Fraction		Brown et al., 2016
Cattle	frac_vol_solid	0.45			Fraction		IPCC Tier 1 (Table 10.22) (IPCC, 2006)

Cattle	frac_vol_liquid	0.4			Fraction		IPCC Tier 1 (Table 10.22) (IPCC, 2006)
Cattle	frac_vol_dailyspread	0			Fraction		
Sheep	frac_vol_solid	0.12			Fraction		IPCC Tier 1 (Table 10.22) (IPCC, 2006)
Cattle	frac_leach_solid	0			Fraction		
Cattle	frac_leach_liquid	0			Fraction		
Cattle	frac_leach_dailyspread	0			Fraction		
Sheep	frac_leach_solid	0			Fraction		
Cattle	fuel_rate	237			MJ / cow-calf / yr		mean of hill and upland (Williams et al., 2006)
Sheep	fuel_rate	93			MJ / ewe-lamb / yr		mean of hill and upland (Williams et al., 2006)
Cattle	concentrate_rate	393			kg / cow-calf / yr		mean of hill and upland (Williams et al., 2006)
Sheep	concentrate_rate	40			kg / ewe-lamb / yr		mean of hill and upland (Williams et al., 2006)
	urea_rate	8.25			kg / ha improved grass / yr		British Survey of Fertiliser Practice (2020)
	liming_rate	67.76			kg / ha improved grass / yr		British Survey of Fertiliser Practice (2020), Table EW1.4 for “grass 5 years and over”
	dolomite_rate	9.24			kg / ha improved grass / yr		British Survey of Fertiliser Practice (2020), Table EW1.4 for “grass 5 years and over”
	ef_fuel	0.089	0.0712	0.1068	kg CO2e / MJ diesel	CO2	(Lamb et al., 2016). 20% error
	ef_concentrate	1.54	2.31	0.77	kg CO2 / kg concentrate	CO2	(Lamb et al., 2016) Table S4
	ef_urea	0.2	0.1	0.4	kg CO2-C / kg urea / yr	CO2-C	IPCC Tier 1; uncertainty factor of 2 (IPCC, 2006)
	ef_liming	0.43971	0.219855	0.87942	kg CO2 / kg limestone / yr	CO2	IPCC Tier 1; uncertainty factor of 2 (IPCC, 2006)
	ef_dolomite	0.47732	0.23866	0.95464	kg CO2 / kg dolomite / yr	CO2	IPCC Tier 1; uncertainty factor of 2 (IPCC, 2006)

1.7 Impacts on bird populations

To estimate the impact of scenarios on bird populations, we used Breeding Bird Survey (BBS) data (Heywood et al., 2023) to fit Generalized Additive Models (GAM) of abundance as a function of land cover. BBS data were selected from 2018 - 2022 from 1-km squares within the National Character Areas of the North Pennines, Yorkshire Dales and Pennine Dales Fringe for NP, and the National Landscape Character Areas of the Cambrian Mountains and Upper Wye Valley for ED. These landscapes are similar in character to our focal landscapes. For each species in each year and each 200-m transect section we calculated the maximum count across the early and late visit, then summed counts across all years. To calculate the effective area, we multiplied detection probability (calculated using distance methods, and varying by species and habitat; see Finch et al. 2023) by transect section area ($200m^2$) and number of years. Individual GAMs were created for each species with count as the predictor variable, x and y coordinates as smoothed terms, and the log effective area as an offset (to account for uneven survey effort and detection probability). Additional explanatory covariates were extracted for each 200-m transection using a 100m-width square buffer (% cover of improved grassland, semi-natural grassland, deciduous woodland, coniferous woodland, scrub, degraded bog, bog and heather; tree canopy cover; mean elevation; mean slope; hedgerow length) and for the containing 1km square (tree canopy cover; % muirburn (NP only); for methods on creating tree canopy cover/scrub/degraded bog, see section 1.3).

To select species for inclusion, we first excluded any species with less than 5 counts across individual 200-m transect sections, then considered only species defined as woodland or upland indicator species (Eaton & Noble, 2023; Noble & Barnes, 2023). We created models for all remaining species and predicted their abundance in each 200-m grid square across each landscape under current and future land and tree cover, keeping x, y, slope and elevation fixed. Predictions were filtered by removing values > 99^{th} percentile, and the R^2 was extracted for each model. We filtered predictions by removing species with poor R^2, which provided the final species for each landscape (see Table 1.6 for species lists). To calculate an overall change in abundance from the present day land cover, we summed the total abundance of each species across each landscape then calculated a bootstrapped geometric mean change for woodland and upland indicator groups (Buckland et al., 2011). For the mid estimate we use the 0.5 quantile, for the lower estimate the 0.025 quantile, and for the upper estimate the 0.975 quantile of the bootstrapped geometric mean change in abundance.

Table 1.7: Woodland and upland bird indicator species used for final bird abundance models & predictions

Landscape	Group	List
Elenydd	Woodland	Blackbird, Blue Tit, Coal Tit, Goldcrest, Nuthatch, Tree Pipit (*N* = 6)
Elenydd	Upland	Meadow Pipit, Wheatear, Whinchat (*N* = 3)
North Pennines & Dales	Woodland	Blackbird, Blackcap, Blue Tit, Chiffchaff, Chaffinch, Great Tit, Robin, Song Thrush, Wren (*N* = 9)
North Pennines & Dales	Upland	Curlew, Carrion Crow, Lapwing, Meadow Pipit, Oystercatcher, Pied Wagtail, Red Grouse, Snipe, Stonechat, Wheatear (*N* = 10)

1.8 Impacts on water run-off

To calculate the current and future changes in total run-off a rainfall storm depth needed to be defined in the equation, in which we used 20mm depth. This depth roughly corresponds to the 99% percentile of daily rainfall between 1931 and 2024, in North East England (17.1mm) and South West England and Wales (19.7mm) calculated using MetOffice HadUKP Data (https://www.metoffice.gov.uk/hadobs/hadukp/data/download.html). Cells were assigned a soil group, but if cells were on slopes of 15 degrees or over, then the soil group with the highest run-off value was assigned, representing the likely higher water run-off on steeper slopes. Then, all cells were assigned a run-off curve number based on soil group and land cover class (Table 1.8).

Table 1.8: Run-off curve number for soil groups A-D across all land cover classes. For land cover classes which do not have published CN numbers, we used the mean of other suitable land cover classes (see notes). Mid estimates were created using the mean between upper and lower estimates.

Land cover class	A	B	C	D	Notes	Type
Deciduous woodland	36	60	73	79	Woodland (Thomas, 2018)	upper
Coniferous woodland	36	60	73	79	Woodland (Thomas 2018)	upper
Mixed Woodland	36	60	73	79	Woodland (Thomas 2018)	upper
Arable	74	83	88	90	Arable (Thomas 2018)	upper
Improved grassland	68	79	86	89	Improved grassland, poor pasture (Thomas 2018)	upper
Neutral grassland	30	58	71	78	set aside grassland, meadow (Thomas & Nisbet, 2017)	upper
Calcareous grassland	30	58	71	78	set aside grassland, meadow (Thomas & Nisbet., 2017)	upper
Acid grassland	30	58	71	78	set aside grassland, meadow (Thomas & Nisbet, 2017)	upper
Heather	35	56	70	77	Heather (Thomas 2018)	upper
Heather grassland	35	56	70	77	Heather (Thomas 2018)	upper
Bog	59	59	59	59	Bog (Menberu et al., 2015)	upper
Saltwater	100	100	100	100	Open water (Thomas 2018)	upper
Saltmarsh	59	59	59	59	Bog (Menberu et al., 2015)	upper
Freshwater	100	100	100	100	Open water (Thomas 2018)	upper
Inland rock	89	92	92	95	Exposed rock (Thomas 2018)	upper
Suburban	61	75	83	87	Suburban (Thomas 2018)	upper
Urban	89	92	94	95	Urban (Thomas 2018)	upper
Bracken	35	56	70	77	Bracken (Thomas & Nisbet, 2017)	upper
Semi natural grassland	30	58	71	78	set aside grassland, meadow (Thomas & Nisbet, 2017)	upper
Wood pasture	38.8	62.6	74.4	80.4	mean between woodland & grassland	upper
Wood meadow	38.8	62.6	74.4	80.4	mean between woodland & grassland	upper
Degraded bog	43.4	62.4	71.6	76.4	mean between bog and grass	upper
Scrub	37.4	61.3	73.7	79.7	mean between wood pasture & woodland	upper
Orchard	52	69.5	79.5	84	mean between woodland & improved grassland	upper
Fen	59	59	59	59	Bog (Menberu et al., 2015)	upper
Deciduous woodland	36	60	73	79	Woodland (Thomas 2018)	lower
Coniferous woodland	36	60	73	79	Woodland (Thomas 2018)	lower
Mixed Woodland	36	60	73	79	Woodland (Thomas 2018)	lower
Arable	74	83	88	90	Arable (Thomas 2018)	lower
Improved grassland	68	79	86	89	Improved grassland, poor pasture (Thomas 2018)	lower

Neutral grassland	68	79	86	89	Neutral grassland, poor pasture (Thomas 2018)	lower
Calcareous grassland	68	79	86	89	Neutral grassland, poor pasture (Thomas 2018)	lower
Acid grassland	68	79	86	89	Acid grassland, poor pasture (Thomas 2018)	lower
Heather	48	67	77	83	dwarf shrub heath (Thomas & Nisbet, 2017)	lower
Heather grassland	48	67	77	83	dwarf shrub heath (Thomas & Nisbet, 2017)	lower
Bog	63	63	63	63	Bog (Menberu et al., 2015)	lower
Saltwater	100	100	100	100	Open water (Thomas 2018)	lower
Saltmarsh	63	63	63	63	Bog (Menberu et al., 2015)	lower
Freshwater	100	100	100	100	Open water (Thomas 2018)	lower
Inland rock	89	92	92	95	Exposed rock (Thomas 2018)	lower
Suburban	61	75	83	87	Suburban (Thomas 2018)	lower
Urban	89	92	94	95	Urban (Thomas 2018)	lower
Bracken	68	79	86	89	Bracken (Thomas & Nisbet, 2017)	lower
Semi natural grassland	68	79	86	89	set aside grassland, meadow (Thomas & Nisbet, 2017)	lower
Wood pasture	52	69.5	79.5	84	mean between woodland & grassland	lower
Wood meadow	52	69.5	79.5	84	mean between woodland & grassland	lower
Degraded bog	67	75.8	81.4	83.8	mean between bog and grass	lower
Scrub	44	64.75	76.25	81.5	mean between wood pasture & woodland	lower
Orchard	52	69.5	79.5	84	mean between woodland & grassland	lower
Fen	63	63	63	63	Bog (Menberu et al., 2015)	lower

1.9 Impacts on nature-based recreation

Table 1.9 Land cover class nature-based recreation values used for predicting total nature-based recreation

Land cover class	Mid	Upper	Lower	Notes
Deciduous woodland	1	1	1	Broad-leaved forest (Burkhard et al., 2009; Vallecillo et al., 2019)
Coniferous woodland	0.9	1	0.8	Conifer forest (Vallecillo et al 2019 lower, Burkhard et al 2009 upper)
Arable	0.275	0.3	0.25	Annual crops (Vallecillo et al 2019), Annual & permanent crops (Burkhard et al 2009)
Improved grassland	0.6	0.6	0.6	Pastures (Vallecillo et al 2019, Burkhard et al 2009)
Neutral grassland	0.7	0.8	0.6	Natural grasslands (Vallecillo et al 2019 upper, Burkhard et al 2009 lower)
Calcareous grassland	0.7	0.8	0.6	Natural grasslands (Vallecillo et al 2019 upper, Burkhard et al 2009 lower)
Acid grassland	0.7	0.8	0.6	Natural grasslands (Vallecillo et al 2019 upper, Burkhard et al 2009 lower)
Fen	0.9	1	0.8	upper (inland marsh) lower (peat bog) (Vallecillo et al 2019)
Heather	0.9	1	0.8	Moors and heathland (Vallecillo et al 2019 lower, Burkhard et al 2009 upper)
Heather grassland	0.9	1	0.8	Moors and heathland (Vallecillo et al 2019 lower, Burkhard et al 2009 upper)
Bog	0.9	1	0.8	upper (inland marsh) lower (peat bog) (Vallecillo et al 2019)
Freshwater	1	1	1	Water bodies & courses (Vallecillo et al 2019, Burkhard et al 2009)
Wood pasture	0.75	0.9	0.6	lower (agro-forestry) upper (mean between forest & natural grassland) (Vallecillo et al 2019, Burkhard et al 2009)

Wood meadow	0.75	0.9	0.6	lower (agro-forestry) upper (mean between forest & natural grassland) (Vallecillo et al 2019, Burkhard et al 2009)
Degraded bog	0.4	0.8	0	lower (burnt areas) upper (peat bog) (Vallecillo et al 2019)
Scrub	0.6	0.8	0.4	Traditional woodland-scrub (Vallecillo et al 2019 upper, Burkhard et al 2009 lower)
Mixed Woodland	1	1	1	Mixed woodland (Vallecillo et al 2019, Burkhard et al 2009)
Orchard	0.75	1	0.5	lower (fruit trees) upper (fruit trees) (Vallecillo et al 2019 lower, Burkhard et al 2009 upper)
Semi natual grassland	0.7	0.8	0.6	Natural grasslands (Vallecillo et al 2019 upper, Burkhard et al 2009 lower)
Bracken	0.7	0.8	0.6	Natural grasslands (Vallecillo et al 2019 upper, Burkhard et al 2009 lower)

1.10 Impacts on timber production

We predicted the impact of scenarios on long-term, cumulative timber production by summing over a 200-year window the total biomass removed through clearfell and/or thinning for broadleaved, mixed and coniferous woodland of different yield classes. Following the assumptions made for the purposes of estimating greenhouse gas emissions (see section 1.6.2), we represented coniferous woodland with Sitka Spruce (thinned and harvested on a clearfell rotation 50-70 years depending on yield class), mixed woodland with 50% Sitka Spruce, 25% Oak and 25% Sycamore/Ash/Birch (thinned and harvested on a clearfell rotation 40-90 years depending on species and yield class), and broadleaved woodland and trees outside woodland with 50% Oak and 50% Sycamore/Ash/Birch (thinned). We derived biomass estimates (removed through thinning in any given year, and standing at the year of clearfelling) for each species and yield class from the Woodland Carbon Code Carbon Calculator (v 2.4). Biomass removals were summed over 200 years, assuming restocking of clearfelled stands.

This approach does not account for variation in the age structure of woodland, but rather considers the long-term potential for timber production from the available woodland resource. This approach means that the permanent felling of a plantation results in a reduction in (long-term) timber production, even though the act of felling may produce timber. Note that some coniferous/mixed stands are unlikely to be commercially viable due to poor growth and access, so our estimates of timber production represent the maximum potential.

References

Bradfer-Lawrence, T., Finch, T., Bradbury, R. B., Buchanan, G. M., Midgley, A., & Field, R. H. (2021). The potential contribution of terrestrial nature-based solutions to a national 'net zero' climate target. *Journal of Applied Ecology*, *58*(11), 2349-2360. https://doi.org/10.1111/1365-2664.14003

Brown P, Broomfield M, Buys G, Cardenas L, Kilroy E, MacCarthy J, Murrells T, Pang Y, Passant N, Ramirez Garcia J, Thistlethwaite G, & N, W. (2016). UK Greenhouse Gas Inventory, 1990 to 2014: Annual Report for submission under the Framework Convention on Climate Change. *Ricardo Energy & Environment*.

Brown, P., Cardenas, L., Del Vento, S., Karagianni , E., MacCarthy, J., Mullen, P., Passant, N., Richmond, B., Thistlethwaite, G., Thomson, A., Wakeling, D., & Willis, D. (2023). UK Greenhouse Gas Inventory, 1990 to 2021, Annual Report for Submission under the Framework Convention on Climate Change. *Ricardo Energy & Environment*.

Buckland, S. T., Studeny, A. C., Magurran, A. E., Illian, J. B., & Newson, S. E. (2011). The geometric mean of relative abundance indices: a biodiversity measure with a difference. *Ecosphere*, *2*(9). https://doi.org/10.1890/es11-00186.1

Burkhard, B., Kroll, F., Müller, F., & Windhorst, W. (2009). Landscapes' capacities to provide ecosystem services - A concept for land-cover based assessments. *Landscape Online*, *15*, 1-22. https://doi.org/10.3097/lo.200915
Chapman, P. (2007). Conservation Grazing of Semi-natural Habitats. *SAC Technical Note TN586*.
DEFRA. (2016). *England Agricultural Census 2016 5km*. EDINA Agcensus Digimap Service, https://digimap.edina.ac.uk.
DEFRA. (2021). The British Survey of Fertiliser Practise, Fertiliser se on farm crops for crop year 2020, https://assets.publishing.service.gov.uk/media/62e11c0de90e0766aa16b354/fertiliseruse-annualreport2020-28jul22.pdf.
DEFRA. (2023). *Structure of the agricultural industry in England and the UK at June*. https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june.
Eaton, M., & Noble, D., G. (2023). UK Biodiversity Indicators 2023, Technical background document: The wild bird indicator for the UK and England
Edwards-Jones, G., Plassmann, K., & Harris, I. M. (2009). Carbon footprinting of lamb and beef production systems: insights from an empirical analysis of farms in Wales, UK. *The Journal of Agricultural Science*, *147*(6), 707-719. https://doi.org/10.1017/s0021859609990165
Elzhov, T, V., Mullen, K. M., Spiess, A. & Bolker, B. (2023) minpack.lm: R Interface to the Levenberg-Marquardt Nonlinear Least-Squares Algorithm Found in MINPACK, 10.32614/CRAN.package.minpack.lm
EnvironmentAgency. (2023). *National Lidar Programme https://www.data.gov.uk/dataset/f0db0249-f17b-4036-9e65-309148c97ce4/national-lidar-programme*.
Evans, C., Artz, R., Burden, A., Clilverd, H., Freeman, B., Heinemeyer, A., Lindsay, R., Morrison, R., Potts, J., Reed, M., & Williamson, J. (2022). Aligning the peatland code with the UK peatland inventory. *Report to Defra and the IUCN Peatland Programme*.
Evans, C., Artz, R., Moxley, J., Smyth, M.-A., Taylor, E., Archer, N., Burden, A., Williamson, J., Donnelly, D., Thomson, A., Buys, G., Malcolm, H., Wilson, D., Renou-Wilson, F., & Potts, J. (2017). Implementation of an Emissions Inventory for UK Peatlands, A report to the Department for Business, Energy & Industrial Strategy. *Centre for Ecology and Hydrology*.
Finch, T., Bradbury, R. B., Bradfer-Lawrence, T., Buchanan, G. M., Copping, J. P., Massimino, D., Smith, P., Peach, W. J., & Field, R. H. (2023). Spatially targeted nature-based solutions can mitigate climate change and nature loss but require a systems approach. *One Earth*, *6*(10), 1350-1374. https://doi.org/10.1016/j.oneear.2023.09.005
Fletcher, T. I., Scott, C. E., Hall, J., & Spracklen, D. V. (2021). The carbon sequestration potential of Scottish native woodland. *Environmental Research Communications*, *3*(4). https://doi.org/10.1088/2515-7620/abf467
ForestResearch. (2023). *Ecological Site Classification http://www.forestdss.org.uk/geoforestdss/*.
ForestryCommission. (2016). *Forest Yield: a PC-based yield model for forest managment in Britain, version 1.0*. In
ForestryCommission. (2018). National Forest Inventory Woodland GB 2017.
Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*, *202*, 18-27. https://doi.org/10.1016/j.rse.2017.06.031
Graham, H. (2023). *gblidar: A package to download tiled and point cloud LiDAR data for Great Britain.*
Heywood, J. J. N., Massimino, D., Balmer, D. E., Kelly, L., Noble, D. G., Pearce-Higgins, J. W., Woodcock, P., Wotton, S., Gillings, S., & Harris, S. J. (2023). The Breeding Bird Survey 2022.
IPCC. (2006). *IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme*.
Jones, A. K., Jones, D. L., & Cross, P. (2014). The carbon footprint of lamb: Sources of variation and opportunities for mitigation. *Agricultural Systems*, *123*, 97-107. https://doi.org/10.1016/j.agsy.2013.09.006

Lamb, A., Green, R., Bateman, I., Broadmeadow, M., Bruce, T., Burney, J., Carey, P., Chadwick, D., Crane, E., Field, R., Goulding, K., Griffiths, H., Hastings, A., Kasoar, T., Kindred, D., Phalan, B., Pickett, J., Smith, P., Wall, E., . . . Balmford, A. (2016). The potential for land sparing to offset greenhouse gas emissions from agriculture. *Nature Climate Change*, *6*(5), 488-492. https://doi.org/10.1038/nclimate2910

Liaw, A., & Wiener, M. (2002). Classification and Regression by randomForest.". *R News*, *2*(3), 18-22. https://doi.org/https://CRAN.R-project.org/doc/Rnews/.

Lumivero. (2023). NVivo (Version 14). *www.lumivero.com*.

Menberu, M. W., Haghighi, A. T., Ronkanen, A.-K., Kværner, J., & Kløve, B. (2015). Runoff Curve Numbers for Peat-Dominated Watersheds. *Journal of Hydrologic Engineering*, *20*(4). https://doi.org/10.1061/(asce)he.1943-5584.0001038

Morton, R., D., & Schmucki, R. (2023). *YMYW - Your Maps Your Way with Google Earth Engine, version 1.0.0, https://github.com/NERC-CEH/YMYW/tree/v1.0.0*.

NaturalEngland. (2020). Ancient Woodland (England).

Natural England. (2021). Priority Habitat Inventory (England).

Natural England, BGS, Cranfield University (NSRI) & OS. (2023). Moorland Deep Peat AP Status.

NaturalResourcesWales. (2021). Ancient Woodland Inventory.

Noble, D., G., & Barnes, A., E. (2023). Development of an Upland Bird Indicator for the UK and for England. *BTO Research Report 757, British Trust for Ornithology, Thetford, UK.*

OrdnanceSurvey. (2023). *OS OpenMap - Local https://www.ordnancesurvey.co.uk/products/os-open-map-local#get*.

Pascual, U., Balvanera, P., Díaz, S., Pataki, G., Roth, E., Stenseke, M., Watson, R. T., Başak Dessane, E., Islar, M., Kelemen, E., Maris, V., Quaas, M., Subramanian, S. M., Wittmer, H., Adlan, A., Ahn, S., Al-Hafedh, Y. S., Amankwah, E., Asah, S. T., . . . Yagi, N. (2017). Valuing nature's contributions to people: the IPBES approach. *Current Opinion in Environmental Sustainability*, *26-27*, 7-16. https://doi.org/10.1016/j.cosust.2016.12.006

Plowright, A. (2023). *ForestTools: Tools for Analyzing Remote Sensing Forest Data. R package version 1.0.0, https://CRAN.R-project.org/package=ForestTools*.

Shewring, M. P., Wilkinson, N. I., Teuten, E. L., Buchanan, G. M., Thompson, P., & Douglas, D. J. T. (2024). Annual extent of prescribed burning on moorland in Great Britain and overlap with ecosystem services. *Remote Sensing in Ecology and Conservation*. https://doi.org/10.1002/rse2.389

Syder, A,. Baker, S., Bowditch, E., Carlisle, S., Finch, T., Minter, M. & Constant, N. (*in prep*) Visioning future treescapes in upland landscapes: using deliberative processes to understand values and land-use preferences of local stakeholders, *Ecosystems and People*

Thomas, H. (2018). Quantifying the hydrological effect of woodland creation in the Camowen and Drumragh catchments, Omagh, Northern Ireland *Report prepared for the Forest Service, Department of Agriculture, Environment and Rural Affairs by Forest Research*

Thomas, H., & Nisbet, T. R. (2017). Slowing the flow in Pickering: Quantifying the effect of catchment woodland planting using the soil conservation service curve number method. *Flood Risk Managment and Response*, *95*. https://doi.org/10.2495/SAFE-V6-N3-466-474

Vallecillo, S., La Notte, A., Zulian, G., Ferrini, S., & Maes, J. (2019). Ecosystem services accounts: Valuing the actual flow of nature-based recreation from ecosystems to people. *Ecol Modell*, *392*, 196-211. https://doi.org/10.1016/j.ecolmodel.2018.09.023

WelshGovernment. (2014). Glastir Woodland Creation Sensitivity Layer - Priority Habitats.

WelshGovernment. (2018). *Wales Agricultural Census 2018 2km*. EDINA Agcensus Digimap Service, https://digimap.edina.ac.uk.

WelshGovernment. (2022). *Survey of agriculture and horticulture: June 2022*. https://www.gov.wales/survey-agriculture-and-horticulture-june-2022.

WelshGovernment. (2023). *LiDAR Welsh Government https://datamap.gov.wales/maps/lidar-viewer/*.

Williams, A. G., Audsley, E., & Sandars, D. L. (2006). Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. *Main Report. Defra Research Project IS0205*.

WWC. (2021). *WWC Woodland Carbon Calculation Spreasheet V2.4*. https://woodlandcarboncode.org.uk/standard-and-guidance/3-carbon-sequestration/3-3-project-carbon-sequestration