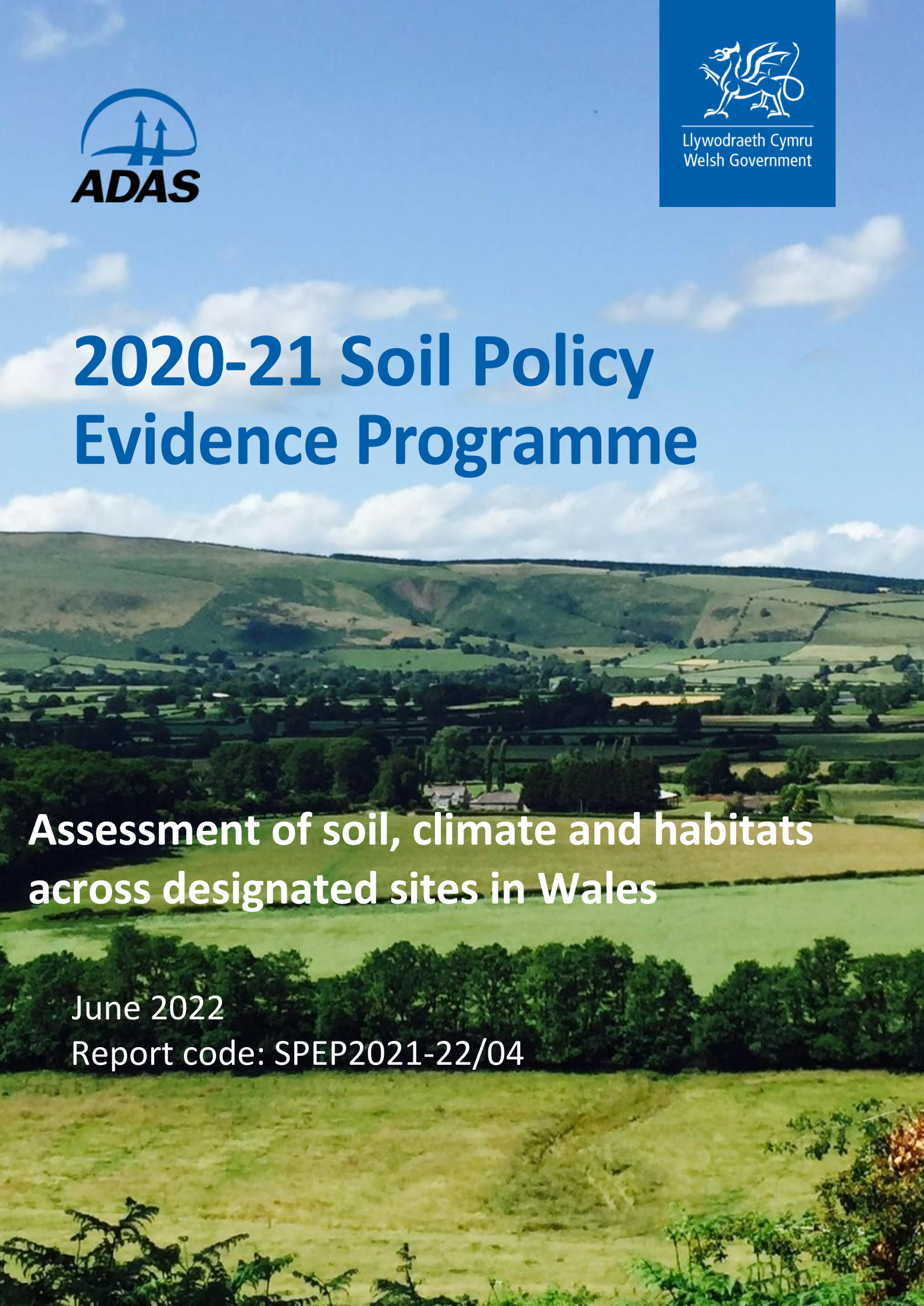

2020-21 Soil Policy Evidence Programme

Assessment of soil, climate and habitats across designated sites in Wales

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Assessment of soil, climate and habitats across designated sites in Wales

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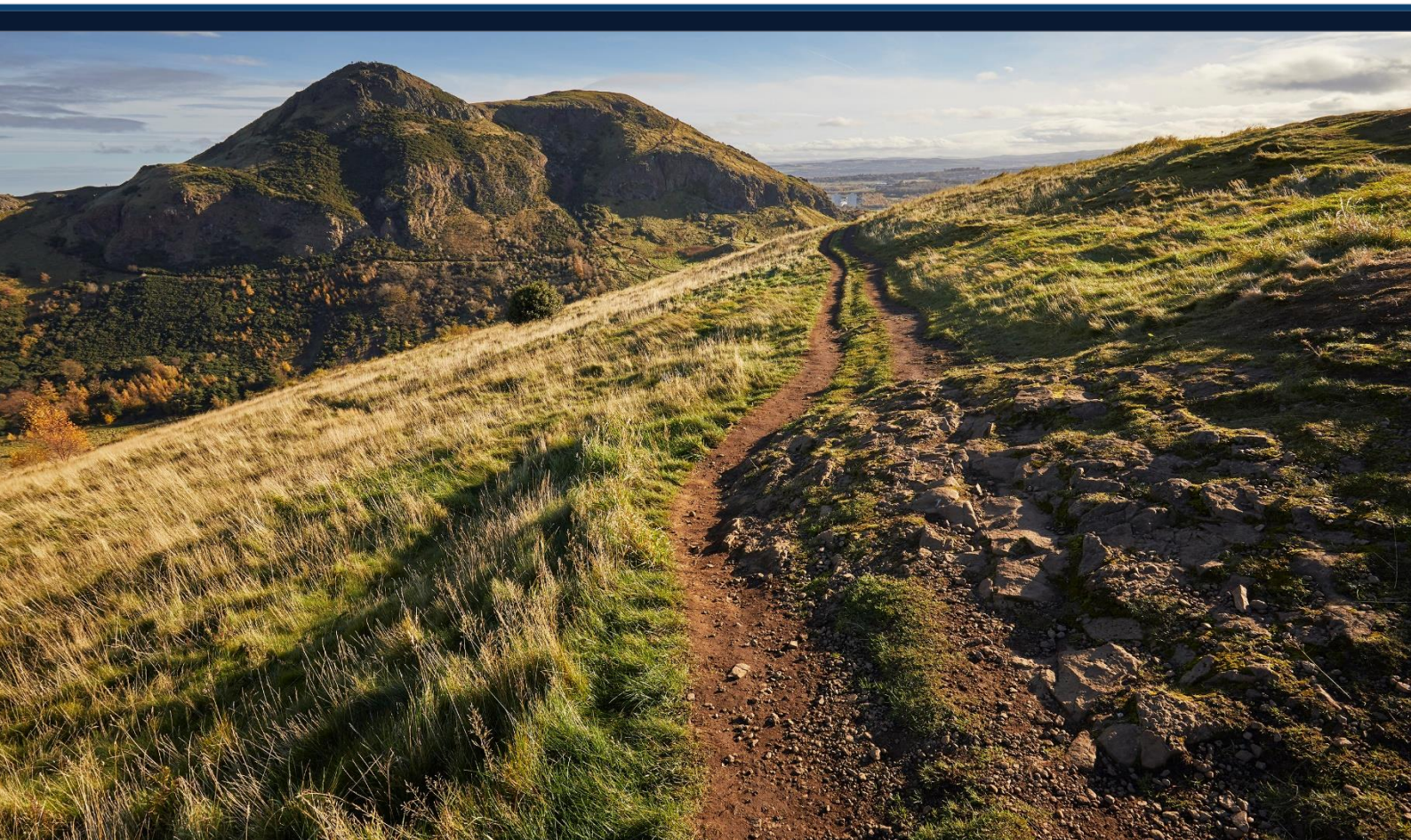


Assessment of soil, climate and habitats across designated sites in Wales

Summary and key messages

Designated sites protect a range of key habitats, wildlife and landscapes within Wales under national and European legislative frameworks. These sites have key contributions to the environment and character of Wales, and many are fundamentally supported by specific soil and climatic conditions. The designation is based primarily on above ground attributes, usually related to specific habitats, and supporting plant and animal assemblages or key geological features. The designations considered in this report are Local Nature Reserves (LNR), National Nature Reserves (NNR), Sites of Special Scientific Interest (SSSI), Special Area of Conservation (SAC) and Special Protection Areas (SPA). Further detailed investigation of SSSI sites is included as most designations are underpinned by SSSI. Soil is not explicitly considered in the designations, although the management of the site may include soil related management options. Conservation aims for designated sites focus on management of above-ground habitats and will often ignore the soil as a component part of this.

This report summarises the key soil, habitat and climate characteristics of sites with designations to understand their unique character, the contribution that soil plays to the importance of the designation and the additional functions that soil provides given these unique characteristics.

Key messages:

- Many designated sites have soil types that specifically support unique habitats and/or flora and fauna, yet the soils are not explicitly taken into consideration in the designation.
- Peat soils only account for 3.5% of the area in Wales yet cover large proportions of designated areas in SSSI, NNR, RAMSAR, SAC and SPA sites, up to 30 and 35% in NNR and SPA areas, respectively. This is due to large areas of uplands that dominate many designated sites.

- The dominant soil groups in SSSI areas are upland peat, podzols and humic surfacewater gley soils, accounting for >50% of the soils in SSSI areas. These soils support specific habitats such as bogs, acid grassland and marshy grassland.
- RAMSAR sites are designated primarily for their wetland features and are dominated by specific soil types: Raw gleys, lowland peat and groundwater gley soils.
- Other very small areas of unique soils, such as man-made soils on old quarry or mining sites, support unique habitats such as Calaminarian grasslands.
- Designated sites need consideration of soil and climate biophysical parameters, and management practices to maintain the habitats. For example, upland habitats have specific climatic envelopes (high rainfall, low temperature), which promotes the formation of organic rich soil and peats, which in turn support specific habitats, plants and animal species that are recognised as part of the designations.
- Inherent characteristics of the soil promotes certain functions that are important for habitats, the soils in these areas commonly have multiple functions such as carbon storage and water retention.
- Bog, marsh, heath, and semi-natural grassland habitats strongly contributed to belowground carbon storage function, while other habitat types contributed more strongly to water regulation. Nutrient availability and soil biology functions were not associated with specific habitat types.
- The majority of SSSI's contributed to water regulation and nutrient availability functions, and fewer sites contribute to carbon storage. However, the sites associated with carbon storage cover greater geographical areas and are characteristic of upland environments. Much fewer sites were associated with higher soil biological activity.
- Many SSSI sites show simultaneous delivery of multiple soil functions in addition to supporting the habitat and species for the SSSI designation.

1.0 Range of soil types, habitat and climate characteristics of designated sites

A summary spreadsheet was developed to indicate key soil, climate and habitat characteristics for each designated site.

1.1 Methodology

A spreadsheet was developed to produce a summary of soil, habitat and climate parameters for each protected area designation. These designations were:

- Local Nature Reserves (LNR) – 94 sites – covering 62 km^2
- National Nature Reserves (NNR) – 76 sites – covering 264 km^2
- Sites of Special Scientific Interest (SSSI) – 1077 sites - covering 2430 km^2
- Special Area of Conservation (SAC) – 75 sites covering 1110 km2 (also 15 coastal sites and 12 marine sites)
- SAC candidate sites – none
- Special Protection Areas (SPA) – 3 sites on land (21 off coast) – covering 743 km^2
- Ramsar – 7 sites on land (5 estuarine) – covering 56 km^2

Many of these designations overlap in their spatial extent. Areas of Outstanding Natural Beauty (AONB), Scheduled Ancient Monuments and National Parks were not included in the analysis.

The key scope for the designated site summaries were to include all sites that have extensive terrestrial areas within the area of the designations so soil and climate could be investigated. We excluded sites that were wholly contained within marine environments or estuaries. Areas such as sand dunes were included as these can support weakly developed soils. Saltmarsh and intertidal zones were also included as these contain raw gley soils. Where sites spanned these intertidal environments only the areas within the low water mark were included in the analysis. Islands within RAMSAR and SAC areas were also included.

Each designated site type was overlaid over the Soils of Wales map and a Tabulate Area function used to determine the areas of each named soil series within the designated areas. This process was repeated with the Texture attribute, Wetness Class (WC) and Depth to Slowly Permeable layer (DSP) from the Soils of Wales map and the Major habitat (i.e. A1) attribute of the Phase 1 Habitat Survey map. The designated areas were then overlaid with the 50m climate data and a Zonal Statistics to Table function used to calculate the Average Annual Rainfall (AAR), Accumulated Temperature above 0° C (AT0), Field Capacity Days (FCD) (Mean, Minimum and Maximum) within each designated area. A flowchart of the methodology is included in Appendix 2. This is written as a ARCGIS model to ensure consistency in the intersects and summaries.

Development of the ArcGIS model means different summaries can be executed should other datasets be used in future analyses. Table 1 provides a summary of datasets used in the project.

It should be noted that the resolution of the soil datasets may not match the resolution of some designated sites that have small extents. The soil data is derived from national mapping and was designed for use at national scale. In some areas finer scale soil mapping is available that will better match the resolution to characterise the smaller designated sites. Therefore, there is some uncertainty when using the soil datasets to attribute a specific soil series to the designated site, especially when the designated site has a small area.

Table 1 Summary of data sources (note soil properties were used for the soil function analysis and are not part of the spreadsheet)

Data type	Data description	Data attributes	Data source
Designated site extents	Designated sites LNR, NNR, SSSI, SAC, SAC candidate sites, SPA, & Ramsar (shapefiles)	Site name, authority, year of designation, SSSI (type, status)	Welsh Government
Soil	Soils of Wales (2019) soil series map at 50m resolution (shapefile)	Soil series name, source, wetness class, topsoil texture, depth to rock. Soil series and attributes are from larger scale national data (NatMap) and smaller scale mapping where available.	Welsh Government / Cranfield University
Soil properties	Soil attributes for each soil series	organic carbon/matter, pH, hydraulic properties, crop available water	Cranfield University
Habitat	NRW Phase 1 habitat survey (shapefile)	Habitat type	Natural Resources Wales (NRW)
Climate	Climatic data on 50m grid resolution for Wales (shapefiles)	Field capacity days (n days per year for 30 year average) Average annual rainfall (mm/year) Average Summer Rainfall (April to September) Accumulated Temperature above 0°C - (January to June) Accumulated Temperature above 0°C - median value (April to September)	Welsh Government/ Cranfield University/ product from the predicted ALC map of Wales

1.2 Summary of soil groups in designated sites

In Wales two thirds of the land area in Wales is dominated by Brown Earth, Brown podzolic and surface water gley soils. However, the dominant soil types within protected or designated areas are different, reflecting the specific habitats, species and features that are listed within the designations. Figure 1 shows the distribution of the different soil types for all designated sites in Wales.

Peat soils only account for 3.5% of the area in Wales yet cover large proportions of designated areas in SSSI, NNR, RAMSAR, SAC and SPA sites, up to 30and 35% in NNR and SPA areas, respectively. Organo-mineral soils such as Podzols cover between 20 and 30% of areas of SSSI, SAC and SPA, compared with 9% across the whole of Wales. These organic rich soils support specific upland habitats such as bog, heath and grassland.

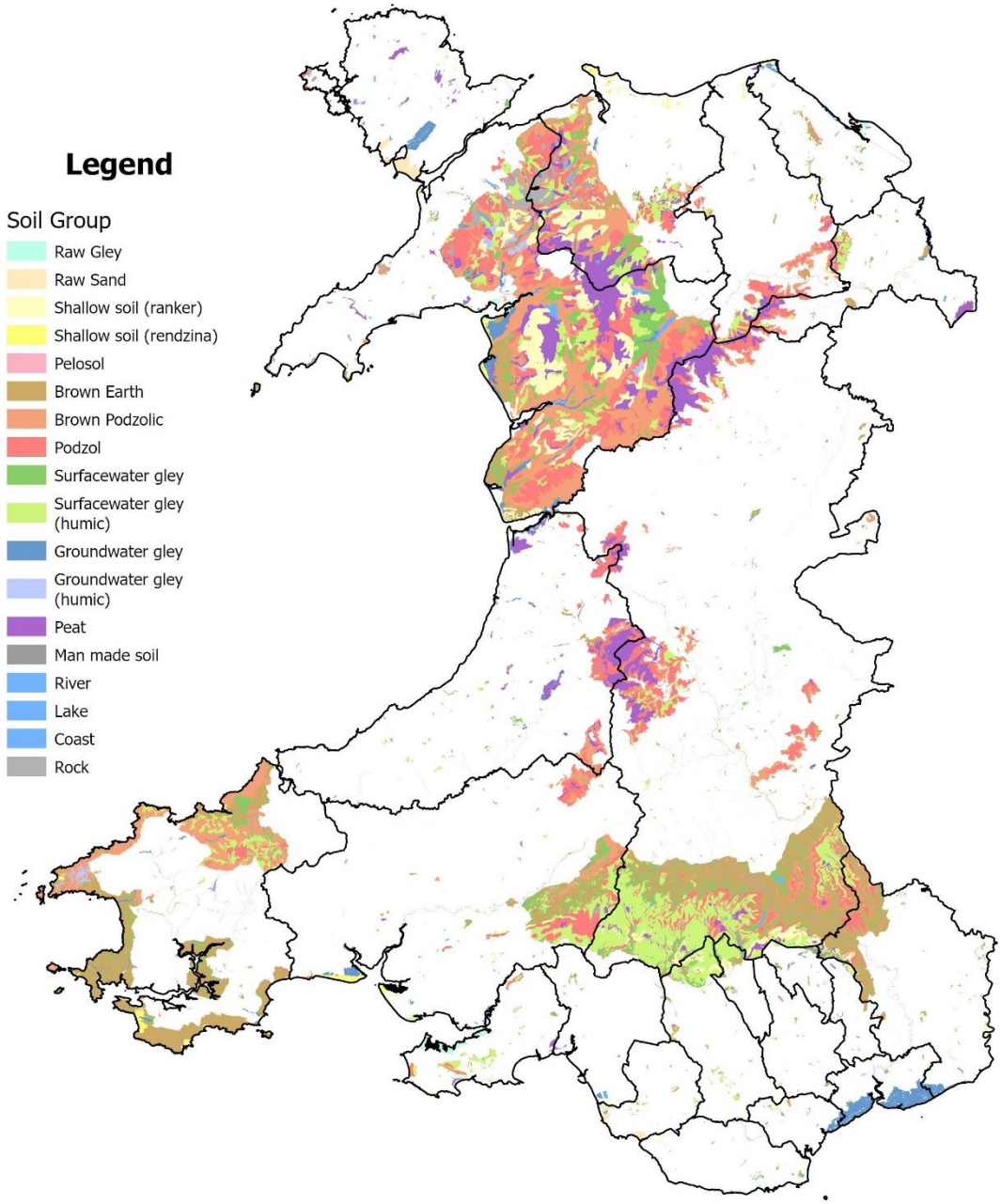


Figure 2 Distribution of soil groups in designated sites in Wales.

Table 2 Proportion of soil groups within the total area of Wales and total area under each designated site category in Wales. SSSI Site of Special Scientific Interest, LNR Local Nature Reserve, NNR National Nature Reserve, RAM RAMSAR, NP National Park, SAC Special Area of Conservation, SPA Special Protection Areas.

Soil Group	Wales %	SSSI %	LNR %	NNR %	RAM %	NP %	SAC %	SPA %
Brown Earth	32.72	6.47	14.48	4.53	4.22	20.53	5.32	2.16
Brown Podzolic	18.59	13.27	4.63	12.70	0.33	21.29	12.69	13.49
Coast	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater gley	3.63	5.92	6.09	3.52	16.41	1.44	2.31	1.48
Groundwater gley (humic)	0.19	0.26	0.00	0.59	0.14	0.59	0.38	0.08
Lake	0.23	0.59	0.23	0.48	6.04	0.51	0.72	0.33
Man made soil	0.72	0.20	9.23	0.18	0.00	0.20	0.14	0.01
Peat (lowland)	0.12	0.55	0.00	3.43	13.36	0.22	0.86	0.09
Peat (upland)	3.29	17.08	0.59	30.45	21.41	7.00	21.95	34.47
Pelosol	0.34	0.02	0.20	0.00	0.00	0.00	0.00	0.00
Podzol	9.11	23.46	0.72	11.06	0.00	14.76	21.52	30.36
Raw Gley	0.27	1.69	6.95	3.45	27.89	0.08	2.56	2.54
Raw Sand	0.29	1.35	12.30	5.82	1.18	0.03	2.06	0.16
River	0.39	1.08	7.34	0.71	1.63	0.56	1.35	0.19
Rock	0.71	3.03	1.07	2.39	0.13	1.59	4.57	0.70
Shallow soil (ranker)	3.06	7.01	13.61	8.79	0.42	7.55	9.55	5.38
Shallow soil (rendzina)	0.52	1.87	5.73	2.75	4.96	0.48	2.61	1.05
Surfacewater gley	16.73	2.90	13.66	2.09	1.78	7.88	2.35	0.89
Surfacewater gley (humic)	9.09	13.26	3.16	7.06	0.13	15.28	9.04	6.63

1.21 SSSI

SSSIs safeguard Wales' natural heritage and cover a wide range and size of habitats, species and geological features. There are 1074 SSSI in Wales covering approximately 12% of the land area. By area, 92.5% SSSI occupy upland areas (equivalent to the upper limit of enclosure) and 7.5% in lowlands. Key soil types in SSSI areas are podzols (23%) upland peat (17%), and humic surface water gley soils (13%), accounting for >50% of the soils in SSSI areas, reflecting the dominance of large upland areas designated as SSSI. Many of these soil groups have relatively small extents over the whole of Wales (e.g. upland peat accounts for only 3% of land area in Wales yet represents 17% of SSSI). At a site level, except in very small sites (<1 ha), multiple soil types can occur that often reflect a mosaic of habitats.

1.22 Local Nature Reserves (LNR)

There are 95 sites local nature reserves that cover 0.1% of the land area of Wales and have special interest to the local area. Many of the larger LNR are sites on reclaimed mine spoil (e.g. Sirhowy Hill woodlands) and are therefore supported by man-made soils, accounting for the larger proportion of these soils on LNR (9%) compared to their limited extent in Wales generally (0.7%). Other significant areas include the terrestrial parts of coastal LNRs supported by raw sand (12%) and raw gley soils (6%) (e.g. Kenfig pool and dunes). Shallow ranker soils also support many woodland LNRs.

1.23 National Nature Reserves (NNR)

The 76 National Nature Reserves cover 1% of the land area of Wales and are also designated as SSSI. Examples span diverse habits and landscapes including Snowdonia, sand dunes of Morfa Harlech, peat bog of Cors Caron and small remote islands such as Skomer. Upland peat soils cover nearly a third of NNR areas (30%) in areas such as Snowdonia and Berwyn and Cors Fochno, the bog area of Dyfi NNR. Other unique habitats such as the calcareous grassland of the Gower NNR are supported by shallow rendzina soils (3%) formed on limestone (Crwbin series).

1.24 RAMSAR

RAMSAR sites are wetlands of national importance and also have SSSI designation. There are 10 sites in Wales. The assessment of soil only includes the land within the RAMSAR site, which is approximately 0.4% of the land area in Wales. Key soil groups in RAMSAR sites are lowland peat (13%), upland peat (21%), groundwater gleys (16%) and raw gleys (30%) reflecting the inland water, coastal and estuarine habitats of RAMSAR designations. Raw gley soils have a small extent in Wales (0.3%), yet nearly a third of RAMSAR sites are located on these soils. Lowland Peat soils also evident in many RAMSAR sites (13%) yet represent a very small area overall in Wales (0.1%)

1.25 National Parks

There are 3 national parks (Snowdonia, Pembrokeshire Coast and Brecon Beacons) covering nearly 20% of land area in Wales. The proportion of soil types is similar to those found across Wales, primarily due to large land area and varied habitats and landscapes contained within the National Park areas.

1.26 Special Areas of Conservation (SAC)

There are 102 Special Areas of Conservation in Wales that conserve habitats and wildlife (other than birds) named in the EC Habitats Directive and are also underpinned by SSSI. SAC cover 6% of the land area of Wales. Sites are dominated by upland peat (22%), Podzols (22%) and Brown Podzolic soils (13%). These typically reflect the upland habitats of SACs.

1.27 Special Protection Areas (SPA)

The Special Protection Areas are designated specifically to conserve wild birds listed as rare and vulnerable in the Birds Directive. They also include sites that migratory birds use as stop-off points. There are 21 sites that cover 6% land area in Wales. Over two thirds of the total SPAs are covered by Peat (34%) or Podzols (30%). These soils are typical of upland bog environments that provide important overwintering and breeding areas for birds such as redshank and curlew.

2.0 Summary of soil, climate and habitat interactions in SSSI sites

SSSI underpin most designations and thus we focus on SSSI for more detailed analyses of the soil, habitat and climate. SSSI support a wide range of habitats in upland and lowland areas, from small fens, bogs and riverside meadows to sand dunes, woodlands and vast tracks of upland areas. In addition, many of the designations are very large (e.g. National Parks) or very small (local nature reserves) and thus meaningful correlations with the different data sources is difficult due to differences in scale of the datasets at the appropriate spatial resolution of the designated areas. The interaction of soil, habitat and climate are important drivers for the preservation and management of sites. Table 3 shows a summary of soil types supporting specific habitats, often bounded by climatic conditions or specific locations in SSSI designated areas.

Table 3 Summary of soil, habitat and climate for SSSI sites in Wales. AAR average annual rainfall; high >2000mm yr; moderate 1600-2000 mm yr, AT0 accumulated temperature > 0°C from January to June (growing season).

Soil groups	Soil series (dominant)	SSSI broad habitats	Other soil features	Climate
Podzol	Hafren Hiraethog	Acid grassland Dry heath Woodland	Subsoils are freely drained but the surface peaty topsoil can be seasonally waterlogged	Upland/hill areas with high to moderate AAR and low AT0
Peat (upland)	Crowdy	Bog Acid grassland	Crowdy series only occupies 3% of Wales yet 55% is within SSSI sites	Upland areas with high AAR and low AT0.
Surface water gley (humic)	Wilcocks Wenallt	Marsh /marshy grassland Bog Wet heath	Peaty topsoil and waterlogged soil with slowly permeable subsurface horizon.	Moderate to high AAR and low AT0

Brown Podzolic	Manod Moor Gate Malvern	Acid grassland	Whilst the soils are well-drained they remain wet (not waterlogged) due to high rainfall.	Hilly areas with moderate to high AAR and moderate to AT0
Shallow soil (ranker)	Bangor Revidge Crwbin* Wetton	Acid grassland Heath *calcareous grassland	Peaty topsoil over rock	Upland areas with high AAR and low AT0.
Groundwater gley	Newchurch Conway	Mixed	Periphery of river habitats and swamps	Occupy sites adjacent to rivers where groundwater is close to the surface
Brown Earth	Denbigh East Keswick Milford	Mixed	Freely drained soils	Hilly and lowland areas. Varied climatic conditions.
Surfacewater gley	Brickfield Cegin	Woodland Scrub Acid Grassland Marsh/marshy Grassland	Slowly permeable horizon causing surface waterlogging	Moderate AAR and moderate to low AT0
Rock dominant	No soil series	Artificial rock exposure Maritime cliff Mixed	Area dominated by rock exposures and little soil	Varied locations
Shallow soil (rendzina and para-rendzina)	Sandwich* Marcham**	*sand dune **calcareous grassland	Shallow soil	Varied locations and coastal areas
Raw Gley	CY/CZY Saline SY saline	Intertidal	Saline sandy or clayey over light silty marine alluvium	Coastal areas
Peat (lowland)	Adventurers' Altcar	Fen	100% of Altcar series appears in SSSI sites	Lowland Fen commonly in coastal areas
Raw Sand	Broomhouse	Sand dunes Intertidal Salt flats	Soil showing little profile development	Coastal areas
River/lake		Running water Standing water		Varied locations
Man-made soil	Disturbed soils	Woodland, improved, neutral grassland, standing water	Disturbed soils from open cast mines	Varied locations

2.1 Soil types, climate and habitats

2.11 Peat soils and organo-mineral soils (Podzols and humic surface water gleys)

Upland peat soils (Crowdy) and organo-mineral soils with peaty surface horizons (Podzols Hafren; Hiraethog, and humic Surface-water gleys Wilcocks; Wenallt) occupy specific climatic conditions that encourage organic matter accumulation and peat formation. This includes upland areas with low annual temperatures and AT0, and high rainfall often exceeding 2000 mm annually. The low temperatures coupled with near saturated conditions from high rainfall and low evapotranspiration slow the decomposition of organic matter, resulting in formation and accumulation of peat. Example habitats supported by the upland climatic conditions and resulting peat soils are blanket bogs and acid grassland and example sites include Pumlumon (Plynlimon) and Migneint in Snowdonia.

In lowland sites, peat (Adventurers') can form in depressions that are continuously waterlogged through being fed by groundwater, and in some areas raised bogs can form. Areas of lowland peat include areas of Anglesey (Cors Bordeilio) and in the valleys bordering Cardigan Bay (e.g.Cors Fochno).

Organo-mineral humic stagnogley soils (Wilcocks; Wenallt) are naturally wet, due to low temperatures, high rainfall and slowly permeable subsoils that cause seasonal waterlogging. They also have low fertility due to acidity from the upper peaty horizons. The low temperatures and high rainfall conditions favour development of peaty surface horizons. These soils are intermediate between deeper peat soils and surface water gleys that have a mineral topsoil. The impeded drainage means the soil is wet or saturated for long period and during the winter cannot readily accept excess winter rainfall, which is consequently transported rapidly to local streams. The Humic Stagnogleys are key to supporting marshy grassland habitats and wet heath and associated flora. These soils should not be agriculturally improved or drained so that the acid, wet and marshy environment is maintained for the associated wet upland plant communities.

Other organo-mineral soils (Podzols: Hafren; Hiraethog) are found on the fringes of the upland peat areas and are often associated with the humic stagnogley soils and peat soils. They are very acid and form on rock substrates, so the subsoil is often freely draining but due to high rainfall and low temperatures the surface horizon can remain wet and favour the accumulation of organic matter. The strong leaching if organic acids from the upper peaty horizons give rise to the strongly coloured subsoils, where iron is redistributed beneath in the subsoil. Some Podzols also have subsurface horizon that impeded drainage (ironpan) which causes waterlogging in the upper subsoil (Stagnopodzols). Due to these conditions and the cold temperatures and high rainfall the peaty surface horizons are often seasonally waterlogged even through the subsoil can be freely

draining. The peaty surface horizon acts like a sponge for excess rainfall, however they are often saturated in winter, so that excess rainfall during this period passes rapidly to the stream network. In unimproved and undrained condition the very low fertility and acidic nature of the soils (and the associated climatic conditions) support upland heath and bog habitats. Where Podzols have been improved (drained and limed) for grazing this compromises the soil conditions necessary to support the heathland habitats.

2.12 Brown Podzolic soils

Brown Podzolic soils (Manod; Moor Gate; Malvern) are soils intermediate between Podzols and Brown Earth Soils. These soils have poor fertility, are acidic and freely draining and tend to occupy steeper slopes in upland areas. These freely draining soils can accept excess winter rainfall, but in areas of higher rainfall they can remain wet for long periods. They commonly support rough grazing or bracken. In their natural state Brown Podzolic soils can support acid grassland. Brown Podzolic soils are extensive in Wales, although many have been improved for agriculture (increasing pH by liming and application of nutrients and fertilisers) and thus do not retain features required to support acid grassland species. To maintain the acid grassland habitat these soils should be in near natural state, where leaching processes (accumulation of surface organic matter and organic acid moving through the soil profile) maintain an acidic soil pH.

2.13 Shallow ranker soils

Ranker soils (Bangor; Revidge) included in the designated sites are other organo-mineral soils with acid, shallow peaty surface horizons formed directly over rock or rock rubble. The rock is normally within 40cm of the soil surface. They occur in upland areas on craggy, steep slopes associated with areas of bare rock and deeper peat on the gentler slopes. These soils typically support heath (heather moors) and some acid grassland. The soils wet up quickly in the high rainfall areas, but the shallow depth means limited storage capacity for accepting excess rainfall, so water if often shed quickly into the catchments. In summer periods the soils can dry out when surrounding areas of deeper peat remain waterlogged. Other shallow ranker soils occur on carboniferous limestone crags (Crwbin), with numerous rocky outcrops and are associated with deeper calcareous brown soils on gentler slopes. Although formed on limestone the ranker topsoil is non-calcareous due to the acidic peat.

2.14 Surface-water gleys

Surface water gley soils (Brickfield; Cegin) have a slowly permeable clayey subsoil horizon causing seasonal waterlogging. They are extensive in hilly land, valleys and foot slopes. In higher rainfall areas (when field capacity days are over 200), they can be wet for long periods. These soils primarily support improved grassland and in drier areas can support some arable cultivation if drained. Typically, when not drained or improved, they can support several different habitats such as woodland, acid grassland and marshy grassland.

2.15 Brown Earth soils

Brown Earths (Denbigh; East Keswick; Milford) are typically well to moderately-well drained, moderately acid and are common in lowland areas (<300m above sea level) in Wales. These soils are normally under grassland and in drier areas are suitable for arable cropping. They support a variety of habitats that do not require specific climatic conditions and are especially suited to woodland and grassland.

2.16 Rendzina

Rendzina (Marcham) are shallow calcareous soils formed on limestone, other calcareous rocks or calcareous substrates that occur within 30cm depth. The topsoil is normally partly calcareous when overlying limestone and they are typically very well drained. The characteristics of these soils are due to the limestone geology and terrain, with little influence of climate on their formation. They are associated with rocky limestone outcrops and other shallow soils such as humic rankers over limestone. They support calcareous grassland habitats such as those found at Great Ormes Head and Pwlldu Head.

2.17 Raw sand and pararendzina

Raw sands and pararendzinas are typically found in coastal areas in sand dune complexes. The pararendzinas (Sandwich) form on the land side of active dunes where stabilised dunes support grasses and scrub and the soil shows weak profile development. The raw sands (Broomhouse) of the active dunes can support marram grass. In slacks (small hollows) and swales (larger elongated depressions) poorly drained Sandy Gley soils are found. These different soils support the mosaic of habitats in the large areas of sand dune environments in SW Anglesey, Cardigan Bay and in the Twyi Estuary. The soils are not associated with specific climatic conditions, rather they are developed by the coastal processes that shape the dune systems.

2.18 Raw gley

Raw gley soils are saline and contain silty and clayey materials that have remained saturated with water since their deposition such as in intertidal areas, estuaries mud flats and salt marshes. Raw gley soils support salt marsh habitats and coastal marshland such as around the Twyi estuary in Carmarthen Bay, and parts of the Dyfi and Dee estuaries. The soils are not associated with specific climatic conditions, rather they reflect their location within active estuarine and intertidal systems.

2.19 Man-made soils

The dominant man-made soils are disturbed soils on restored open cast coal workings, in mid and south Wales. Soil characteristics vary depending on the nature of the restoration and the original soil stripped from the site, but most disturbed soils of this type will have a loamy topsoil of varying thickness over a compacted clay loam overlying rock waste. These sites tend to support open mosaics of grassland, shrub or woodland depending on the restoration outcomes in the designated areas. Many areas are local nature reserves that have become naturally colonised

with vegetation. A key priority habitat supported by these soils are Calaminarian grasslands (such as at Cwmystwyth, Ceredigion) that support rare metallophyte grass and lichen species requiring soil with high concentrations of heavy metals.

2.2 Relevance of soil to SSSI site designation

The SSSIs are considered the most important areas for habitat and species conservation, at both national and international levels and each SSSI represents a significant component of the biodiversity resource of Great Britain (JNCC, 2013). The previous section illustrates the importance of soil and climate that support many SSSI habitats, primarily in upland sites. The determination of SSSI requires a descriptive recording of biological attributes and controlling features of the physical environment and an evaluation of this information against criteria to determine the nature conservation value of a site. Thus, the presence of a specific habitat and/or species is often supported by soil type and climate. We explore the relevance of soil to supporting the SSSI designation. An initial broad level assessment of SSSI designation (biological, mixed, geological) was used to split the sites into groups. Within the SSSI designations additional information on the site was used to identify the features of the SSSI that have soil relevance. We used two approaches first to identify SSSI that had terrestrial habitats as the main designation and designated fauna and flora that would require a specific habitat supported by soil.

2.21 Identifying SSSI sites with terrestrial habitats as the designation

SSSI sites with terrestrial habitats within the designation were identified as these areas will be primarily supported by soil. To identify the importance of soil to the SSSI designation, the proportion of the total SSSI site covered by a terrestrial designated habitat was calculated. This was calculated from the total area of the SSSI site (in ha) and area occupied by the designated habitat or habitats within the SSSI site. Using this proportion, differentiate between SSSIs that have a large proportion of soil-related habitat/s (e.g. peat bogs) within the SSSI are distinguished from SSSIs that only have small pockets of soil-related features (e.g. woodland) within features not supported by soil, such as rock outcrops.

Many SSSI sites in Wales have terrestrial habitats recorded as part of the SSSI designation (743 sites), in these sites it is assumed that soil has a direct relevance to the designation as it supports the terrestrial habitat. These designated habitat areas cover >100,000 ha collectively across the SSSI sites, although the area within each site is typically small (over two thirds are < 25 ha, Table 4). Over 43% of SSSI sites in Wales have > 50% of the area occupied by terrestrial habitats that form part of the designation (Table 5).

In SSSI sites where no terrestrial habitat is specified as part of the designation or habitat area is indicated as 0 ha (n = 364), soil is assumed to have little direct relevance to the designation (Table

5). Many of these sites are designated by a non-soil related habitat (e.g. marine), the presence of one or more species or a specific geological feature.

Table 4 Summary of terrestrial habitat size in SSSI.

habitat size (ha)	n	%
0	32	4
0.1 to 25	492	66
26 to 50	74	10
51 to 100	52	7
100 to 250	47	6
>250	46	6

Table 5 Summary of number of SSSI sites by proportion of terrestrial habitat area within the site. Biological, geological and mixed refer to broad categories for SSSI designation. Note 0 category includes 32 sites where terrestrial habitats are part of the habitat designation but are indicated as 0 ha in area.

Proportion of SSSI with terrestrial habitat	Biological	Geological	Mixed	Total
0	154	180	30	364
<25%	70	0	24	94
25 to 50%	129	0	24	153
51 to 75 %	164	0	17	181
75 to 100 %	261	0	21	282
Total	778	180	116	1074

2.22 Identifying SSSI sites with soil-relevant fauna and flora as the designation

The list of broad animal or plants (e.g. Insect butterfly or flowering plant) used in SSSI designations and the feature descriptions for the habitats (e.g. Marshy grassland) and was reviewed to highlight features with relevance to soil. The total count of the number of these ‘soil related’ features was recorded for each SSSI. This provided additional information on how

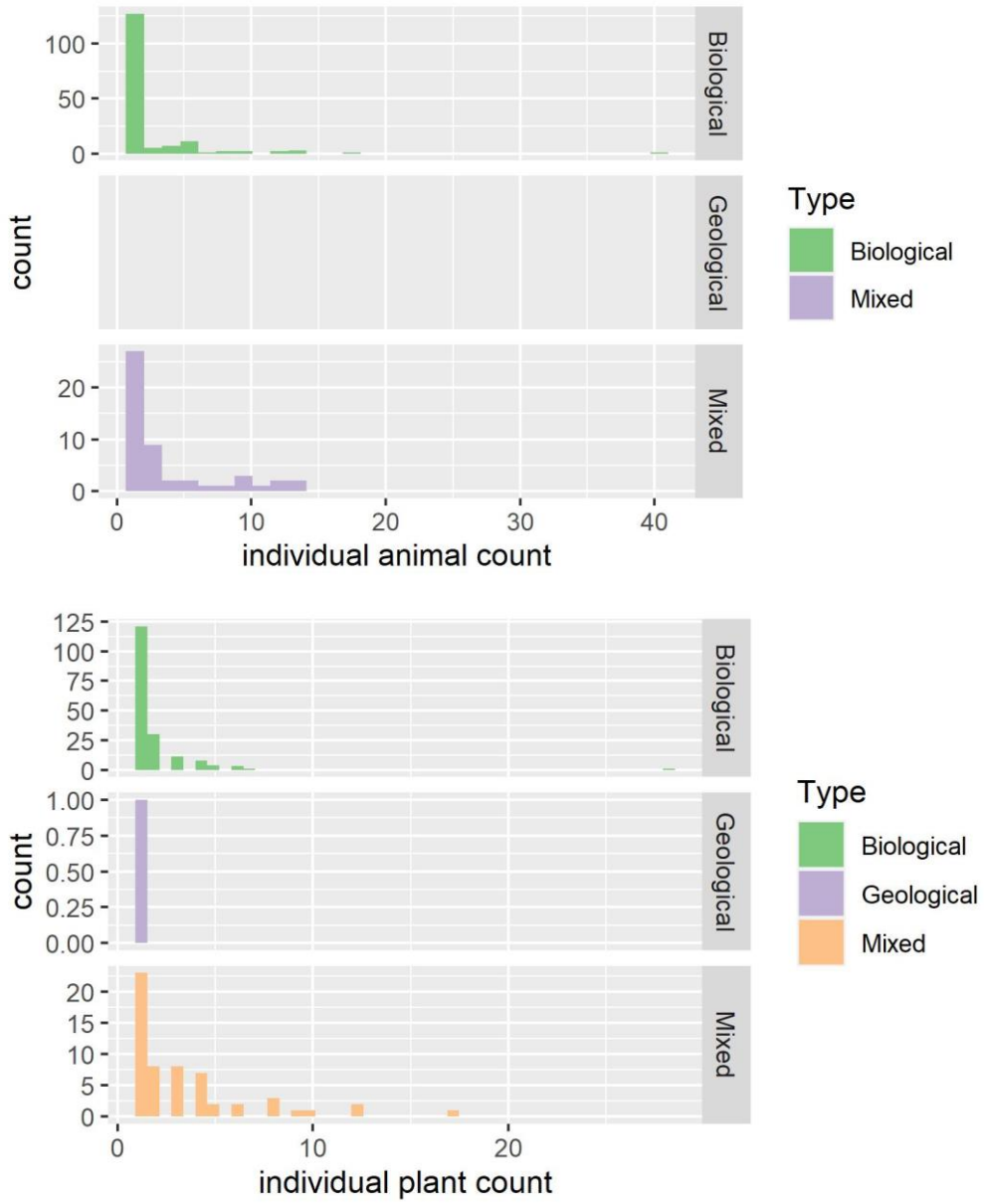


Figure 3 Summary SSSI sites with counts for individual number of plant or animal species recognised in each SSSI site designation.

3.0 Soil properties and functions in SSSI

To represent soil functions key soil properties were selected that could represent a specific soil function, such as soil organic carbon representing carbon storage (climate mitigation). Statistical models were used to represent the function based on the relationship between selected soil properties that serve as an indicator for the soil function. The relative contribution of the soil function for each SSSI site was determined from the predicted outputs from the models. Additional data sources for several soil properties (Table 1) were used to link to the soil series identified in the SSSI sites. Recent work has demonstrated that there are consistent differences in soil physical and chemical properties across habitat types, for example soil carbon decreasing and pH increasing across the habitat productivity gradient from bogs to grasslands to arable systems

(Seaton et al., 2020). This study indicated that grouping of soils based on soil property data was related more to habitat type and management than the taxonomic soil classes.

Four soil functions were chosen to highlight the key delivery of services from soils in SSSI these were

1. Carbon storage
2. Water regulation
3. Nutrient cycling
4. Soil biodiversity

3.1 SSSI soil and site properties

Soil properties for each SSSI were calculated using the area of the soil series within the SSSI and soil series properties, correcting for the area of each site not covered by soil. Three sites - Mwyngloddfa Castell (Ceredigion), Mynydd Parys (Ynys Môn), and Ynysoedd Glannau Penfro (Sir Benfro) - were completely covered by four obscure " soil series" (lake, misc. coastal features, , rock dominant), which indicate the presence of rocks, water bodies (lakes and rivers) and miscellaneous coastal features, for which no soil property data was available. For other SSSI's some soil series were missing, and so soil properties were omitted from the analysis if the available soil data represented less than 50% of the soil area per site. Most site and soil properties show skewed distributions across SSSI sites, indicating a small proportion of sites with high and low values (Figure 4).

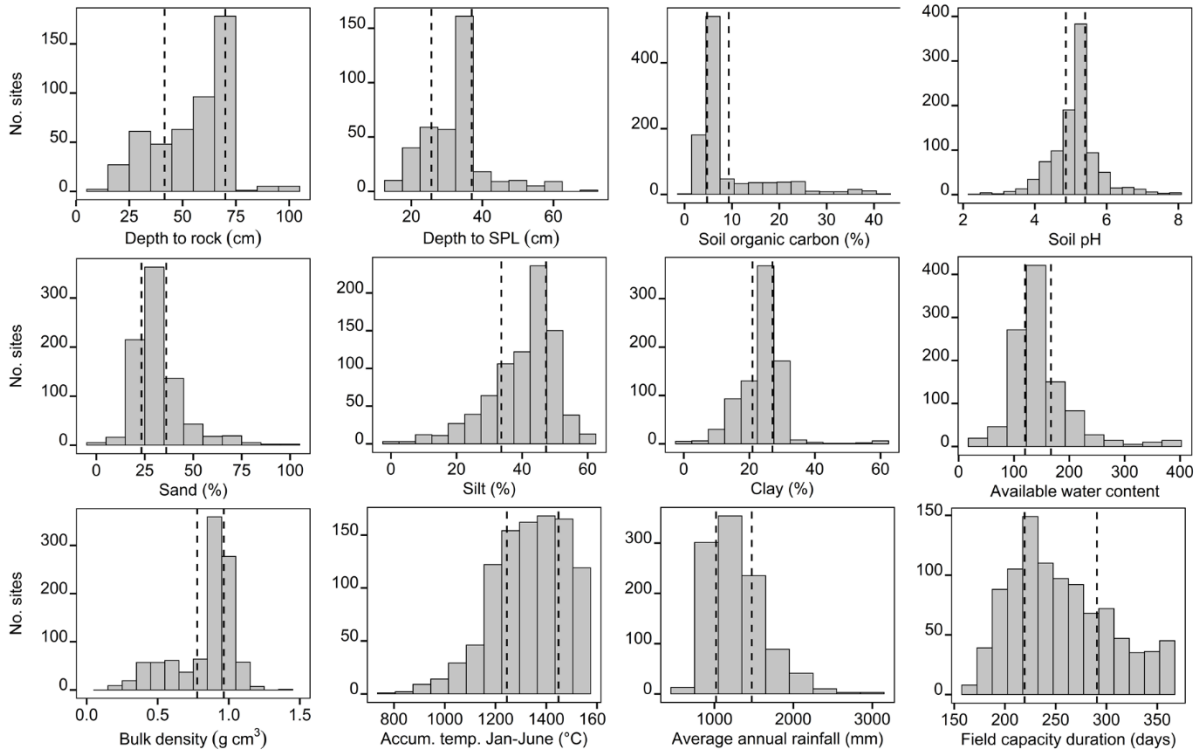


Figure 4. Summary of soil properties and selected climate properties for SSSI's in Wales. The dashed lines represent the 1st and 3rd quartiles for each attribute, therefore 50% of the data occur between the two dashed lines. SPL: slowly permeable layer.

- Nearly three quarters of SSSI sites have rock within 75cm of the soil surface, reflecting the shallow soils, Podzols, Brown Podzolic and Brown earth soils common in SSSI sites.
- Three quarters of SSSI sites have a slowly permeable layer with 40cm reflecting the impeded drainage of humic surface water gley soils and stagnopodzols, supporting marshy grassland and peripheral peatland sites.
- Half of SSSI sites have organic carbon concentrations between 5 and 10% and a quarter of sites have concentrations above 10% reflecting the organo-mineral and peat soils in upland SSSI sites.
- Most soils in SSSI sites are acidic (< pH 7) and half of the sites are within the pH range 5.0-5.5. This is due to the organic nature of soils at some sites and acidic Podzol and Brown Podzolic soils characteristic of acid grasslands.

Correlations between soil properties indicate differing strengths of the linear relationships between pairs of attributes (Figure 5). Strongly negative correlations are demonstrated between soil organic carbon (SOC) and bulk density (BD), which is expected as increasing organic matter reduces the soil bulk density. Likewise negative correlations of sand with silt and clay content are expected as the different soil texture components are additive, a reduction in one would mean an increase in another. Positive correlations are demonstrated between soil pH and BD, because of lower pH in soils with higher organic matter contents that have lower BD values. Annual average rainfall (AAR) and field capacity days (FCD), and available water content (AWC) and wetness class (WC), have positive correlations demonstrating the effect of climate on soil wetness and duration of field capacity.

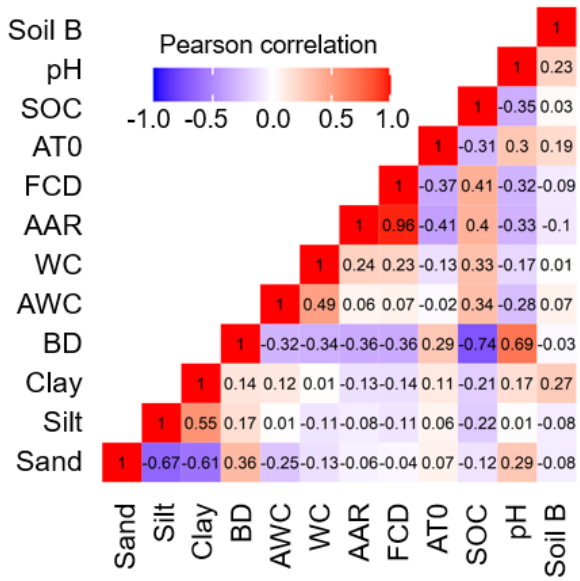


Figure 5. Correlation matrix for soil properties at SSSIs with no missing values (n = 738). The correlation matrix indicates the strength of linear (straight line) relationships (either positive: red or negative: blue) between pairs of properties. The correlation matrix indicates the strength (0 to 1 or -1) of increases (red) or declines (blue) between pairs of site attributes, assuming a linear relationship.

Whilst there are some clear linear correlations between selected soil and site attributes, there will also be non-linear relationships between different soil properties that can affect the prediction of the soil function.

3.2 SSSI soil functions

First, a proxy for the soil function was selected from the soil or site attributes from the SSSI to best represent the function. In Figure 6 soil or site attributes selected as proxies for each function are shown by the orange squares. Carbon storage is represented by soil organic carbon. Average annual rainfall and field capacity days (FCD) were used to approximate the function water regulation, in which a shorter duration at field capacity given high rainfall was considered more favourable for regulating water. Greater FCD means soil is saturated for longer and excess water would flow rapidly from the soil to streams or channels, reducing the capacity for the soil to regulate water storage and flow. Soil pH regulates nutrient availability, closer to neutral pH being optimal for grass and crops. In the absence of specific soil biology data, the site designation was selected as a proxy for soil biology. Site designation represents the number of above ground animal and plant counts in the SSSI designation (Figure 3) as a proxy for the below ground soil biodiversity. The assumption that below ground soil biology will support the above ground animal and plant species.

3.21 Generalised additive models

SSSI soil and site attributes were used to predict soil functions across SSSIs with generalised additive models (GAMs) which can account for non-linear relationships. Rather than a straight line between the proxy of the function and the associated predictor variables GAMs can allow for smoothed lines (‘wiggly models’) that better follow the shape of the relationships between the data. Modelled relationships between site attributes and functions are shown in Figure 6, with orange squares the proxy of function (e.g. SSSI site destination plant and animal counts is a proxy for soil biology function), dark green squares the predictors of that function (biology is correlated closely with temperature and clay content), and lighter green squares indicating assumed covariation between attributes (AAR, soil pH and bulk density show some correlation with the predictors temperature and clay content).

Function	Site attributes	Accumulated temp.	Average annual rainfall	Field capacity days	Sand	Silt	Clay	Bulk density	Wetness class	Available water content	Soil organic carbon	Soil pH	Site designation
Carbon storage													
Water regulation													
Nutrient availability													
Soil biology													

Figure 6. Relationships between SSSI attributes and functions used in the generalised additive models. Orange boxes were used as proxies of the function, dark green boxes as the predictors and light green boxes indicate assumed covariation between other attributes.

Predictor attributes used in the GAMs for each soil function are shown in Figure 7, this is used to illustrate the form of the relationship between average values of the predictor on the x-axis (e.g. AWC) and changes in the slope of these non-linear relationships on the y-axis (e.g. AWC against soil organic carbon). Figure 7 shows how the GAMs account for non-linear and smoothed relationships, which are not possible using other statistical modelling approaches. For instance, correlations (Figure 5) can only account for a straight line between two variables.

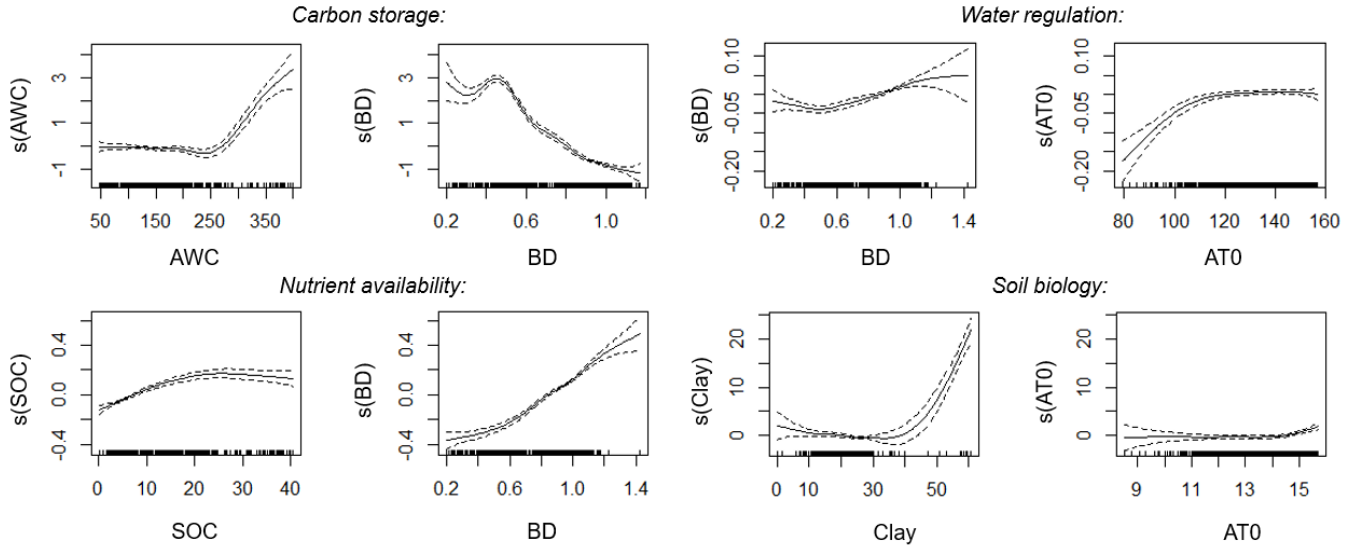


Figure 7. Generalised additive model predictors to link site attributes to different functions, indicating the form of each attributes non-linear relationship with the proxy attribute identified in Figure 6. Average values on the x-axis and changes in the slope of these non-linear relationships on the y-axis. For carbon storage AWC shows little relationship with soil carbon until 250mm of Available Water Content (AWC) above this value a positive linear relationship is

shown (as AWC increases, so does soil carbon). For BD there is a general negative linear relationship with soil carbon.

GAM predictions for each soil function were scaled using the median of the proxy for each soil function, to account for skewed attribute distributions across SSSIs. Scaled functions, on a 0 to 1 scale, are presented alongside the selected proxy for the soil function in Figure 8. The scale represents higher (nearer 1) or lower (nearer 0) delivery of the soil function. All models showed good predictions of the function proxy: carbon storage (n = 995, R^2 = 0.872), water regulation (n = 797, R^2 = 0.399), nutrient availability (n = 1006, R^2 = 0.587), and soil biology (n = 752, R^2 = 0.388) with all model intercepts and fixed effect terms showing significant ($p < 0.0001$) interactions. Figure 8 shows how the scaled function predictions differ from the proxy used in the model. A deviation from a linear relationship between the proxy and prediction shows how the GAMs account for non-linear interactions between the proxy and the predictors indicated in Figure 6. Overall, however, there should be an increase in the scaled function with the proxy.

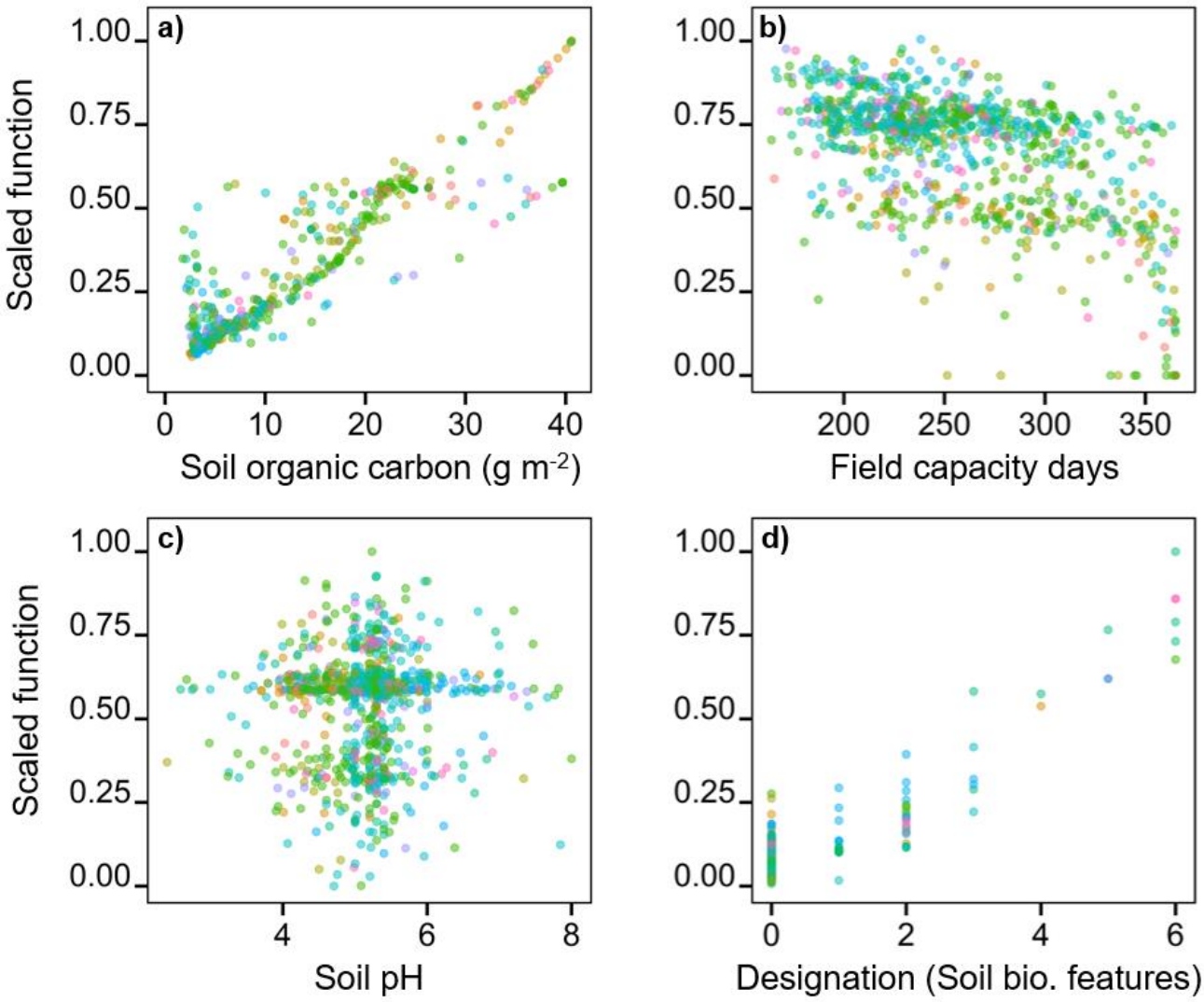


Figure 8. Scaled functions for a) carbon storage, b) water regulation, c) nutrient availability, and d) soil biology predicted by the generalised additive models across SSSIs for which attribute data were available together with the proxies for each function.

3.22 Soil functions in SSSI habitats and sites

The scaled soil functions for each SSSI were predicted by the GAM. These were summarised according to the dominant habitat type of each SSSI in Figure 6. Bog, marsh, heath, and semi-natural grassland habitats show greatest delivery of carbon storage function. However due to near-saturated conditions these habitats show lower delivery of the water regulation function, compared to other habitats. Nutrient availability and soil biological activity did not show any apparent relationships with specific habitat types, although soil biology was overall higher in intertidal habitats. Soil biological features across SSSI's were generally low given the coarse information used for site designations.

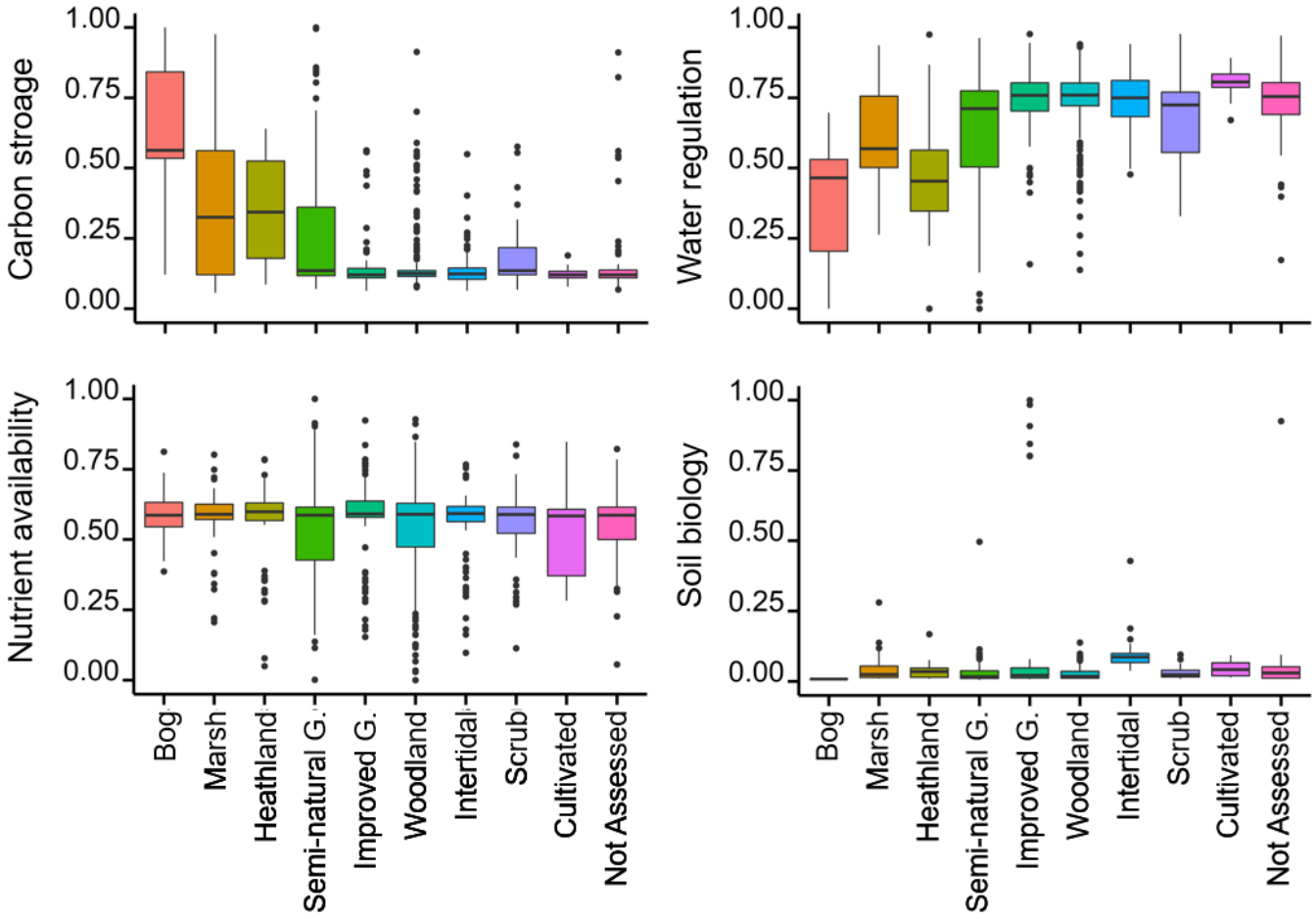


Figure 6. Distribution of scaled (predicted) functions across dominant habitat types of SSSIs in Wales. The black solid line horizontal indicates the median, whiskers indicate the interquartile range and black symbols indicate outliers.

Hierarchical cluster analysis was used to demonstrate how scaled functions are distributed across SSSIs. The dendrogram indicates both separation and co-occurrence of soil function clusters. The cluster associated with soil biology (purple lines, Figure 7) was separate to carbon (orange lines), nutrients (blue lines) and water (green lines). Sites associated with high soil carbon functioning were also clustered separate to water and nutrients. There was high covariation

between water and nutrient functions. Overall, Figure 7 indicates the delivery of multiple soil functions across SSSI's, but that carbon and biology functions are associated with fewer sites. Figures 8-11 show the scaled functions mapped onto the SSSI sites in Wales. Whilst there are relatively few sites with high values for soil carbon and soil biology functions these sites cover larger areas than many of the smaller SSSI sites. Some SSSI sites are missing data, so the soil function could not be predicted, hence the missing sites differ between the functions.

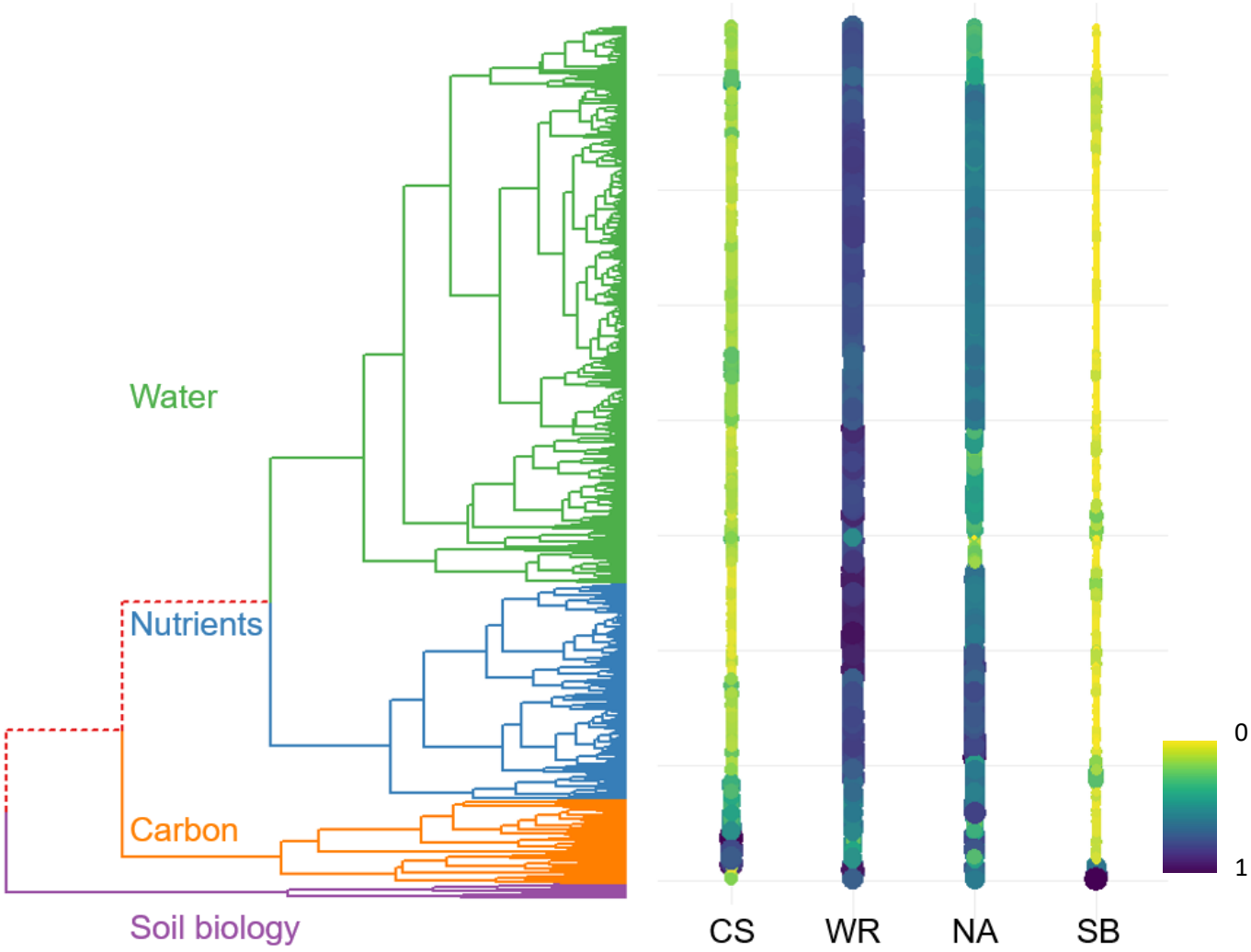


Figure 7. Left: Dendrogram demonstrating the distribution of SSSIs in Wales delivering different soil functions (soil biology: purple, carbon storage: orange, nutrient availability: blue, water regulation: green). Right: Each SSSI is plotted from top to bottom showing the scaled function for each soil function: carbon storage CS, water regulation WR, nutrient availability NA and soil biology SB. Symbol colour and size indicates the contribution of individual sites to each scaled function between a value of 0 and 1. Yellow indicate low, green indicate mid, and blue and purple indicate higher values.

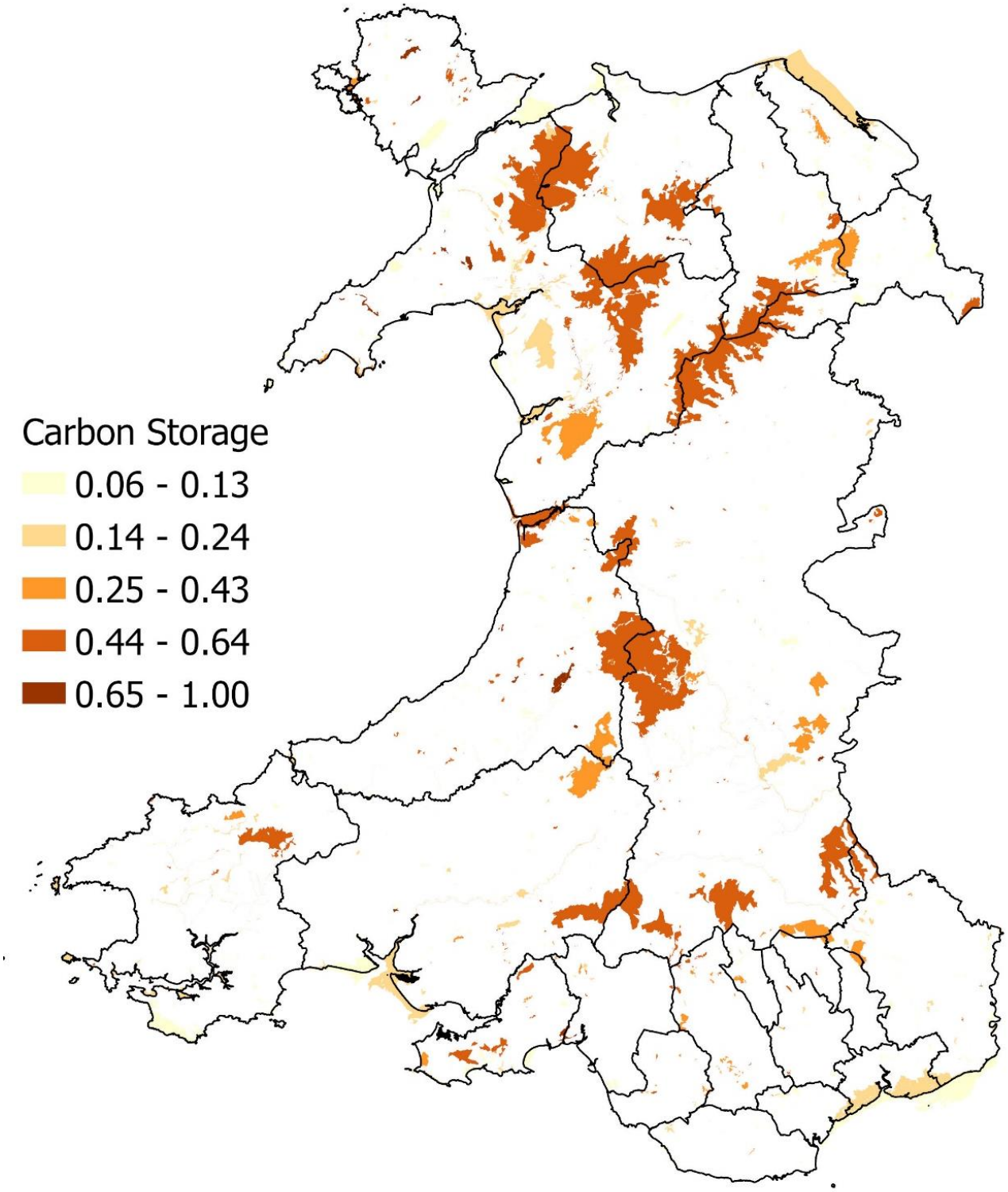


Figure 8. Distribution of carbon storage soil function in SSSI sites in Wales (995 sites)

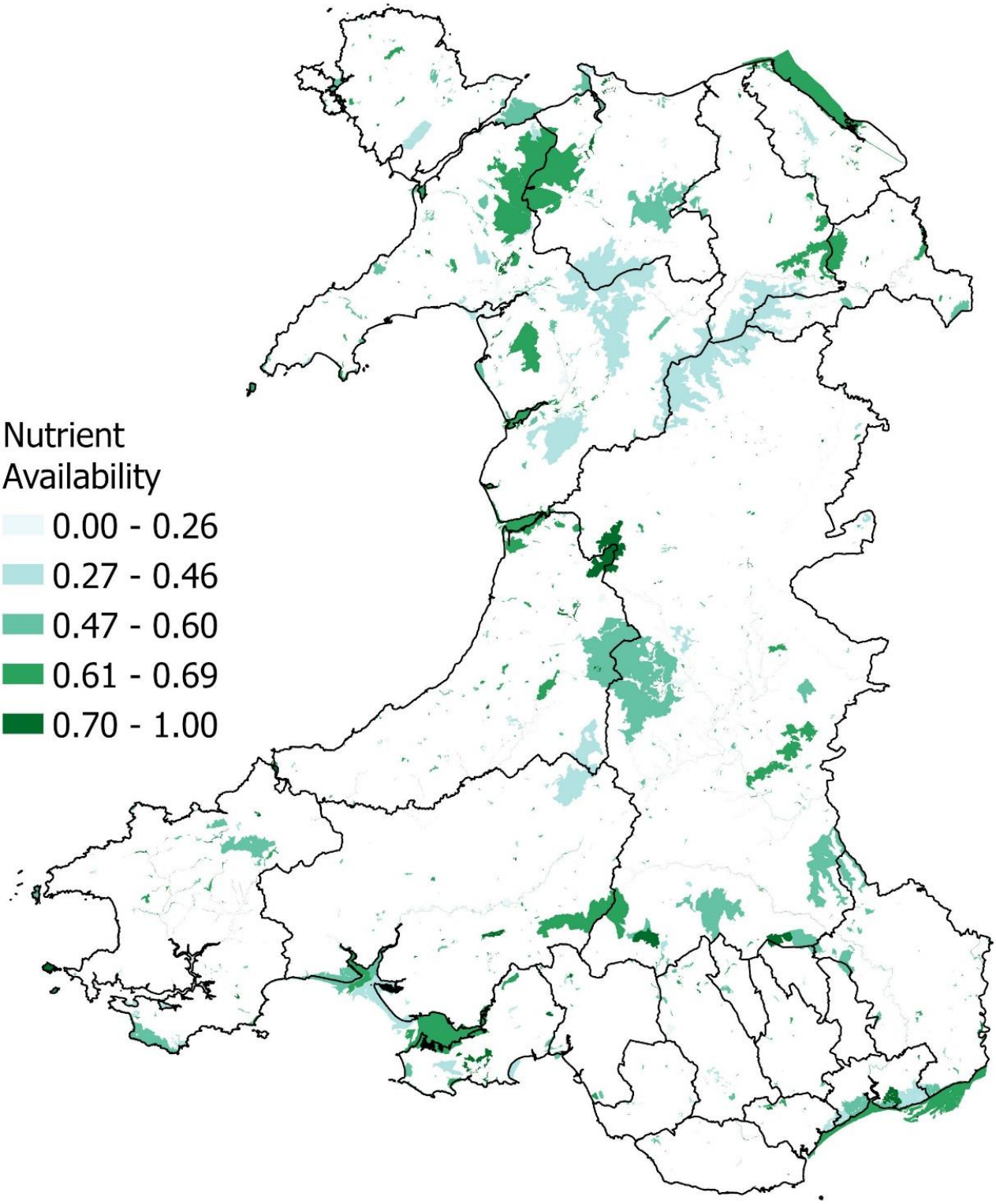


Figure 9. Distribution of nutrient availability function in SSSI sites in Wales (1006 sites)

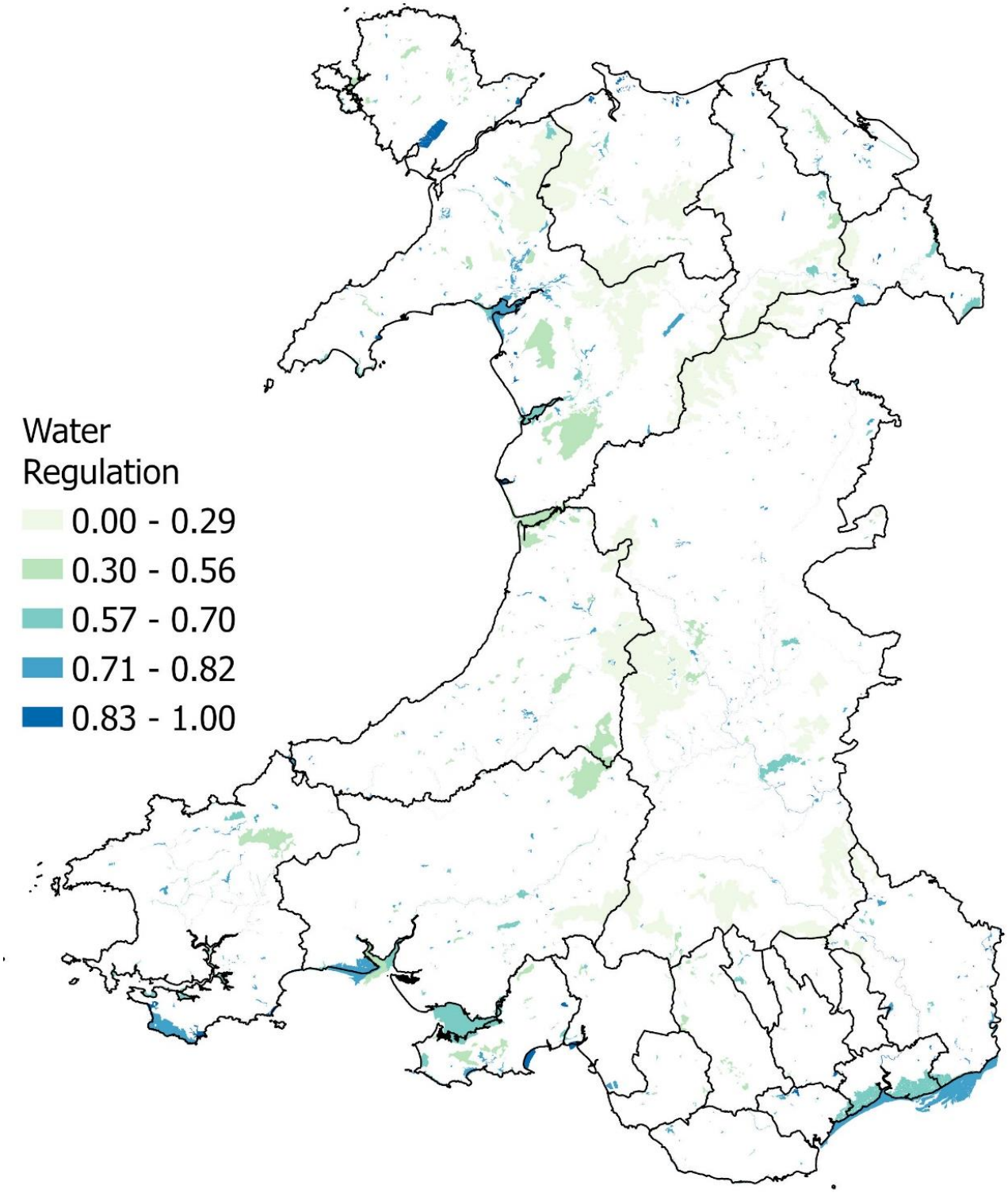


Figure 10. Distribution of water regulation function in SSSI sites in Wales (797sites)

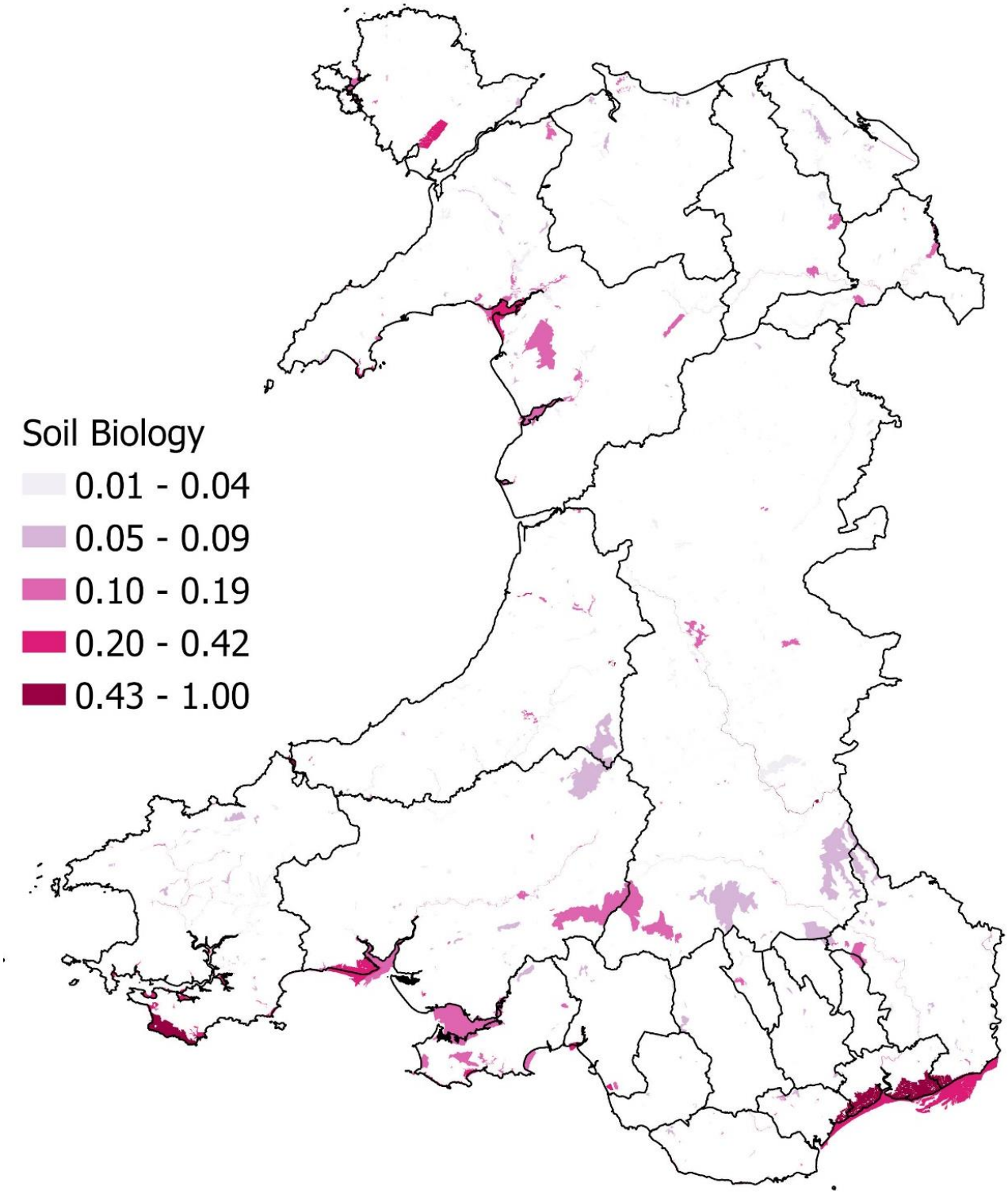


Figure 11. Distribution of soil biology function in SSSI sites in Wales (752 sites)

3.3 Summary of SSSI soil properties and functions

- Soil texture, bulk density, soil organic carbon and soil pH explained much of the variation between SSSI attributes.
- Non-linear relationships between proxies and predictor variables for four soil functions were integrated in generalised additive models to extrapolate across SSSIs.
- Bog, marsh, heath, and semi-natural grassland habitats strongly contributed to belowground carbon storage, while other habitat types contributed more strongly to water regulation. Nutrient availability and soil biology functions were not associated with specific habitat types.
- The majority of SSSI's contributed to water regulation and nutrient availability functions, and fewer sites contribute to carbon storage. However, the sites associated with carbon storage over greater geographical areas and are characteristic of upland environments. Much fewer sites were associated with higher soil biological activity.
- Many sites show simultaneous delivery of multiple soil functions in addition to delivering on the habitat and species for the SSSI designation.

4.0 Summary

Many designated sites have soil types and climate conditions that specifically support unique habitats and/or flora and fauna. Some of these sites include soils that are not widespread in Wales but are common within the designations. For example, peat soils supporting bog and heath habitats only account for 3.5% of the area in Wales yet feature in larger proportions in designated areas, reflecting the large areas of designated upland sites where these soils are common. Other designations such as RAMSAR have specific soils that reflect the wetland environment such as lowland peat and raw gley soils, yet these are not widespread in Wales. Other very small areas of unique soils, such as man-made soils on old quarry/mining sites, support rare habitats such as Calaminarian grasslands.

Designated sites need consideration of soil and climate biophysical parameters, and management practices to maintain the habitats. For example, upland habitats have specific climatic envelopes (high rainfall, low temperature), which promotes the formation of organic rich soil and peats, which in turn support specific habitats, plants and animal species that are recognised as part of the designations.

Soil properties can be linked to certain functions or ecosystem services, thus soil on designated sites can support additional ecosystem services beyond habitat provision. Soils in SSSI commonly deliver multiple functions such as carbon storage and water retention. Bog,

marsh, heath, and semi-natural grassland habitats strongly contributed to belowground carbon storage. Soil in other habitat types strongly contributed to water regulation.

Appendix 1 Definitions of designations for protected sites

This information was taken from the Lle Geo-Portal for Wales in March 2022. Lle was developed as a partnership between Welsh Government and Natural Resources Wales and serves as a hub for data and information covering a wide spectrum of topics, but primarily around the environment.

Site of Special Scientific Interest (SSSI)

SSSIs cover a wide range of habitats from small fens, bogs and riverside meadows to sand dunes, woodlands and vast tracks of uplands. Most are in private ownership, although some are owned and managed by local wildlife trusts, or other voluntary conservation bodies. Notification of an SSSI under the Wildlife and Countryside Act 1981 has since been amended by the Countryside and Rights of Way Act 2001, which brought about numerous changes in the way SSSI are notified managed and protected. In order to ensure consistent, favourable long-term management of these sites, Natural Resources Wales (NRW) with landowners have prepared management plans for all SSSI in Wales. Local planning authorities are required to consult NRW before allowing any development to proceed that may affect an SSSI. Water, gas and electricity companies must also do the same. SSSIs have been designated over a number of years, from 1949 to the present day, and are on-going.

Local Nature Reserve (LNR)

Local Nature Reserves are established and managed by local authorities, following consultation with Natural Resources Wales (NRW) under the National Parks and Access to the Countryside Act 1949. For a site to become an LNR it must have natural features of special interest to the local area, and the authority must either have a legal interest in the land or have an agreement with the owner to manage the land as a reserve. LNR prove to be useful not only to protect habitats and wildlife but increase people's awareness of their environment. They are places where children can learn about nature, and they are often situated in or near urban areas. Please refer to Countryside Act 1949 for reasons for capture of original designation. The LNRs have been designated over a number of years, from 1970 to the present day, and are on-going.

National Nature Reserve (NNR)

NNRs represent the very best examples of our wildlife habitats and geological features and can range in size between five hectares to well over 2,000. NNR are declared by Natural Resources Wales (NRW) under the National Parks and Access to the Countryside Act of 1949, or under the Wildlife and Countryside Act of 1981. They are owned or leased by NRW, or the land is held by an approved body, such as a County Wildlife Trust. Each reserve has a programme of work to manage the site's special features. All of them are also Sites of Special Scientific Interest (SSSI) and may provide places for educational projects, research and management trials. Some reserves require permits to gain access to them. NNRs are designated over a number of years, beginning in 1954 and on going.

RAMSAR (RAM)

In ratifying the Convention in 1976, the UK government accepted a commitment to promote the conservation of internationally important wetland sites within its territories. Wetlands are vital for many types of birds particularly waterfowl and Wales have some prime sites that are essential to the survival of many wetland plants and animals.

Wetland sites can be areas of marsh, fen, peatland or open water; natural or artificial; permanent or temporary; with water that is fresh, brackish or salty. They can also include shallow areas of sea. All Ramsar sites are also Sites of Special Scientific Interest (SSSI). Wetlands of International Importance are identified by Natural Resources Wales (NRW), in collaboration with the UK Joint Nature Conservation Committee (JNCC), and designated by the First Minister for the National Assembly for Wales. The Ramsars have been designated over a number of years, from 1976 to the present day, and are on-going.

National Park (NP)

National Parks were established to protect beautiful and relatively wild countryside by:

- Preserving the characteristic beauty of the landscape;
- Providing access and facilities for public open-air enjoyment;
- Protecting wildlife, buildings and places of architectural and historic interest; whilst allowing sustainable farming use to continue as before.

Powers to create National Parks were established under the National Parks and Access to the Countryside Act 1949. In Wales, since 1991, the designation of National Parks are proposed by former Countryside Council for Wales (CCW) which now forms part of, Natural Resources Wales (NRW), and confirmed by the First Minister for the Welsh Government. Since 1996 the Parks have been administered by independent free-standing authorities.

Special Area of Conservation (SAC)

The EC Habitats and Species Directive came into force in 1992 with the aim of conserving biodiversity by protecting a wide range of habitats and species of animals and plants. All SACs, together with Special Protection Areas (SPAs) designated under the EC Wild Birds Directive to protect rare and migratory species of birds, comprise a network of sites across the EU known as 'Natura 2000'. Most SACs in Wales were first proposed in the mid-1990s and were formally designated in 2004.The sites used in this project are the SACs that have completed the full legal designation process.

Special Protection Areas (SPA)

The EC Birds Directive of 1979 requires member states to establish SPAs to conserve the habitats of two categories of birds:

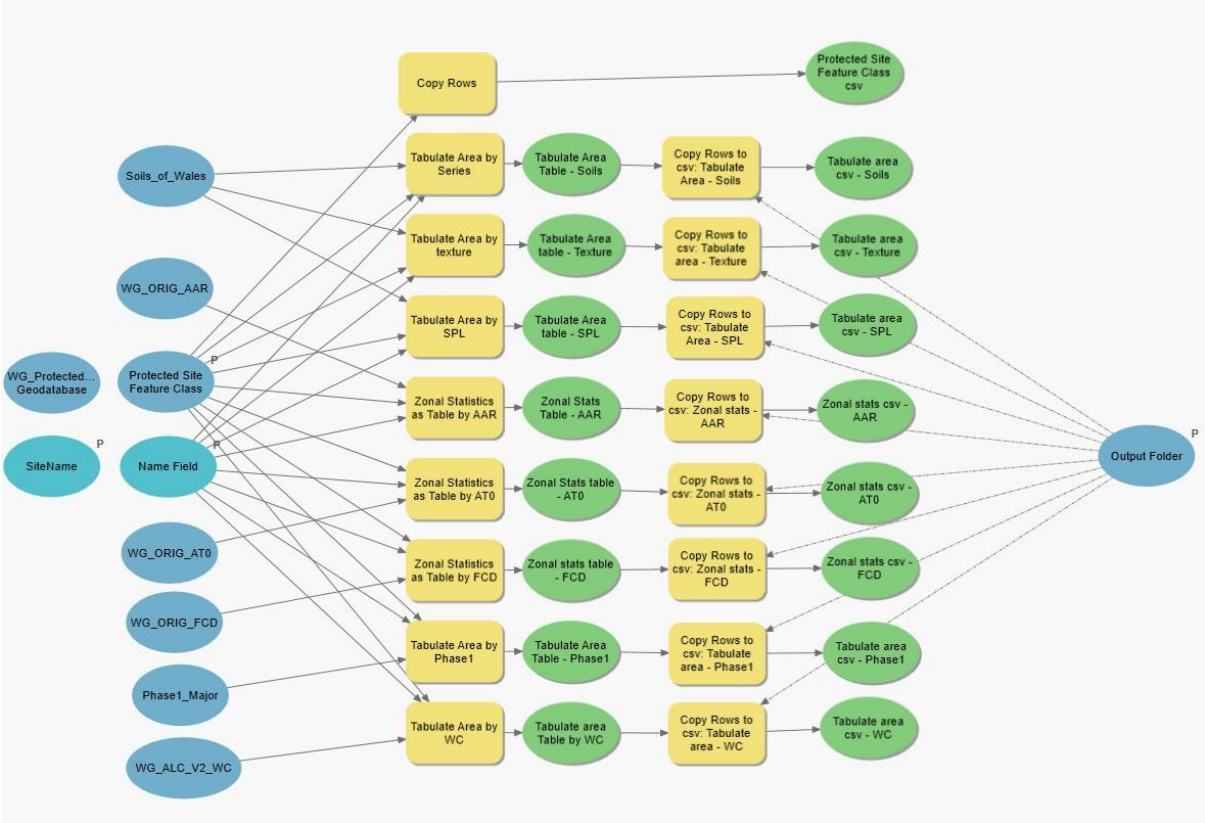
i. Species which are rare or vulnerable, of which there are forty-eight in the UK.
ii. Some migratory species which visit our shores regularly.

SPAs in Wales are identified by NRW, in conjunction with the UK Joint Nature Conservation Committee, and designated by the First Minister for the Welsh Assembly Government. These sites are also protected through being Sites of Special Scientific Interest (SSSIs). The 1994 Conservation Regulations also provide a means of protecting such areas at sea. SPAs together with SACs will contribute to a European Union network of protected sites to be known as 'Natura 2000' (N2K sites). SPAs have been designated over a number of years, from 1982 to the present day, and are on-going.

Appendix 2 Data sources used for designated sites summaries

Data	Filename
Natural Nature Reserves (NNR)	NRW_NNRPolygon
https://data.gov.uk/dataset/ce3bdae3-cc24-4fa9-8db0-a1fc2217e995/national-nature-reserves-nnrs	
Local Nature Reserves (LNR)	NRW_LNRPolygon
https://data.gov.uk/dataset/c0c66de2-ef27-471f-a501-ebf2713f8649/local-nature-reserves-lnrs	
National Parks (NP)	NRW_NATIONAL_PARKPolygon
https://data.gov.uk/dataset/949976cb-f952-4405-9fa1-bf531fdca0f5/national-parks	
Ramsar	NRW_RAMSARPolygon
https://data.gov.uk/dataset/bd0cd4e0-0c1d-456f-bebe-e27045336ee6/ramsar-sites-wetlands-of-international-importance	
Special Areas of Conservation (SACs)	NRW_SACPolygon
https://data.gov.uk/dataset/4908e142-5266-4917-9a3d-751ff1c058cd/special-areas-of-conservation-sacs	
Special Protection Areas (SPA)	NRW_SPAPolygon
https://data.gov.uk/dataset/20883869-b2b8-4f85-b3a1-fe46e3423134/special-protection-areas-spa	
Sites of Special Scientific Interest (SSSI)	SSSI_June2020
https://data.gov.uk/dataset/c84ab987-8504-4ae7-a0db-c28822083890/sites-of-special-scientific-interest-sssis	
Phase 1 Habitat Survey	PHASE1_HABITAT
https://data.gov.uk/dataset/35ea7f50-b410-467c-8419-5fbfedb8dcb7/terrestrial-phase-1-habitat-survey	
Soils of Wales	Soils_of_Wales
Keay C. 2020b. Capability, Suitability & Climate Programme Volume 2 - Soils of Wales - Series Map. Accessible at: CSCP Volume 2	
Original ALC climate data on a 5km grid interpolated to 50m using OSTerrain50 DTM	AAR, FCD, AT0
Meteorological Office (1989). Climatological data for Agricultural Land Classification. HMSO, ISBN-0-86180-249-7.	

Appendix 3 Data Workflow



Appendix 4 Soil-relevant SSSI habitats

Terrestrial habitats identified in the SSSI designations with relevance to soil.

Code	Habitat	soil relevant
A1	Woodland	y
A2	Scrub	y
A3	Parkland/ scattered trees	y
A4	Recently-felled woodland	y
B1	Acid grassland	y
B2	Neutral grassland	y
B3	Calcareous grassland	y
B4	Improved grassland	y
B5	Marsh/marshy grassland	y
B6	Poor semi-improved	y
C1	Bracken	y
C2	Upland species-rich ledges	y
C3	Other tall herbs and ferns	y
D1	Dry dwarf shrub heath	y
D2	Wet dwarf shrub heath	y
D3	Lichen/bryophyte heath	y
D4	Montane heath/dwarf herb	y
D5	Dry heath/acid grassland mosaic	y
D6	Wet heath/acid grassland mosaic	y
D7	Other heath	y
E1	Bog	y
E2	Flush/Spring	y
E3	Fen	y
E4	Bare peat	y
F1	Swamp	y
F2	Marginal and inundation	y
G1	Standing water	n
G2	Running water	n
H1	Intertidal	n
H2	Saltmarsh	y
H3	Shingle above high tide mark	n
H4	Boulders/rocks above high tide mark	n
H5	Strandline vegetation	n
H6	Sand-dune	y
H8	Maritime cliff and slope	n
I1	Natural rock exposure	n
I2	Artificial rock exposure	n
J1	Cultivated/disturbed land	y
J2	Boundaries (Hedges/Walls etc)	n
J3	Built-up areas	n
J4	Bare ground	n
J5	Other Habitat	n
?	Unknown	n
NA	Not Assessed	n