Nature Net Zero

Part 1: Carbon in semi-natural habitats

August 2025

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Part 1 Executive summary

Natural England's Nature Net Zero (NNZ) research aims to assess the potential for England's ecosystems to deliver the greatest increase in biodiversity in ways that preserve carbon storage, increase carbon sequestration rates and reduce greenhouse gas emissions. The research seeks to identify the habitats and geographical locations that would make the best return on investment to deliver biodiversity targets and achieve long term functional recovery of "carbon in nature".

Natural England commissioned TEP to carry research and spatial analysis. Part 1 of the research estimates how much carbon is stored in, and sequestered by, semi-natural habitats and how this is distributed in England's protected sites and landscapes.

Part 1 Outputs

- A rapid review and refinement of the reported range of carbon storage values and sequestration rates in England's priority habitats and selected non-priority habitats; specifically aiming to refine existing estimates for deciduous woodland and habitats overlying peat.
- A short-list of nature-rich habitats that have the highest value, if enhanced or restored, in terms of safeguarding and increasing the amount of carbon stored by England's habitats; in short, 'High-Carbon, High-Nature' habitats.
- Information about the quantity and distribution of habitat carbon in England's Protected Sites, Designated Landscapes and National Character Areas.

Habitats in Scope

This study considers 26 priority habitats, including wood pasture and parkland (WPP). The study also examines, in lesser detail, 4 selected "non-priority habitats" which are available within the Priority Habitat Inventory data layer. They are considered to be potentially restorable to priority status through intervention and are useful contextual information.

Peaty Soils

This study examined the association between habitats and the national peaty soils dataset, with a view to ensuring that, where peat underlies a habitat, its contribution to habitat carbon storage is identified in a more granular way than the currently-available carbon estimates allow.

Carbon Stored in Habitats

A rapid literature review, drawing extensively from Natural England's Carbon Storage and Sequestration by Habitat 2021 report (NERR094 - Gregg and others (2021)), quantified carbon storage in most priority habitats. The literature separately quantifies carbon stored in soil and vegetation, with ranges expressed as upper and lower estimates of tonnes carbon per hectare (t C ha^{-1}), with confidence levels (high, medium, low).

We used data from this review, alongside analysis of the peaty soils dataset to derive:

- A typical carbon storage estimate, per hectare, for all habitats
- A carbon storage estimate for relevant habitats that considers the contribution of underlying peat

The typical storage estimate was set between the upper and lower range, taking account of expert advice from Natural England's Senior Specialist on the distribution of habitats and confidence in the data. For the deciduous woodland grouping of six priority habitats, a typical storage estimate was derived by stratifying storage data between old (>100 y) and young woodland (30-100 y). It is hoped that future iterations of the priority habitat inventory (PHI) will provide more granular data about the location and extent of each of the six woodland types. This means that woodland-specific carbon storage estimates will replace the typical estimate used in this study.

For priority habitats where >25% of the national coverage overlies peaty soils, the typical carbon storage estimate was adjusted to take account of the national proportions of the habitat that overlie deep peat (>40cm peat depth), shallow peat (<40cm peat depth), soil with peaty pockets, or soil without peat. This adjustment, when applied nationwide, resulted in a 6.5% increase to the estimated habitat carbon store.

Carbon Storage in England's Priority Habitats – Key findings

The results summarised below use the typical carbon storage estimate for above and below ground, adjusted for consideration of peat where appropriate.

Where is carbon in nature?	Total carbon stored in priority habitats	Proportion of English total
All English priority habitats	518 million tonnes	100%
English deciduous woodlands	231 million tonnes	44.7%
English blanket bogs	114 million tonnes	22.1%
English Upland heathland	50 million tonnes	9.6%
Priority habitats in the SSSI network	215 million tonnes	41.5%
Priority habitats in National Parks	126 million tonnes	24.3%
Priority habitats in National Landscapes (formerly Areas of Outstanding Natural Beauty)	136 million tonnes	25.8%
Priority habitats in the top five upland National Character Areas (North Pennines, Yorkshire Dales, Dark Peak, Border Moors and Forests, Southern Pennines	129 million tonnes	25%
Priority habitats in the top five wooded National Character Areas (Cotswolds, High Weald, Low Weald, North Downs and Wealden Greensand)	42 million tonnes	8.1%
Non-priority habitats (grass moorland, good quality semi-natural grassland, fragmented heath and 'no main habitat but other habitats present'	31 million tonnes	N/A

Carbon Sequestration in England's Priority Habitats – Key findings

England's priority habitats have an estimated net carbon sequestration rate of 7.3 million tonnes of carbon dioxide equivalent per year (t CO_2e y^{-1}) on the basis of available evidence. This is comprised of a total of 8.4 million tonnes sequestration, offset by 1.1 million tonnes emission. It should however be noted that there is very little evidence available for some habitats so confidence is relatively low.

Woodland and coastal saltmarsh habitats have higher reported net sequestration rates, whereas other habitats have either no significant net sequestration rates, or have typical net emission rates; for most habitats, nationally-consistent data is limited and for some habitats data is absent.

Taking the data that are available, priority habitats in England's designated landscapes could be sequestering approximately [a net balance] 2 million t CO_2e y^{-1} of carbon dioxide.

Priority habitats in England's SSSI network emit an estimated 0.45 million t CO_2e y^{-1}, on a net basis. This is because they include significant areas of peat-based priority habitats which are net carbon emitters often due to being in poor condition.

Deciduous woodlands in well-wooded National Landscapes and National Character Areas are the most significant sequestration resources; the five NCA's in South England named in the summary above collectively sequester 1.33 million tonnes CO2e y^{-1}, about 16% of the total national carbon sequestered by priority habitats.

Ranking of Habitats for Nature Net Zero prioritisation

A shortlist of priority habitats was drawn up, based on upper and lower range carbon storage estimates and relative abundance of underlying peat. The list is as follows, showing estimated carbon storage. The ranking is not derived solely from stored carbon in habitat, it also considers the proportion of the habitat overlying peat soils, with adjustment for this by increasing the carbon storage estimate for non-peatland habitats where they overlie peat soils.

1. Deciduous woodland – 231 million tonnes
2. Blanket bog – 114 million tonnes
3. Upland heath – 50 million tonnes
4. Coastal and floodplain grazing marsh – 24 million tonnes
5. Lowland raised bog – 20 million tonnes
6. Wood pasture and parkland (exc. other priority habitat) – 15 million tonnes
7. Lowland fen – 14 million tonnes
8. Coastal saltmarsh – 14 million tonnes
9. Lowland heath – 6 million tonnes
10. Upland flushes, fens and swamps – 4 million tonnes

These habitats account for 95% of all carbon stored in priority habitats in England.

The study also noted that some non-priority habitats listed in the inventory data layers, such as ‘grass moor’ and ‘fragmented heath’ have estimated carbon storage values above the lower range estimates for some of the short-listed priority habitats. In total approximately 31 million tonnes of carbon is stored within these areas, that could be safeguarded with habitat restoration.

Limitations

This report results from a rapid literature review and spatial analysis and has been subject to light-touch verbal review and steering from Natural England specialists – it is not a fully peer-reviewed study. It did not involve any field measurements. It is based on analysis of the Priority Habitats Inventory and the Peaty Soils dataset available in 2024; which have inherent limitations in terms of confidence about precision at any given location.

The Priority Habitat Inventory is the basis of this review. It has limitations in that it is based on field evidence of varying age and survey methodology; and for some habitats confidence of consistent habitat diagnosis is low. The deciduous woodland category is a large aggregation of several woodland types and it would have been preferable to summarise the extent of each different type. Coastal and floodplain grazing marsh is a priority habitat type undergoing a full review of its definition and future iterations of the PHI will likely rename the habitat and provide updated distribution maps.

The literature on carbon value per habitat is not based on a wide evidence base, and there are different methodologies for calculation of carbon storage in soil and vegetation. Carbon sequestration values for different habitats are based on fewer long-range studies and data is influenced by the historic management of the vegetation being studied.

The ‘Nature Returns’ programme is seeking to fill gaps in the evidence base about habitat carbon. Additionally an updated England Peat Map has been made available in May 2025.

The Priority habitat classification is the basis of this review, but it is based on vegetation types, so there is not always a ‘read-across’ to habitats described in the carbon literature. Thus some priority habitats, like deciduous woodland will have a broad range of carbon values in different locations, whereas others are more tightly defined by reference to vegetation, and align better with reported carbon values.

Nevertheless, the findings use the best available evidence and are considered to provide a national overview of “carbon in nature”, and an identification of ranking and priorities for future research, policy formulation and habitat implementation. Improvement can certainly be made in future on the back of an improving evidence base.

Contents

1. Introduction

The Environment Partnership (TEP) was commissioned by Natural England in November 2023 to assess the potential for England's terrestrial and coastal ecosystems to deliver the greatest increase in biodiversity while retaining carbon storage and increasing sequestration rates; in short a rapid review of the contribution that semi-natural habitats can make to the Net Zero mission. The project seeks to identify those habitats and geographical locations that would make the best return on investment to achieve long term functional recovery of carbon in ecosystems. The project has four strands:

Part 1: A national assessment of the range of carbon storage and sequestration values in existing priority habitats, generating a short-list of high carbon habitats.

Part 2: An assessment of the impacts of climate change on high carbon habitats to determine the risks to their mitigation value and potential adaptation measures to reduce vulnerability at 1.5, 2 & 4 degrees of heating.

Part 3: An evaluation of the potential of new habitats & ecosystems restoration to deliver the greatest increase in biodiversity while retaining carbon storage and increasing sequestration rates; using FCS (Favourable Conservation Status) figures for high carbon habitats. Based on the above evidence, analysis of what types of landscapes are needed to achieve the functional restoration of these ecosystems and be most effective in delivering carbon & biodiversity outcomes in the long term. Part 3 also includes Nature Net Zero 'pathways' in other words various scenarios which deliver carbon benefit and nature recovery.

Part 4: An outline of the trade-offs between different land uses and where good integrated delivery can achieve better outcomes.

This report relates to Part 1 and aims to quantify the total carbon stored in, and sequestered by, priority habitats in England. The study also extends to carbon-rich non-priority habitats.

A principal output is a short-list of nature-rich habitats that have the highest value, if enhanced or restored, in terms of safeguarding and increasing the amount of carbon stored by England's habitats; in short, "High-Carbon, High-Nature" locations.

Another principal output is information about the quantity and distribution of habitat carbon in England's Protected Landscapes and Sites.

Study Boundary and Scope

The study analyses the terrestrial land and coastal zone of England to mean low water.

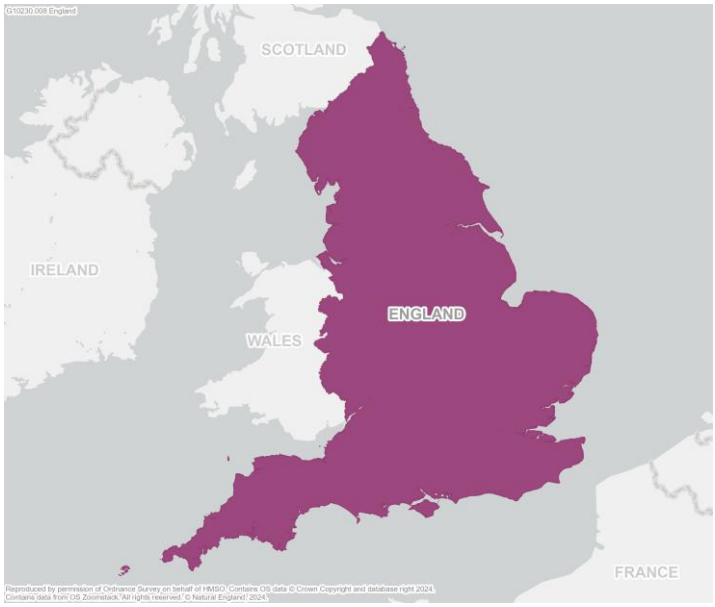

Figure 1. Area of study
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2. Data Sources

This section of the report provides an overview of the key datasets and carbon literature used in the analysis described in the Methodology (chapter 3).Various Natural England open source data sources were used to determine existing carbon storage and sequestration across England's priority habitats – see Table 1.

Table 1 GIS data sources and dataset currency

Dataset	Download Date	Dataset Currency
Priority Habitats Inventory (England)	21-11-2023	28-07-2023
Wood Pasture and Parkland (England)	28-11-2023	28-05-2020
Peaty Soils Location (England) (Ref: NE257)	04-12-2023	25-04-2022
Areas of Outstanding Natural Beauty (England)*	04-12-2023	25-08-2020
National Character Areas (England)	04-12-2023	01-02-2023
National Nature Reserves (England)	04-12-2023	17-11-2023
National Parks (England)	04-12-2023	17-11-2023

Dataset	Download Date	Dataset Currency
Ramsar	04-12-2023	21-02-2023
Special Areas of Conservation (England)	04-12-2023	19-10-2023
Special Protection Areas (England)	04-12-2023	21-02-2023
Sites of Special Scientific Interest (England)	04-12-2023	19-10-2023

Priority Habitat Inventory (PHI)

A spatial dataset providing the geographic extent and locations of 25 habitats of principal importance for biodiversity conservation and enhancement, under Section 41 of the NERC Act 2006 in England. The selection of UK habitats for the priority list followed consideration by expert working groups against a set of criteria, based on international obligations, risk, and the importance for key species. The list of all priority habitats was last revised in 2007, and habitat definitions last revised in 2011. The full list and habitat descriptions is maintained by JNCC.

This study used the PHI [User Guide 3.0] as the basis for estimating "carbon in nature". England's framework for habitat protection and restoration is focussed on safeguarding, enhancing, restoring and creating priority habitats.

The PHI allows for nationwide spatial analysis of habitat carbon data, as it is the only nationally consistent inventory of habitat types. Thus Nature Net Zero is focussed on calculating carbon stored in, and sequestered by, priority habitats. Some of the habitat carbon literature uses the PHI as a framework for estimating carbon stores, and other carbon literature can be "read across" to the priority habitats.

However, there are some additional habitat inventories which were included in this study, as set out below.

Wood Pasture and Parkland (WPP)

WPP is listed within the UK Biodiversity Action Plan and is regarded as a s41 habitat. However, it is not currently in the PHI. It is available as a separate dataset of provisional priority habitat due to a lower certainty of habitat quality. The dataset provides the spatial locations of large open-grown or high forest trees within a matrix of grazed grassland, heathland or woodland floras. Consequently it has high cross over with some other habitats. It is likely to be a high carbon habitat, so was added to the PHI dataset for analysis.

Non-Priority Habitats

Spatial Datasets were also accessed for the following non-priority habitats:

- Good quality semi-improved grassland
- Fragmented heath

- Grass Moorland
- Priority Habitat Inventory - No main habitat but additional habitat exists

The non-priority habitats inventory for Fragmented Heath, Grass moorland & No Main Habitat were extracted from Farm Environment Plan surveys & HLS data when surveying and setting up HLS agri-environment schemes (Natural England, 2010). Although not considered to meet the quality criteria for priority habitats, these habitats hold potential importance for conservation of biodiversity in England. For example, they can indicate a mosaic of habitat which may contain priority habitats, have restoration potential and/or contribute to ecological networks. Where evidence indicates the presence of unmapped or fragmented priority habitats within such polygons, these are attributed as additional habitats.

These non-priority habitats were included in the study due to their potential for high carbon storage values and/or high rates of carbon sequestration. Edwards and others (2020) identify these habitats as potentially capable of restoration to priority types in the National Habitat Network Maps. For example, when fragmented heath and/or grass moor are found on deep peat; and “no main habitat” with blanket bog present are all considered to be restorable to blanket bog.

Peaty Soils

The Peaty Soils dataset provides the spatial locations of 3 different categories of soils supporting peat reserves;

- Deep Peaty Soils (above 40cm peat depth),
- Shallow Peaty Soils (below 40cm peat depth),
- Soils with Peaty Pockets (soils with peat present but more scattered).

The presence and extent of underlying peat and the carbon stored within it needs to be understood in relation to priority and non-priority habitats as peat will significantly affect the amount of carbon stored within each habitat type.

Priority habitats types are separated in their classification between those dependent on and/or found almost exclusively on peat (also called ‘peatland habitats’), and others that may also be found on mineral soil types or across a much wider range of soil conditions. This study investigated the relationship between peaty soils and habitat types. For example we would expect the majority of deep peat soils to sit under blanket bog, raised bog, or fen habitat, but the analysis indicates peat is found under a wider range of habitats and some priority habitats are found over a range of peaty and mineral soils.

It is also recognised that much peat, even underlying priority habitat, is not in favourable nature conservation condition and is suffering from oxidation and emission of carbon dioxide (Evans et al. 2017, 2023), so its restoration is a priority for both nature recovery and climate mitigation. Often where these peat habitats are degraded we see other habitat types becoming dominant due to the change in condition and much drier state.

The study analysed the co-incidence of habitat types and peat soils in order to refine the nationwide habitat carbon estimates and to inform the ranking and short-listing of habitats for future consideration in Natural England's Nature Net Zero workstream.

Dataset Limitations

All datasets used for this study are subject to a general caveat that the input field data was collected and subsequently digitised at varying times, so may not reflect the current status. There is also no national assessment of the condition of all the priority habitats so the assessment in this study is generic in terms of habitat condition. This is not considered a significant limitation for this study which collates and presents the best available data on a national or landscape-scale basis.

UK habitat classification used is largely based on vegetation communities, using a range of botanical and physico-chemical parameters to separate habitats, sometimes with locational parameters to separate habitats between upland and lowland types. Some of the priority habitats such as Coastal and Floodplain Grazing Marsh (CFGM) and Lowland Pasture and Parkland also include land with relatively low ecological value. In the case of the former this is understood to be addressed shortly with an update to Floodplain Wetland Mosaic (FWM) priority habitat (pers. comm. Ian Crosher Natural England Senior Specialist Climate Change).

Some broad habitat types have much greater stratification than others, perhaps due to historic research priorities. For example grassland has 7 types based on various abiotic gradients (wet through to dry, and acid through to calcareous), whereas fen is only subdivided by lowland or upland location.

Thus, when estimating habitat carbon, the literature shows that some habitats have much greater carbon ranges due to covering several broad abiotic gradients that each influence the amount of carbon found within a habitat.

The deciduous woodland dataset consists of an aggregate of six individual priority woodland habitats (lowland beech and yew woodland, lowland mixed deciduous woodland, upland birchwoods, upland mixed ashwoods, upland oakwood, wet woodland).

These individual types are starting to be identified as individual attributes or "feature codes" within the aggregated "DWOOD" layer, but at the time of writing there is insufficient granularity of data to reliably estimate areas of the different priority woodlands. Natural England expects the use of these data fields to expand in forthcoming PHI updates with new features and codes.

However, as deciduous woodland is the largest data layer and the carbon literature records significant ranges between lower and upper values for carbon storage and sequestration in woodland; any nationwide or landscape-scale estimate of habitat carbon in priority woodland must be stated within wide ranges.

The different woodland types have different carbon storage and sequestration values, in part due to the carbon density of the timber, so once more data is available about the

extent of each woodland type, it will be possible to produce more confident and refined estimates of typical woodland habitat carbon. As described in Chapter 3, a “workaround” for this difficulty was found by stratifying the deciduous woodland dataset into “old” and “young” classes, for which habitat carbon estimates can be made.

Carbon Value Limitations

Carbon storage value and sequestration rates of habitats were collated from a number of published sources, notably the following “Defra family” reports:

- Evans, C. et al (2023). Aligning the Peatland Code with the UK Peatland Inventory. London, Defra.
- Gregg, R. et al. (2021) Carbon storage and sequestration by habitat: a review of the evidence (second edition) Natural England Research Report NERR094. Natural England, York.
- Swaile, G. et al (2022) Blue carbon – mapping risks and opportunities. Natural England Research Report ME5440 to Defra.

The main source (Gregg et al. (2021) (NERR094)) is a review of published scientific literature and assigns confidence levels to the data based on the number of repeated papers on a habitat and breadth of samples that were taken across a geographical spread. The report itself has been peer reviewed by external academics, conservation stakeholders and nature conservation agencies. The confidence levels adopted for this study are based on those given in NERR094.

For some habitats, the report provides a minimum and maximum reported range and provides a median or representative value of carbon stored in soils and/or in vegetation.

There are no definitive carbon storage and sequestration values for all priority habitats present in England. Notable evidence gaps in the literature are in wetland and fen habitats types including, purple moor grass and rush pasture as well as some grassland types and wood pasture and parkland habitats.

Less data is generally available for sequestration rates in England, and it is far more variable due to being dependent on past and future management practices. As mentioned previously there is also no national dataset for condition of habitats so any variation in condition is not accounted for in the stated carbon storage and sequestration figures. Where higher condition or ecosystem function delivering better carbon outcomes.

Most of the published sources describe their own evidence limitations. For example for some habitats, notably grasslands, values are only available for the carbon storage within the upper 15cm of top soil and not the above ground vegetation.

Direct field measurement of carbon storage and sequestration was not within the scope of the study. Professional judgements in collaboration with Natural England Senior Specialist Climate Change Ian Crosher were made in order to assign typical carbon storage and sequestration values to the habitats that have data gaps. Judgements were based on:

- the available data, taking account of upper and lower estimates, and confidence levels in the data;
- the extent of peaty soils underlying the habitats e.g. where a habitat has a wide range for estimated carbon storage due to whether or not it overlies peat, a typical value was generated based on the national proportion of the habitat that overlies peat;
- analysis of likely age classes for deciduous woodland, a very broad category of priority habitat that encompasses six woodland types and hence has a very high upper carbon storage estimate based on just one of the six types. It would have been preferable to stratify the carbon storage values and ranges in terms of the six types. However a national area breakdown was not available for the six woodland types, so the dataset was stratified based on an approximate 50:50 split of ages (100 year and 30 year mixed native broadleaved woodland) which broadly reflect the available age class data from the national Forestry Statistics (Forest Research, 2023). Carbon storage values were assigned to the two age classes.

Direct comparisons between different habitats therefore has to be made in the context of these limitations.

3. Methodology

The flow chart below sets out the overall process, followed by a narrative on each stage, including aims, analysis and outputs.

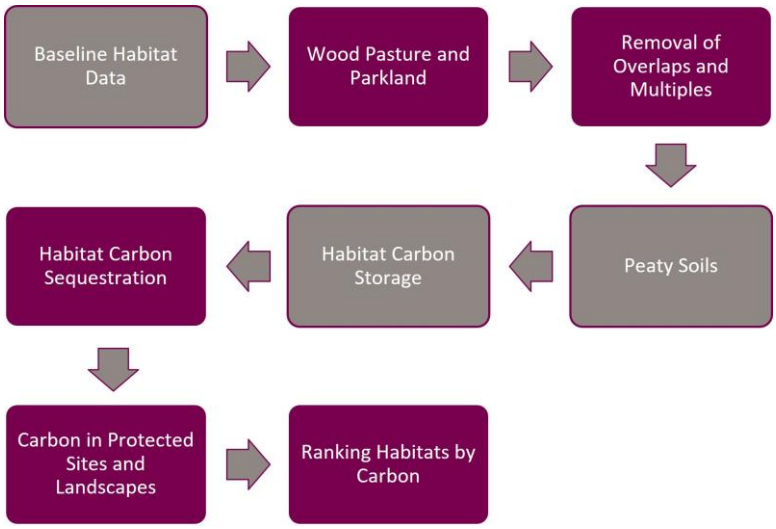

Figure 2. Methodology flow chart

Stage 1: What area is covered by Priority and non-priority habitats?

This work stage aimed to produce a baseline dataset of Priority and non-priority habitats suitable for further analysis.

The raw PHI dataset was analysed using ArcGIS Pro to identify any overlapping polygons, or polygons which shared multiple habitat classifications.

Where overlaps or multiple classifications occurred, they were assigned to the most likely single habitat, using a hierarchical system, as advised by Natural England's scientific officer.

An example of overlapping habitat data is illustrated in Figure 3. An individual polygon for 'Upland flushes, fens and swamps' overlaps an individual polygon for 'Upland heathland'. In this case, the hierarchy determined that 'Upland flushes, fens and swamps' took priority and thus the underlying habitat 'Upland heathland' was removed from the dataset.

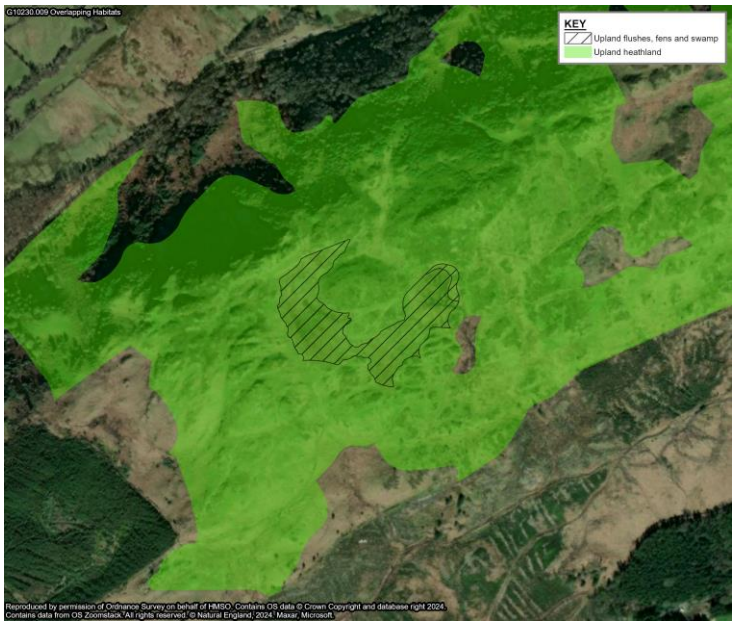

Figure 3. Example of overlapping polygons within Priority habitat Inventory dataset. Example provided shows an overlap between "Upland flushes, fens and swamp" and "Upland heathland". Reproduced by permission of Ordnance Survey on behalf of HMSO. Contains OS data © Crown Copyright and database right 2024. Contains data from OS Zoomstack. All rights reserved. © Natural England, 2024. Maxar, Microsoft.

Some polygons have attribute data assigned to multiple habitats. Based on the hierarchy, a single habitat was assigned to the polygon.

As described at chapter 2, the study also includes four categories of habitat which are non-priority habitats, but are potentially capable of enhancement or restoration to high-nature, high-carbon status, for example because they are often found close to priority habitats and so offer an opportunity to be managed for nature recovery by the same landowner. These are:

- Fragmented Heath
- Good quality semi-improved grassland
- Grass moor
- No main habitat but additional habitats present

The output of this work stage was a PHI dataset, free of a) spatial overlaps between polygons and b) multiple habitat classifications in any individual polygon. The dataset also includes selected non-priority habitats.

Stage 2: Adding Wood Pasture and Parkland to the dataset

The aim of this stage was to supplement the PHI baseline dataset by adding Wood Pasture and Parkland data. WPP is likely to be a “high-carbon” habitat, although it is recognised that many sites have been subject to agricultural improvement or leisure development so any individual WPP is not necessarily “high nature”.

Wood Pasture and Parkland (WPP) is not a dataset in the Priority Habitat Inventory (PHI). A provisional dataset for WPP is available, however this overlaps with the PHI dataset.

These overlaps were removed, with the PHI taking priority over the provisional WPP layer. Figure 4 shows an area of WPP (hatched). The whole WPP includes some deciduous woodland PHI (green wash) and lowland calcareous grassland PHI (brown wash). The deciduous woodland and lowland calcareous grassland PHI are preserved as such in the dataset, and WPP outside deciduous woodland is added to the dataset – in this case the hatched area that is not covered by green or brown wash.

Figure 4. Example of an overlap of Wood Pasture and Parkland with other Priority Habitat Inventory data.
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The output of this workstage was an updated baseline habitat dataset including Wood Pasture and Parkland (WPP) habitats.

Note that reference to priority habitats in this report includes WPP, but quantitative data for WPP has been “cleaned” as described above so that any overlaps with other priority

habitats have been removed. In other words, if a parcel of WPP is 100 hectares in extent, of which 20 hectares is deciduous woodland, WPP is recorded as 80 hectares in the dataset.

Stage 3: Quantify the relationship between Priority Habitat and Peaty Soils

The aim of this work stage was to quantify how much peat underlies different habitats, with a view to estimating the contribution of peaty soils to carbon storage in different priority habitats.

Peat is the largest terrestrial habitat carbon store in England. For some priority habitats such as blanket bogs, it is the principal component of their carbon store, and indeed the habitat is dependent on the presence of peat. Other priority habitats are not always dependent on peat but in places may be underlain by peat e.g. reedbeds, deciduous woodland. Other habitats such as calcareous grassland or upland hay meadows would not normally be expected to overlie significant peat areas.

Stage 3 seeks to quantify the extent and depth of peaty soils underlying priority and other habitats, with a view to providing more context to habitat carbon storage calculations (Stage 4) and short-listing of high-carbon, high-nature habitats (Stage 7).

Natural England's Peaty Soils dataset provides information as to whether a habitat overlies Deep Peat (above 40cm depth), Shallow Peat (below 40cm depth), Soils with Peaty Pockets (where some peat is present), or no peaty soils at all.

Relationships between each priority habitat polygon and Peaty Soils data were analysed, resulting in habitat polygons sub-divided in terms of the presence and depth of underlying peat.

The output of this work stage was information about the extent and depth of peat underlying priority and non-priority habitats and information about the extent and depth of peat which is not overlain by Priority habitats. For example, Figure 5 shows a map from the Peak District where a reasonably high proportion of the PHI and the selected non-priority habitats overlie peat.

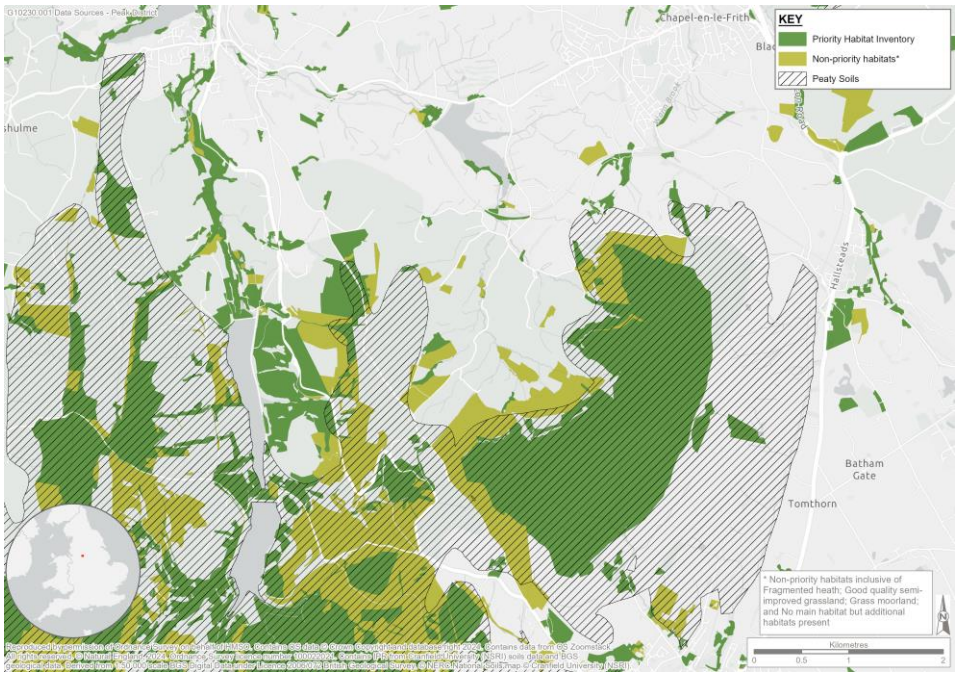

Figure 5. Map showing priority habitats; non-priority habitats; and their relationships with the Peaty Soils dataset.
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Stage 4: Establishing a national estimate for carbon stored in priority and non-priority habitats

The aim of this work stage was to estimate total habitat carbon stored nationwide in priority habitats, and the selected non-priority habitats.

Carbon storage values for each priority habitat were identified from a rapid review of the literature referenced in the bibliography.

The literature estimates habitat carbon storage on a “tonnes of carbon per hectare” basis with the following principal variables:

- Carbon storage in soil and vegetation is often provided as separate estimates, with the soil depths not always consistent across different literature sources;
- Upper and lower estimates are provided for some habitats, sometimes associated with whether the habitat is over organic (peat) soils;
- For some priority habitats, carbon storage data is not available;

- Some priority habitats are aggregated for the purpose of estimating carbon storage;
- Expert confidence in the data is also provided in the literature.

The literature was analysed to provide, for each habitat:

- soil, vegetation and combined estimates of carbon storage (t C ha^{-1});
- upper and lower ranges
- confidence in the estimate, expressed as High, Medium, Low
- an estimate of typical carbon storage

In order to derive the estimates, some data had to be extrapolated or inferred from similar habitats; for example no reference values are available for the maritime cliff and slopes priority habitat and therefore those for lowland dry acid grassland were adopted.

In the carbon literature, the priority habitat category “deciduous woodland” is a grouping of a range of woodland types:

- Lowland beech and yew woodland
- Lowland mixed deciduous woodland
- Upland birchwoods
- Upland mixed ashwoods
- Upland oakwood
- Wet woodland

These will vary considerably in terms of carbon storage hence there is a considerable range between upper and lower estimates. However, there is insufficient data on carbon storage or extent of coverage by different woodland habitats to allow a stratified estimate of carbon storage.

The upper woodland estimate thus inevitably over-states national carbon storage in priority deciduous woodland habitat. An adjustment was made based on an approximate 50:50 split of ages (100 year and 30 year mixed native broadleaved woodland) which broadly reflects the available age class data from the national Forestry Statistics (Forest Research, 2023).

The non-priority habitats were also subject to an estimate of carbon storage, with data extrapolated from analogous habitats as described above.

The individual estimates of habitat carbon per hectare were then multiplied by the extent of habitat nationwide in order to estimate the total habitat carbon stored in priority and non-priority habitats in England.

Example calculations are set out below for two habitats, one with no underlying peat, and one that overlies peat in part of its national range.

Priority Habitat: Mudflats (no underlying peat)

Total Area: 66,216 hectares

Typical Carbon Store: 132 t C ha^{-1}

Proportion underlain by peat: <0.1%

Total National C Store: **8,740,473 tonnes** (no peat correction needed)

Priority Habitat: Reedbeds (27.3% underlain by peat)

Total Area: 4,283 hectares

Typical Carbon Store: 168 t C ha^{-1}

Typical Carbon Store over Deep peat: 1,971 t C ha^{-1}

Total National Carbon Store not considering underlying peat: 719,544 tonnes

Proportion underlain by peat: 27.3%

Total National C Store taking account of proportion of underlying peat: **2,103,316 tonnes**

The output of this workstage were typical carbon storage value per hectare (above and below ground) for 27 out of 30 priority and non-priority habitats, including upper and lower ranges where relevant.

This enabled an England-wide estimate of total carbon stored within priority and non-priority habitats, with breakdowns per habitat type.

Stage 5: Establishing a national estimate for carbon sequestered by priority habitats

The aim of this work stage was to estimate the nationwide carbon sequestration rates for priority habitats and the selected non-priority habitats, including identifying net emission rates for habitats which are net carbon emitters.

Carbon sequestration rates for priority habitats were identified from the literature review. Eight priority habitats, including WPP, do not have available data so were not included.

Upper, lower and typical sequestration estimates were identified. Negative values in sequestration rates indicate sequestration from the atmosphere back into the vegetation or soil by the ecosystem, and positive values indicate emissions to the atmosphere.

Then total nationwide sequestration was calculated based on the hectarage of priority habitats studied.

There is a considerable range in the carbon sequestration rates for the aggregated “deciduous woodland” category of priority habitat, but it was not possible to stratify the range in terms of different woodland types and areas, for the reasons described at Stage 4.

Nevertheless, the aggregated sequestration rate for deciduous woodland was adjusted based on an approximate 50:50 split of ages (100 year and 30 year mixed native broadleaved woodland) which broadly reflect the available age class data from the national Forestry Statistics (Forest Research, 2023). Sequestration rates were therefore apportioned based on this approximate age split in order to generate a typical rate for woodland, as follows:

Deciduous Woodland (young - 30-100 years)

Lower Sequestration Estimate: -2.5t CO_2e y^{-1} ha^{-1}

Upper Sequestration Estimate: -25.5t CO_2e y^{-1} ha^{-1}

Typical Sequestration Estimate: -14.5t CO_2e y^{-1} ha^{-1}

Deciduous Woodland (old - >100 years)

Lower Sequestration Estimate: -2t CO_2e y^{-1} ha^{-1}

Upper Sequestration Estimate: -13t CO_2e y^{-1} ha^{-1}

Typical Sequestration Estimate: -7t CO_2e y^{-1} ha^{-1}

Total Area all deciduous woodland = 759,522 hectares, allocated equally between old and young classes

Annual Sequestration of Deciduous woodland (young) = - 5,506,533t CO_2e y^{-1}

Annual Sequestration of Deciduous woodland (old) = - 2,658,326t CO_2e y^{-1}

Annual Sequestration of All Deciduous woodland = **-8,164,859t CO_2e y^{-1}**

Some data was available for non-priority habitats, but as these are mostly grassland or heathland habitats, with relatively few trees and assumed to be in a continuous state of management, they will have relatively low net sequestration / emission rates. As they do not cover as significant an area as the priority habitats, they were not taken forward for detailed analysis in respect of their contribution to sequestration.

Negative values indicate sequestration of atmospheric carbon into vegetation and soil, whereas positive values indicate net emission of carbon from the ecosystem into the atmosphere.

The output of this work stage was, for 18 priority habitats, a typical carbon sequestration rate per hectare, with upper and lower ranges and a confidence value.

This enabled an England-wide estimate of carbon sequestration rates in terms of these priority habitats.

Stage 6: Summarising the carbon stored and sequestered in priority habitats in England's landscapes and protected sites

The aim of this work stage was to provide data on the quantity of carbon stored in, and sequestered by, priority habitats and selected non-priority habitats in various categories of protected sites and landscapes across England.

Using data accumulated from Stages 1 to 5, a dataset was created detailing:

- Spatial extent and location of priority and non-priority habitats;
- Extent of the above underlain by peat;
- Carbon storage per hectare against upper, lower and typical estimates;
- Carbon sequestration rate per hectare, against upper, lower and typical estimates.

This dataset was then analysed to quantify the total extent of priority and non-priority habitat and associated carbon storage/sequestration associated with the following categories of site and landscape:

- Ecologically protected areas
    - SSSI, SPA, SAC, Ramsar, NNR
- Landscape designations
    - National Parks and National Landscapes (formerly Areas of Outstanding Beauty)
- National Character Areas

For landscape designations and National Character Areas, analysis was also made on a site-specific basis; for example identifying how much deciduous woodland and associated carbon is present in the Lake District National Park as well as National Parks in general.

The output of this work stage was data on carbon stored and sequestered by priority habitats and selected non-priority habitats in ecologically designated sites, landscape designations and national character areas. This allows the calculation of existing 'carbon for nature' across England in respect of the priority habitat inventory, against upper, lower, and typical carbon storage values and sequestration rates.

Stage 7: Ranking and short-listing of "high-carbon" habitats

The aim of this work stage was to rank habitats in terms of their national significance for carbon storage and sequestration, in order to help Natural England focus their programmes of work under the Nature Net Zero priority. Put colloquially, the aim of this stage was to produce a 'Top Ten' of 'High-Carbon, High-Nature' habitats.

The 27 priority habitats, including WPP, were ranked against the following three criteria:

- Total Carbon Stored (Upper Range Estimate)
- Total Carbon Stored (Lower Range Estimate)
- Total area of habitat underlain by deep or shallow peat

An overall ranking was then made based on a combined index of the three criteria. There was considerable commonality in the upper part of the ranking, with some anomalies due to uncertainty about data, for example with “coastal and floodplain grazing marsh” and “mudflats”, as is explained later. Nevertheless the upper ranked habitats (in the top 5) accounted for well over 90% of the habitat carbon in store, using any of the methods of ranking.

Through discussions with Natural England and TEP Ecologists, a “top ten” of priority habitats were shortlisted for further study (Nature Net Zero Project Parts 2 to 5) with a view that these be included in Natural England work programmes for research and nature recovery.

The output of this workstage was that priority habitats can be ranked in terms of their contribution to England’s habitat carbon store, with a shortlisting of around ten ‘High-Carbon, High-Nature’ habitats for further study and prioritisation in Natural England’s nature recovery work programmes.

4. Baseline Habitats Dataset and their Relationship with Peat

This chapter reports on methodological stages 1 to 3 i.e. the production of a national dataset of priority and selected non-priority habitats with information on the relationship between these habitats and underlying peat. Results are summarised under the following headings:

- Priority habitat coverage
- Non-priority habitat coverage
- Extent of priority habitats overlying peat
- Extent of deep and shallow peat that underlies priority habitat
- Priority habitats and their proportion overlying peat
- Extent of non-priority habitats overlying peat

Priority Habitat Coverage

The overall extent of priority habitats, including Wood Pasture and Parkland (WPP), in England is 1,997,537 hectares. This takes account of the removal of overlapping habitat polygons.

A full breakdown of priority habitat coverage is found in Appendix 1, Table 1.

About 80% of the full extent of priority habitats is comprised of 5 types – see Figure 6; deciduous woodland, blanket bog, upland heathland, coastal and floodplain grazing marsh (CFGM) and wood pasture and parkland (WPP). However, it is noted that Natural England has fairly low confidence in whether the national deciduous woodland dataset accurately reflects the full extent of priority woodland habitats; and of course this habitat type covers at least six woodland types, as noted at Chapter 3 - Stage 4.

As noted at Chapter 2, CFGM is a dataset that is subject to internal review by Natural England and a refined definition and habitat map is expected in 2024.

The WPP layer used in this study excludes other priority habitat types (see Chapter 3, Stage 2) and so the actual habitats present on the ground (woodland, grassland, cropland, amenity parkland) may have limited current nature conservation value.

The area covered by the “top 5” priority habitats is shown at Figure 6.

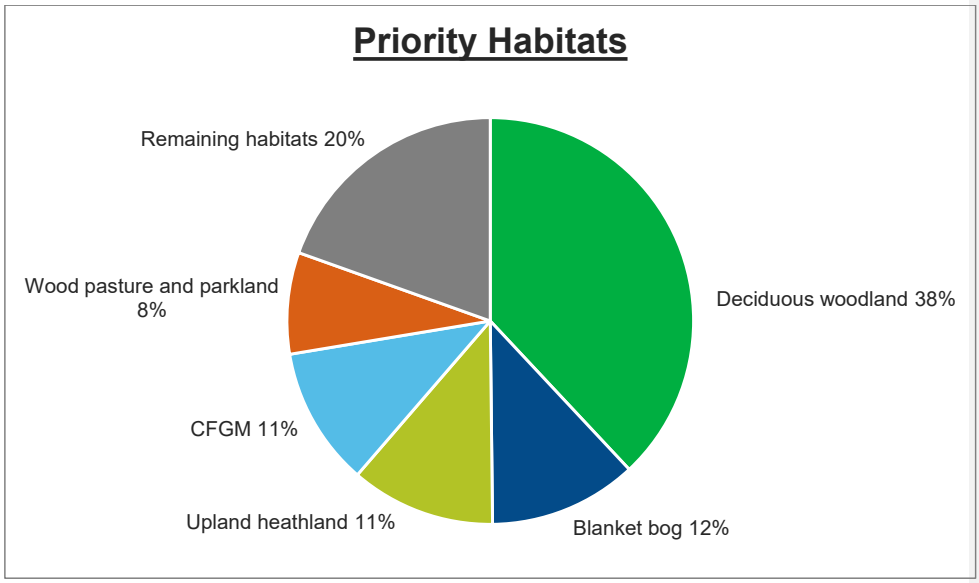

Figure 6. Breakdown of priority habitat types by proportion of the total Priority Habitat Inventory

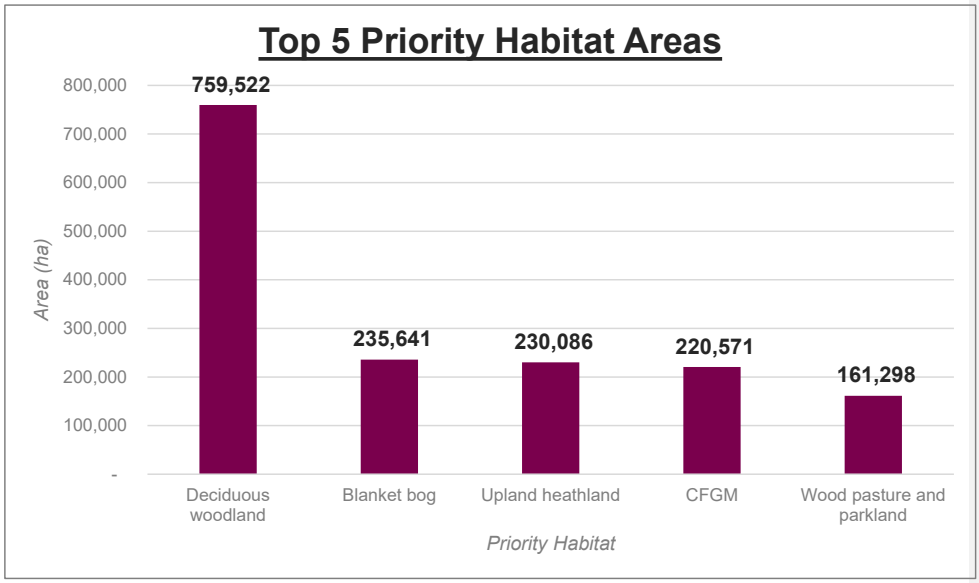

Figure 7. Coverage of "top 5" priority habitats (hectares)

Non-Priority Habitat Coverage

The overall extent of selected non-priority habitats in England is 420,633ha, broken down as shown at Figure 8. Details are at Appendix 1, Table 2. This takes account of the removal of overlapping habitat parcels. In respect of the study's aim of identifying habitats that could be managed to deliver nature and carbon outcomes in tandem, the extent of grass moorland is notable, as this habitat is often located close to blanket bog and other upland carbon-rich priority habitats – see Figure 5 at Chapter 3, for example.

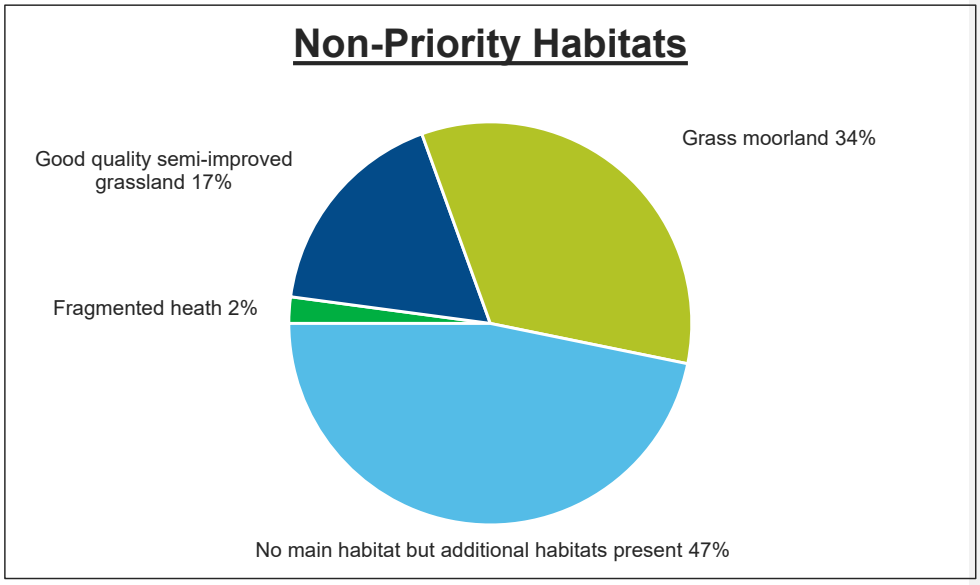

Figure 8. Breakdown of selected non-priority habitats

Priority Habitats Overlying Peat

26.5% of all priority habitats overlie deep and shallow peaty (carbon-rich) soils. Of the 1,997,537ha of priority habitats across England;

- 354,212ha are underlain by deep peaty soils (17.7% of all priority habitats);
- 175,209ha are underlain by shallow peaty soils (8.8% of all priority habitats);
- 82,099ha on are soils with peaty pockets (4.1%);
- 1,386,015ha are not located on peaty soils (69.4%).

Table 2 lists priority habitats where >5,000 hectares overlie deep or shallow peat, together with the proportion of the nationwide extent of the priority habitat that overlies deep or shallow peat.

A full breakdown of priority habitat coverage in relation to the peaty soils dataset is found in Appendix 1, Tables 3 and 5.

Table 2. Priority habitats in terms of extent overlying deep and shallow peat

Priority Habitat	Area over Deep & Shallow Peat (ha)	Proportion of the priority habitat that overlies Deep & Shallow Peat (%)
Blanket bog	229,957	97.59%
Upland heathland	182,616	79.37%
CFGM	40,998	18.59%
Deciduous woodland	25,024	3.29%
Lowland raised bog	11,973	96.21%
Upland flushes, fens and swamps	9,564	74.24%
Lowland fens	7,340	36.82%
Lowland heathland	5,742	10.54%
All other PHI	16,208	N/A
Total PHI	529,422	26.50%

The peaty soils data totals 1,207,118ha, made up of 679,925ha of deep peat and 527,193ha of shallow peat. Of this, only 529,422ha is covered by existing priority habitats 354,213ha and 175,209ha for deep and shallow peat respectively.

Of the peat covered by existing priority habitats, blanket bog and upland heathland dominate, with a coverage of 43% and 34% respectively.

If we are to look at deep and shallow peat separately however (see Tables 3 and 5, Appendix 1 for a full breakdown), then blanket bog makes up 60% of all deep peat underlain existing priority habitats – whilst upland heathland makes up just 10%.

Upland heathland however covers 75% of all shallow peat underlain existing priority habitats, whereas blanket bog covers just 10% of such.

Other habitats which are a significant (>5%) proportion are CFGM and deciduous woodland – see Table 3.

Table 3. Deep and shallow peaty soils underlying priority habitats

Priority Habitat	Area of habitat on Deep & Shallow Peat (ha)	% of Total Deep & Shallow Peat that underlies Priority Habitat
Blanket bog	229,957	43%
Upland heathland	182,616	34%
CFGM	40,998	8%
Deciduous woodland	25,024	5%
All other priority habitats	50,827	10%

Table 4 shows the priority habitats where a significant proportion (>25%) of their geographical extent is underlain by deep and shallow peat. Unsurprisingly lowland raised bog, and various upland priority habitats are exclusively or predominantly found over peat. 37% of lowland fens, 33% of purple moor grass and rush pastures, and 27% of reedbeds overlie deep peat.

Table 4. Priority habitats with large shares of underlying peat

Priority Habitat	Deep Peat (ha)	Shallow Peat (ha)	Deep & Shallow Peat (%)
Mountain heaths and willow scrub	446	1,040	99%
Blanket bog	212,482	17,476	98%
Lowland raised bog	11,762	210	96%
Upland heathland	52,259	130,356	79%
Upland flushes, fens and swamps	4,108	5,456	74%
Lowland fens	6,054	1,286	37%
Purple moor grass and rush pastures	2,175	1,317	33%
Reedbeds	1,167	2	27%

Non-Priority Habitats Overlying Peat

Of the 420,664ha of non-priority habitats included in this study;

- 46,345ha are underlain by deep peaty soils (11.02%);
- 79,264ha are underlain by shallow peaty soils (18.84%);
- 13,595ha on are soils with peaty pockets (3.23%);
- 281,430ha are not located on peaty soils (66.91%).

Thus 29.86% of all non-priority habitats overlie deep and shallow peaty (carbon-rich) soils. The great majority is grass moorland, of which 99,007 hectares overlie deep and shallow peat. Details are at Appendix 1, Tables 4 and 6

5. Carbon Storage and Sequestration in Habitats

This chapter reports on methodological stages 4 and 5 i.e. the estimation of habitat carbon (storage and sequestration) in priority and selected non-priority habitats in England. Results are summarised under the following headings.

- Habitat Carbon Storage Values and Range, per hectare
- Consideration of peat in generating typical habitat carbon storage values
- Carbon in Nature - Storage
- Carbon in Nature – Sequestration

Habitat Carbon Storage Values and Range, per hectare

Carbon storage values and carbon sequestration rates, per hectare, including soil and vegetation estimates, upper and lower ranges, confidence levels and the typical value generated for this study are presented in full at Supplement 1. Appendix 2, Tables 7 and 8 provide an expanded version of the data below, including confidence limits.

Table 5 summarises carbon storage estimates per habitat. The typical value is used as the basis for estimating nationwide carbon storage in priority habitats – see Chapter 6.

Figure 9 displays the data in chart format. As the very high values for lowland raised bog affect the legibility of the chart, Figure 10 excludes this and displays the data for all the other habitats to improve legibility.

Table 5. Carbon Storage Estimates for priority and non-priority habitats

Priority Habitat * denotes non-priority habitat	Upper Carbon Storage Value t C ha^{-1}	Lower Carbon Storage Value t C ha^{-1}	Typical Carbon Storage Value t C ha^{-1}
Blanket bog	619	354	525
Calaminarian grassland	0	0	0
Coastal and floodplain grazing marsh	109	109	109
Coastal saltmarsh	713	113	393
Coastal sand dunes	23	5.6	14.5
Coastal vegetated shingle	0	0	0
Deciduous woodland (old)	517	149	354
Deciduous woodland (young)	377	130	255
Fragmented heath *	87	87	87
Good quality semi-improved grassland *	69	33	60
Grass moorland *	87	87	87
Limestone pavement	0	0	0
Lowland calcareous grassland	69	69	69
Lowland dry acid grassland	87	87	87
Lowland fens (not on deep peat)	259	76	168
Lowland heathland	112	90	100
Lowland meadows	69	33	60
Lowland raised bog	2530	810	1610
Maritime cliff and slope	87	87	87
Mountain heaths and willow scrub	112	90	100
Mudflats	356	13	132
No main habitat but additional habitats present *	69	69	69
Purple moor grass and rush pastures	87	87	87
Reedbeds	259	76	168
Saline lagoons	0	0	0
Traditional orchard	341	56	95
Upland calcareous grassland	69	69	69
Upland flushes, fens and swamps	268	251	259
Upland hay meadow	69	33	60
Upland heathland	112	90	100
Wood pasture and parkland	341	56	95

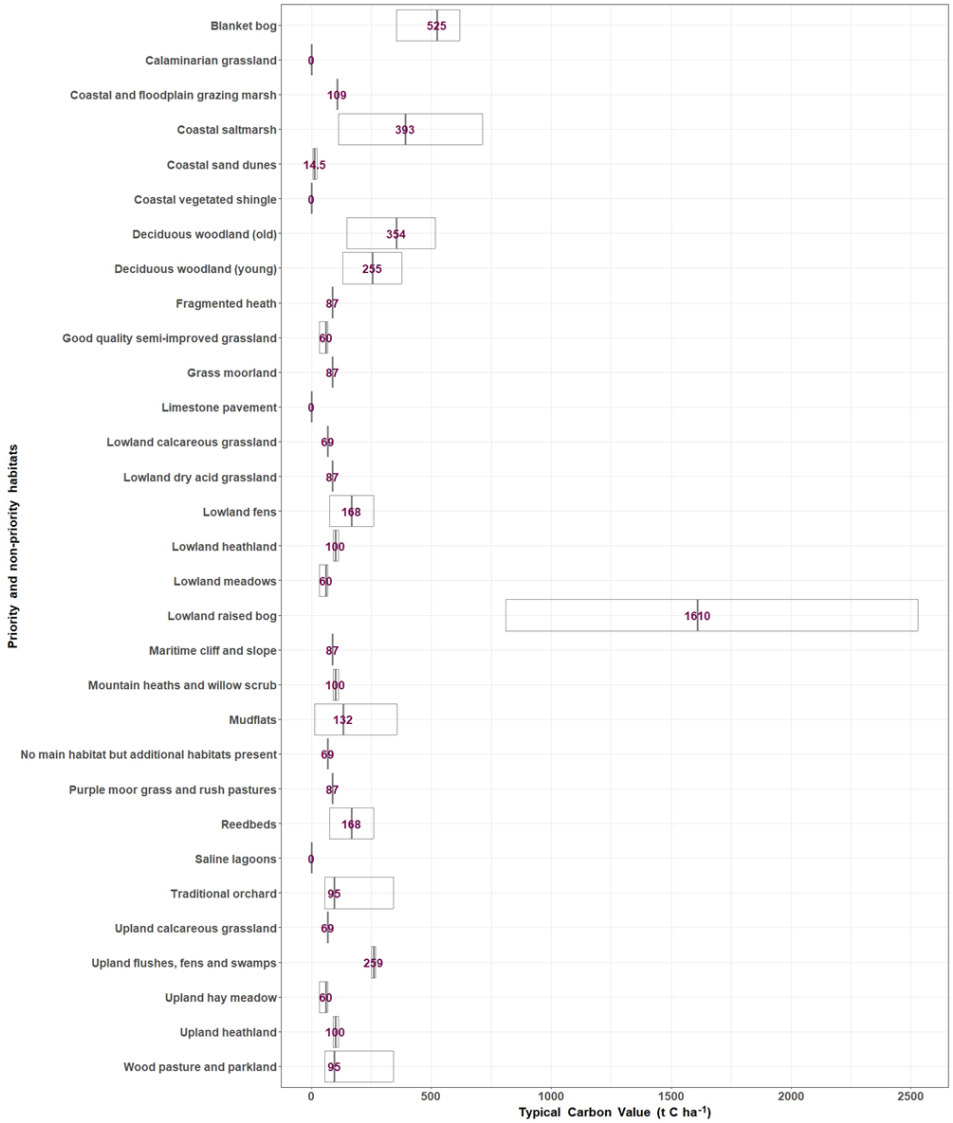

Figure 9. Priority and non-priority habitat typical carbon values, inclusive of upper and lower limit ranges

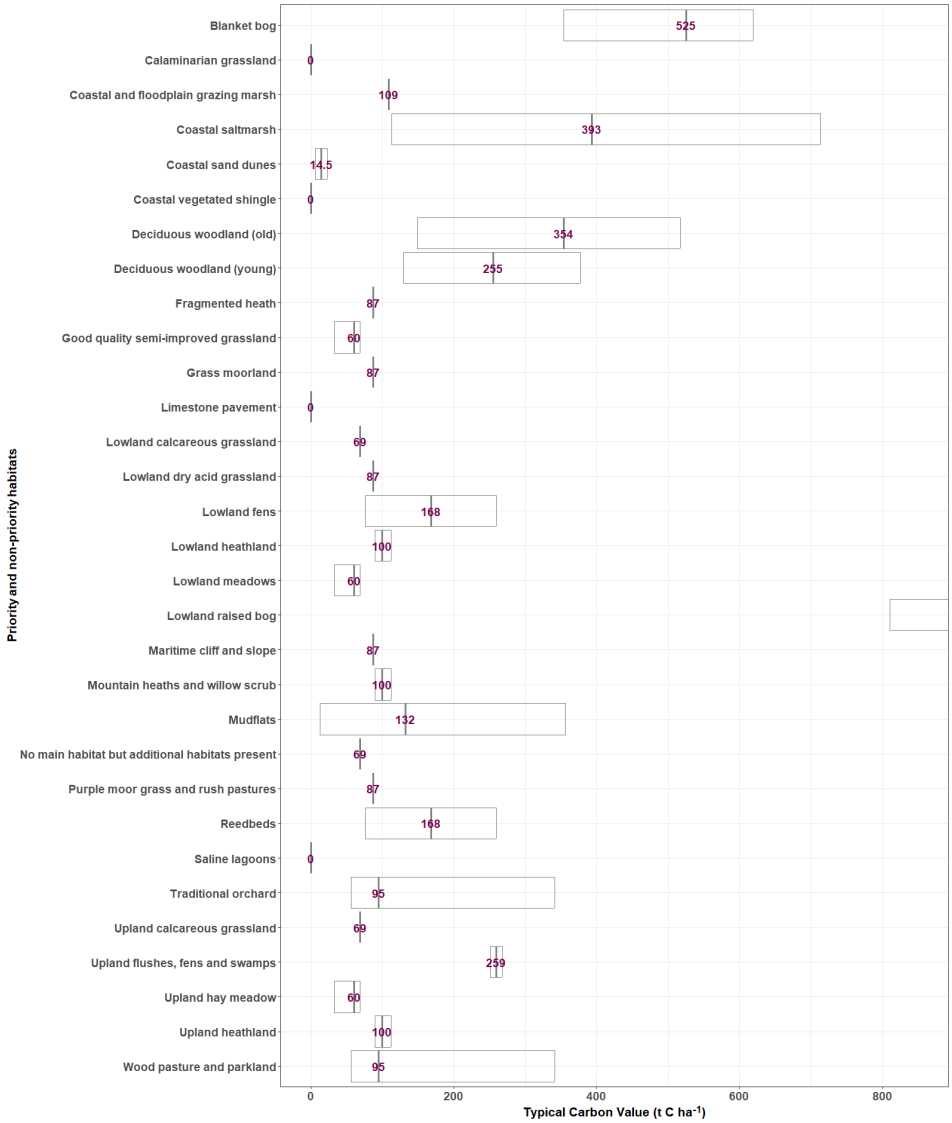

Figure 10. Priority and non-priority habitat typical carbon values, inclusive of upper and lower limit ranges shown to a limited extent.

Consideration of peat in generating typical habitat carbon storage values

The current priority habitat classification has limitations when assessing carbon in habitats. Although the PH Inventory is an extremely useful data set for use in this work, its habitat classifications are based on the vegetation component, found above ground.

Much carbon is stored below ground and especially in peat soils. Thus, understanding both the above and below ground carbon components is essential e.g. heathland on peaty soils will have more carbon stored than the same habitat on thin inorganic soils.

Adjusting Carbon Storage per hectare values

Table 6 adjusts the approach to selected priority habitats that overlie peat by stratifying carbon storage depending on peat depth, using the three bandings in the peaty soils dataset (deep, shallow, peaty pockets). This allows for refinement of the typical total carbon storage values by consideration of peat.

The typical carbon storage value (column 2) is estimated from the literature review as described at Chapter 3 – Stage 4.

Where the PHI coincides with the peaty soils dataset for deep, shallow and peaty pockets, the carbon storage value was adjusted to the values in columns 3,4 and 5 respectively. Where the PHI does not overlie the peaty soils dataset, the carbon storage value in column 6 was used. The adjustments in columns 3 to 6 were made by reference to typical or lower range estimates for the habitat in question (or analogous habitats) derived from the literature review; and were agreed with Natural England's Senior Scientific Specialist (Climate Change).

For example a storage value of 132 t C ha^{-1} can be derived from Baggaley and others (2021) for wet heath over shallow peat in Scotland (peat depth <30cm) and can be extrapolated to use on analogous habitats and peat depths in Table 6 below.

For lowland fens, the typical value is based on lowland fens over mineral soils. A storage value of 1,971 t C ha^{-1} for deep peats was derived from Evans and others (2017) based on an average store of 11.3 t C ha^{-1} per centimetre of peat depth and a mid-range depth of 175cm.

In the case of lowland raised bog, it can be safely inferred that all incidences of it in the PHI relate to actual deep peat, even where the peaty soils dataset does not coincide exactly with lowland raised bog. Thus the same value is used for all lowland raised bogs.

Table 6. Adjusted carbon storage values on priority habitats relevant to peat (t C ha^{-1})

Priority Habitat	Typical Carbon Store	Carbon Store over Deep Peat	Carbon Store over Shallow Peat	Carbon Store over Peaty Pockets	Carbon Store where habitat not over Peat
Blanket bog	525	525	132	132	100
Lowland fens	168	1971	168	168	168
Lowland heathland	100	525	132	100	100
Lowland raised bog	1610	1,610	1610	1610	1610
Reedbeds	168	1,971	168	168	168
Upland flushes, fens and swamps	259	525	259	132	100
Upland heathland	100	525	132	132	100

Appendix 2, Table 11 contains carbon storage estimates, per hectare, for priority habitats when considering peat as described earlier.

Adjusting Total Carbon Storage Values to consider peat

The effect of adjusting nationwide carbon storage values considering peat is shown at Table 7. The total estimate of carbon store for priority habitats in England increases to 517,732,004t C - an increase of 31,814,224t C, or 6.5%, compared to the estimate based on typical storage values. Appendix 2, Table 12 provides total carbon storage estimates for priority habitats in England, adjusted to consider peat. Appendix 2, Table 13 shows the share of carbon storage across priority habitats.

This method allows more weight to be given to the presence and depth of peat underlying priority habitats when estimating their carbon storage value. For example, the typical storage value for lowland fens (168 t C ha^{-1}) is based on non-existent or relatively shallow peat, whereas a significant area (6,054 hectares – refer to table 4) overlies deep peats. When these deep peats are included at the higher carbon storage value of 1,971 t C ha^{-1}, the carbon storage estimate for lowland fens rises significantly.

The carbon storage value for blanket bog decreases, because the typical value is based on an assumption that all blanket bog lies on deep peat, whereas Table 4 shows at least 17,476 hectares overlies shallower peats.

Table 7. Priority habitats overlying peat – adjusted total carbon store when considering peat depths

Priority Habitat	Total Storage based on typical estimates t C	Storage with Peat Consideration t C	Total Value Change t C
Blanket bog	123,711,683	114,486,899	-9,224,784
Lowland fens	3,348,923	14,264,103	+10,915,179
Lowland heathland	5,446,103	6,013,157	+567,054
Lowland raised bog	20,035,888	20,035,888	0
Reedbeds	719,557	2,822,873	+2,103,316
Upland flushes, fens and swamps	3,336,573	3,909,941	+573,368
Upland heathland	23,008,613	49,888,704	+26,880,091
All priority habitats	485,917,779	517,732,004	+31,814,224

Carbon in Nature - Storage

All carbon storage values reported in the following narrative refer to carbon storage values considering peat, unless otherwise specified. As Table 8 indicates, about 518 million tonnes carbon is stored in England's priority habitats.

About 31 million tonnes carbon is stored in the non-priority habitats also included in this study (fragmented heath, good quality semi-natural grassland grass moor, no main habitats but other habitats present) – see Appendix 2, Table 14 for details of storage in each habitat.

Table 8 also shows the total estimates based on the typical estimates of carbon storage, but it is believed the value considering peat is a better representation of carbon in priority habitats.

Table 8. Carbon storage values within priority and non-priority habitats

	Total Storage using typical estimates (t C)	Total Storage considering peat (t C)
Priority Habitats	485,917,779	517,732,004
Non-Priority Habitats	31,079,832	31,079,832

67% of all carbon stored in priority habitats is attributed to just 2 priority habitats - deciduous woodland (231,274,397t C) and blanket bog (114,486,900t C). Refer to Figure 11. As noted earlier, the deciduous woodland grouping in fact consists of 6 UK BAP priority habitats.

The dominance of these habitats in terms of carbon storage can be attributed to a combination of a high carbon storage value per hectare and their large spatial extents.

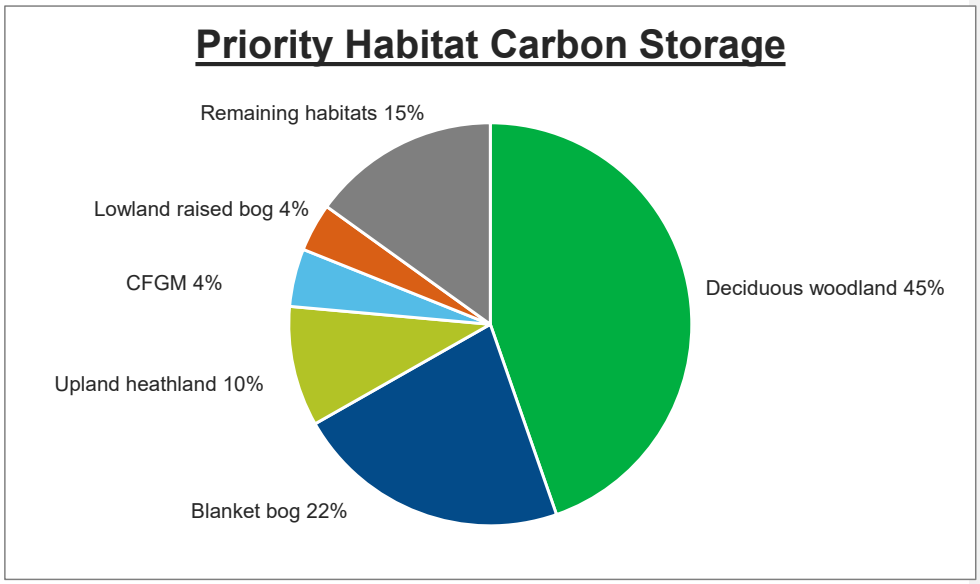

Figure 11. Carbon storage share per priority habitat, based on typical values with a consideration for peat

Carbon in Nature - Sequestration

England's priority habitats are estimated to have a net sequestration rate of about 7.3 million tonnes CO_2 equivalent per year, based on the typical estimates for each habitat included in the dataset. Note that 8 priority habitats, including wood pasture and parkland, do not have data on sequestration. Details are found at Appendix 2, Table 9 for sequestration rates per hectare and Appendix 2 Table 15 for the total estimated annual sequestration by habitat.

Table 9 shows the upper and lower ranges in sequestration estimates and the typical rate used for this study. Positive values indicate net emissions of carbon to the atmosphere.

Table 9. Carbon sequestration rates for priority habitats for which data is available

	Total Lower t CO_2e y^{-1}	Total Upper t CO_2e y^{-1}	Total Typical t CO_2e y^{-1}
Priority Habitats	+3,444,447	-14,985,898	-7,324,960

The net sequestration rate is primarily due to the deciduous woodland grouping of priority habitats. Net sequestration occurs in the following habitats:

- Deciduous woodland: -8,164,860 t CO_2e y^{-1}
- Coastal saltmarsh: -188,611 t CO_2e y^{-1}
- Traditional orchard: -53,592 t CO_2e y^{-1}
- Coastal sand dunes: -22,945 t CO_2e y^{-1}

Net emissions, totalling 1,105.048 t CO_2e y^{-1} are estimated for the other priority habitats in the analysis.

The above rates use the typical estimates, and as noted at Chapter 3 (Stage 5) actual sequestration / emission rates will vary from site to site, depending on local conditions.

While sequestration data for non-priority habitats is appended (see Appendix 2, Table 10), it should be noted that these were assumed generally to be grasslands or heathlands in a “steady-state” with no net sequestration / emission.

6. Habitat Carbon in Ecologically Protected Sites

Carbon Storage in Priority Habitats

Collectively priority habitats within England's SSSIs store an estimated 215 million tonnes of carbon – see Table 10 column 3, which uses the carbon storage values adjusted to consider peat.

Table 10 also shows the carbon storage in various categories of ecologically protected sites, all of which are also SSSI's. The additional designations often also overlap.

Appendix 3, Table 16 provides more details of lower, upper and typical storage values for ecologically protected sites.

Table 10. Carbon storage in priority habitats within statutory designated sites

Designation	Total Storage using typical estimates (t C)	Total Storage considering peat (t C)
All SSSIs	189,983,110	215,119,551
Ramsar Sites	*32,162,450*	*37,991,092*
Special Protection Areas	*116,500,104*	*134,444,149*
Special Areas of Conservation	*140,199,977*	*158,017,933*
National Nature Reserves	*24,983,587*	*29,667,493*

Carbon Sequestration in Priority Habitats

Collectively, priority habitats in England's SSSIs are net carbon emitters, with an estimated flux of 447,039 tonnes CO_2 equivalent per year through oxidation of soils and litter releasing carbon dioxide to the atmosphere – see Table 11. This is due to the large area of peat-based habitats in the SSSI network, which are net emitters due to generally being in degraded condition. Continued restoration work, including re-wetting will bring reduction, or abatement of baseline emissions.

Ramsar sites are the only category of protected site which has a net sequestration of carbon due to its priority habitats. Net sequestration in Ramsar sites, based on the typical estimates per habitat, is -157,680t $CO_2e\ y^{-1}$. This net sequestration may be attributed to the relatively high proportion of coastal saltmarsh in Ramsar sites, and the limited cover of significant "net emitter" habitats.

All other categories of designated sites have net emissions arising from their priority habitats.

Appendix 3, Table 17 provides more details of lower, upper and typical sequestration rates for ecologically protected sites.

Table 11. Carbon sequestration rates from priority habitats in statutory designated sites, based on typical estimated sequestration rates

Designation	Total Sequestration (t CO2e yr-1)
All SSSIs	447,039
Ramsar Sites	*-157,680*
Special Protection Areas	*195,455*
Special Areas of Conservation	*111,108*
National Nature Reserves	*92,378*

7. Habitat Carbon in Landscape Designations and National Character Areas

Designated Landscapes

This work identifies how important England's designated landscapes are for carbon in nature. England's National Parks (10% of England) and National Landscapes (15% of England) store about 259 million of carbon within their priority habitats. This is about 50% of the carbon stored in all of England's priority habitats.

441,902ha of priority habitats are found within England's National Parks and 479,674ha within National Landscapes (formerly Areas of Outstanding Natural Beauty).

About 259 million tonnes of carbon is stored by priority habitats in the designated landscapes – see Table 12. This equates to 24% and 26% of all carbon stored in England's priority habitats in National Parks and National Landscapes respectively.

Table 12. Carbon storage values for priority habitats in designated landscapes

Designation	Total Storage using typical estimates (t C)	Total Storage considering peat (t C)
National Park	113,553,834	125,618,082
National Landscapes	125,879,635	133,540,927
Total	239,433,469	259,159,009

Priority habitats in National Parks sequester 491,885t CO_2e y^{-1} and in National Landscapes, 1,546,756t CO_2e y^{-1} when applying typical sequestration rates – see Table 13. This equates to, respectively, 7% and 21% of all carbon sequestered in England's priority habitats. The high figure for National Landscapes is due to their more wooded character, compared to National Parks with National Parks being more upland located with higher amounts of peat.

Table 13. Annual Carbon sequestration by priority habitats in designated landscapes

Designation	Total Sequestration t CO_2e y^{-1}
National Park	-491,885
National Landscapes	-1,546,756
All Designated Landscapes	-2,038,641

National Parks

Carbon Storage

Details of carbon storage in priority habitats in National Parks are found at Appendix 4, Table 20.

Of all England's National Parks, the Yorkshire Dales has the largest individual carbon store in its priority habitats; with an estimated 30 million tonnes – see Table 14. This is about a quarter of the carbon stored in priority habitats across all England's National Parks. This is due to its large area and the high proportion of its priority habitats overlying peat.

Figure 12 displays the carbon storage in the Yorkshire Dales NP, using a colour band where dark blue represents highest carbon in store.

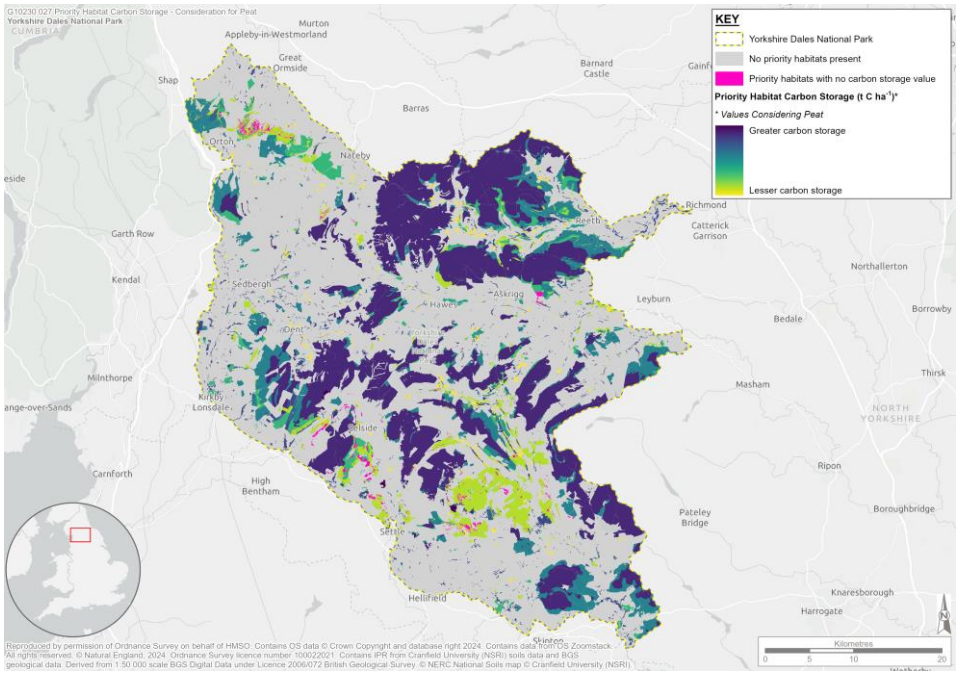

Figure 12. Yorkshire Dales National Park - priority habitat carbon storage per hectare. Reproduced by permission of Ordnance Survey on behalf of HMSO. Contains OS data © Crown Copyright and database right 2024. Contains data from OS Zoomstack. All rights reserved. © Natural England, 2024. Ordnance Survey licence number 100022021. Contains IPR from Cranfield University (NSRI) soils data and BGS geological data. Derived from 1:50 000 scale BGS Digital Data under Licence 2006/072 British Geological Survey. © NERC.National Soils map © Cranfield University (NSRI). Esri UK, Esri, TomTom, Garmin, FAO, NOAA, USGS.

Table 14. Carbon storage values for priority habitats in England's National Parks

National Park	Total Storage using typical estimates (t C)	Total Storage considering peat (t C)
Dartmoor	11,928,626	12,340,048
Exmoor	4,272,566	4,796,637
Lake District	15,311,336	16,780,747
New Forest	6,241,515	6,290,875
North York Moors	7,485,066	10,447,191
Northumberland	8,885,113	10,298,693
Peak District	17,687,460	19,271,902
South Downs	9,637,743	9,887,209
The Broads	2,420,094	5,444,824
Yorkshire Dales	29,684,316	30,059,956

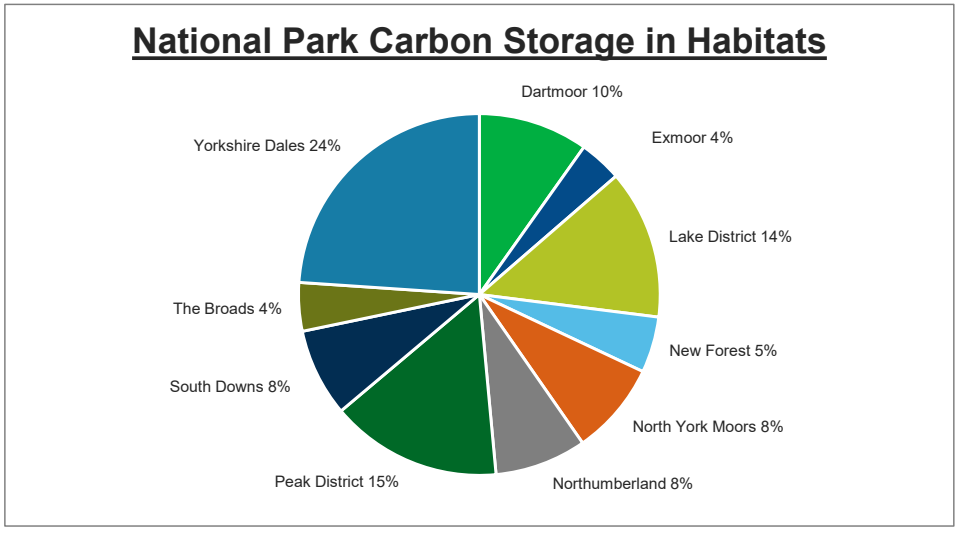

Figure 13. Carbon storage share across England's National Parks, based on typical values with a consideration for peat

Carbon Sequestration

Details of carbon sequestration in National Parks are found at Appendix 4, Table 21. The South Downs National Park sequesters the greatest amount of carbon within its priority habitats, estimated at around 287,092 t CO_2e y^{-1}. By contrast, the Yorkshire Dales is the largest carbon emitter at around 139,062 t CO_2e y^{-1}. Refer to Table 15.

Table 15. Annual carbon sequestration within England's National Parks

National Park	Total Sequestration (Typical) t CO_2e y^{-1}
Dartmoor	-12,535.39
Exmoor	-42,936.70
Lake District	-86,704.88
New Forest	-135,588.48
North York Moors	-92,527.20
Northumberland	24,797.36
Peak District	21,823.45
South Downs	-287,092.50
The Broads	-20,183.33
Yorkshire Dales	139,062.55

National Landscapes

Carbon Storage

Details of carbon storage in priority habitats in National Landscapes are found at Appendix 4, Table 22.

The North Pennines NL supports the largest priority habitat carbon store of England's National Landscapes, totalling 45,064,403t C, based on storage values that consider peat – this is equivalent to 34% of all carbon stored within priority habitats across the National Landscapes.

As Figure 14 indicates, this is by far the largest carbon store amongst National Landscapes. This is mostly due to its large size, coupled with the extent of upland habitats. The High Weald and the Cotswolds are examples of well-wooded National Landscapes that store large quantities of carbon within deciduous woodland priority habitats.

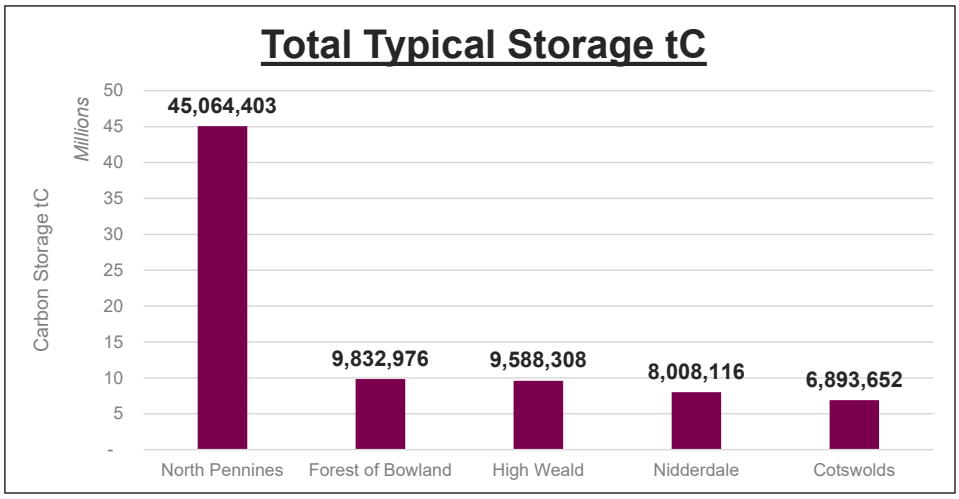

Figure 14. Top 5 National Landscapes with the greatest amount of carbon storage, with a consideration for peat

Carbon Sequestration

Details of carbon sequestration in priority habitats in National Landscapes are found at Appendix 4, Table 23.

The High Weald also sequesters the most carbon amongst National Landscapes, based on typical values, annually sequestering an estimated 311, 721t $CO_2e\ y^{-1}$. See Figure 15.

This is due to its extensive cover of priority deciduous woodland, and relative lack of degraded net-emitter habitats such as deep peats and fens.

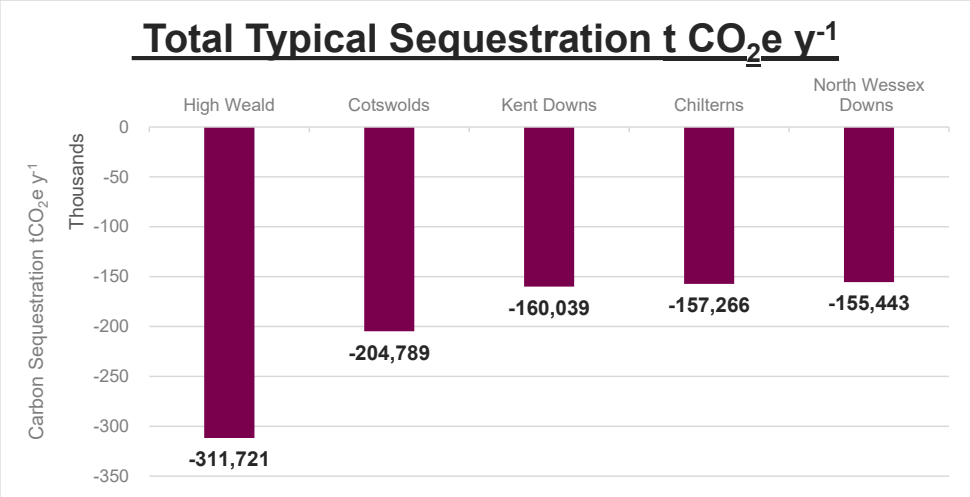

Figure 15. Top 5 National Landscapes with the greatest amount of carbon sequestration, based on typical values

National Character Areas

Carbon Storage in National Character Areas

Details of carbon storage in priority habitats in National Character Areas are found at Appendix 5, Table 24.

Across England's National Character Areas (NCA), the North Pennines and Yorkshire Dales store the greatest amount of carbon in priority habitats, with values of 45,567,863 tC and 37,686,644 tC respectively, based on carbon storage estimates that consider peat habitats – see Table 16.

This can be attributed to the overall size and extent of blanket bog in these NCAs, making up 64% and 53% of all priority habitat respectively.

Table 16. Top 10 National Character Areas in terms of total carbon storage

National Character Area including national ranking	Total Storage using typical estimates (t C)	Total Storage considering peat (t C)
1 North Pennines NCA	42,691,115	45,567,863
2 Yorkshire Dales NCA	35,304,002	37,686,644
3 Dark Peak NCA	14,988,362	16,755,694
4 Border Moors and Forests NCA	12,061,970	14,822,977
5 Southern Pennines NCA	12,595,165	14,338,951
6 Dartmoor NCA	11,644,610	12,048,766
7 Cumbria High Fells NCA	10,838,992	11,970,252
8 High Weald NCA	11,015,542	11,015,542
9 North York Moors and Cleveland Hills NCA	8,050,695	11,012,832
10 Cotswolds NCA	8,304,370	8,304,370

Figure 16 provides an illustration of carbon storage across the NCA's showing the ten highlighted NCA's, which collectively store about 25% of England's priority habitat carbon.

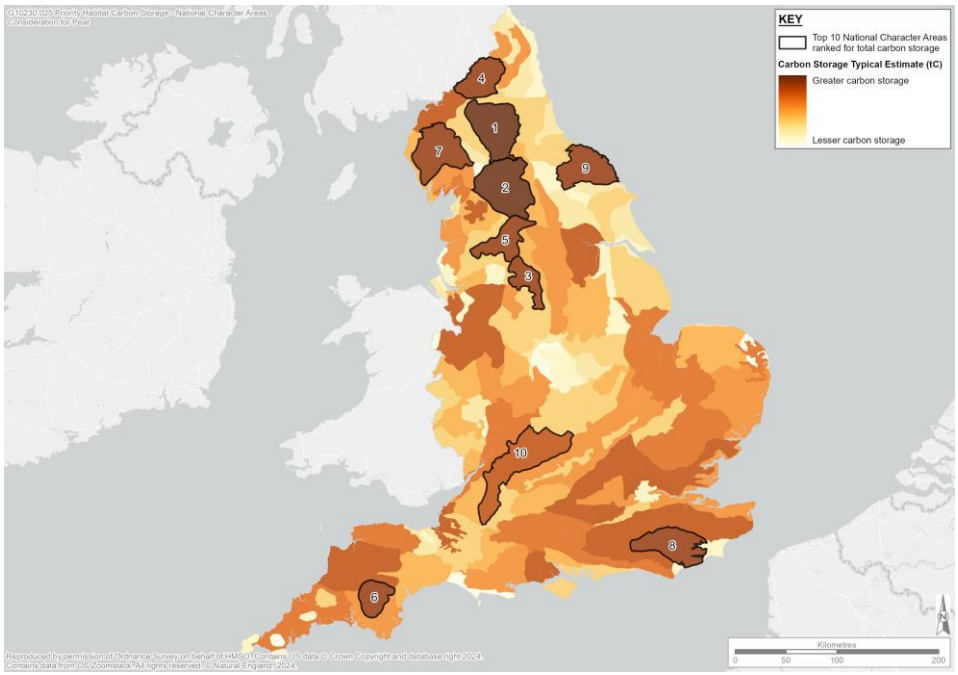

Figure 16. Total Carbon Stored in National Character Areas, based on typical storage values considering peat
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When considering carbon storage "density" measured by t C ha^{-1} in priority habitats across the landscape, Bowland Fells NCA holds the greatest amount of carbon per hectare i.e. 221t C ha^{-1}, as shown at Table 17 and Figure 17.

Table 17. Top 10 National Character Areas with the greatest carbon storage per hectare, based on storage values with a consideration for location on peat

National Character Area	Carbon Storage t C ha^{-1}	Rank
Bowland Fells NCA	221.34	1
North Pennines NCA	212.37	2
Dark Peak NCA	193.47	3
Yorkshire Dales NCA	157.04	4
North Norfolk Coast NCA	144.07	5
Dartmoor NCA	137.85	6
Southern Pennines NCA	119.78	7

National Character Area	Carbon Storage t C ha^{-1}	Rank
Border Moors and Forests NCA	116.57	8
Morecambe Bay Limestones NCA	109.00	9
The Broads NCA	105.36	10

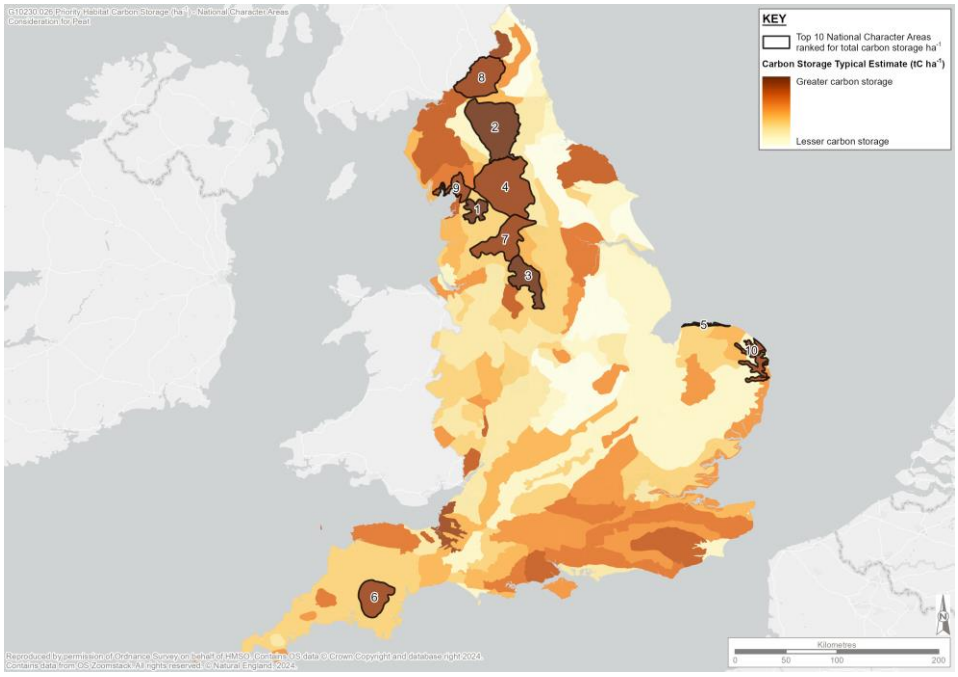

Figure 17. National Character Areas - carbon storage per hectare, based on typical storage values considering peat
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Carbon Sequestration in National Character Areas

Details of carbon sequestration in priority habitats in National Character Areas are found at Appendix 5, Table 25.

National Character Areas currently sequestering the greatest amount of carbon in their priority habitats are clustered in the South East of England, due to the high volume of deciduous woodland present – see Figures 18 and 19.

The Cotswolds is an outlier, although is in the top 5 for NCA carbon sequestration with 58% of all priority habitats present being deciduous woodland. The High Weald sequesters

the greatest amount of carbon, with an estimated 367,026t CO_2e y^{-1}. Morecambe Bay Limestones NCA, have many other habitats beyond it's limestone ones with high areas of Bogs, Woodlands and Coastal Floodplain grazing marsh.

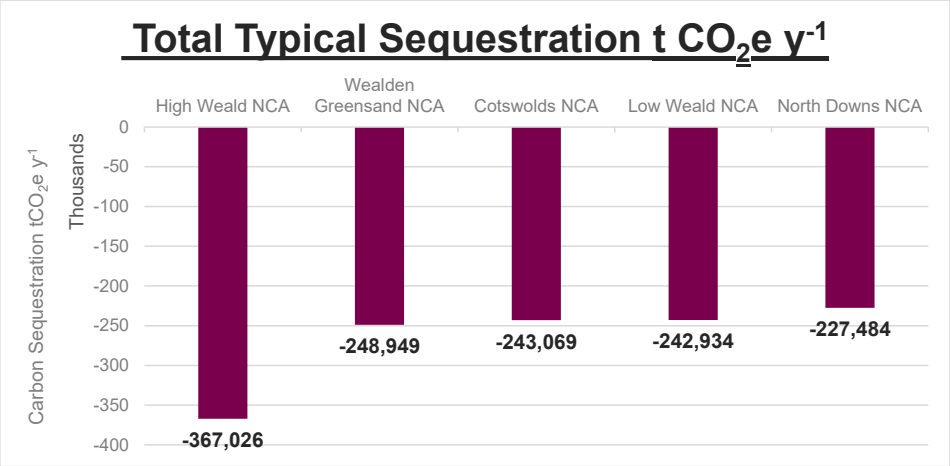

Figure 18. **Top 5 National Character Areas with the greatest amount of carbon sequestration, based on typical rates**

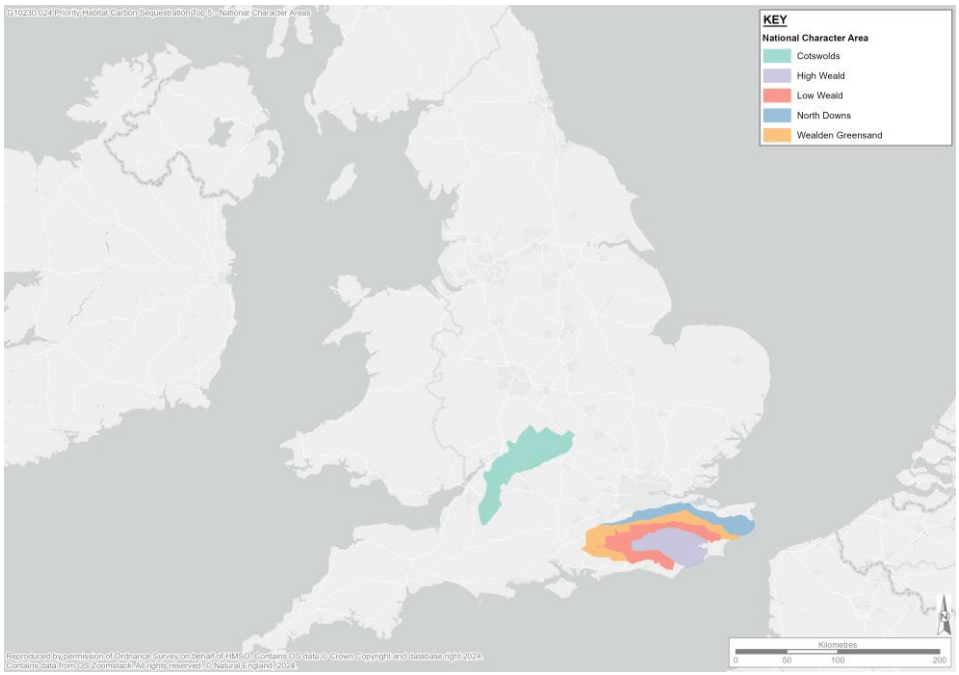

Figure 19. The top 5 National Character Areas with the greatest amount of carbon sequestration, based on typical values
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8. Ranking “Carbon in Nature”

The final output of this research strand was to identify habitats with a high contribution to national carbon storage; the intention being that Natural England would prioritise these in its Nature Net Zero work programmes.

All 26 priority habitats were ranked on the following bases:

- 1 to 26 in terms of total carbon in store, based on the upper range estimate
- 1 to 26 in terms of total carbon in store, based on the lower range estimate
- 1 to 26 in terms of the amount of deep and shallow peat underlying the habitat

An average rank calculated from above three ranks was calculated to identify the ‘top ten’ for carbon storage. The ‘top ten’ habitats for carbon storage, taken forward for further assessment in the project are:

1. Blanket bog
2. Deciduous woodland
3. Upland heath
4. Coastal and floodplain grazing marsh
5. Lowland raised bog
6. Lowland fen
7. Wood pasture and parkland (exc. other priority habitat)
8. Lowland heath
9. Coastal saltmarsh
10. Upland flushes, fens and swamps

Whichever ranking is used, these habitats account for over 90% of all carbon stored in priority habitats in England.

The study also noted that the non-priority habitats grass moorland and no main habitat but additional habitats present have carbon storage estimated values which place them above the lower range estimates for some of the priority habitats “top ten”.

9. Recommendations & Conclusions

This study builds on the excellent compendium of information about carbon in habitats available in Gregg and others (2021) and later studies. A rapid review of the literature, analysis of the Priority Habitats Inventory and correlation with the Peaty Soils Dataset has enabled the following outputs:

- Typical carbon storage estimates per hectare for most priority habitats, including wood pasture and parkland; and for some non-priority habitats which offer potential to restoration to priority types with relatively high carbon storage values. The typical values help to narrow the range between upper and lower carbon store estimates and can be used for high-level analysis and prioritisation of future investment in restoration of habitats for carbon and nature.
- An adjustment of the typical carbon storage values to consider the relative contribution of underlying peaty soils to the carbon store; particularly applicable to certain priority habitats that can overlie deep, shallow or non-peaty soils.
- Narrowing of the large range between upper and lower estimates of carbon stored in the deciduous woodland priority habitat, by stratification of this aggregated dataset into age classes. However it is hoped that future evolution of the PHI will enable a full stratification into the six component woodland habitats and more specific carbon-storage estimates for each type, so the age-class stratification method used in this study can fall away.
- A “digitally-cleansed” version of the Priority Habitats Inventory suitable for a range of geographic analyses. The cleansing has involved removal of polygon overlaps and assignation of multiply-coded polygons to a dominant habitat.
- A national dataset of habitat carbon storage values and sequestration rates for all priority habitats, including wood pasture and parkland.
- Summaries of habitat carbon storage values and sequestration rates across a range of geographies, including ecologically protected sites (SSSI, SAC, SPA, Ramsar, NNR), designated landscapes (National Parks and National Landscapes) and National Character Areas. The dataset could be used for other geographies not explored in this study e.g. local authority administrative areas, river catchments.
- A ranking of 26 habitats and a shortlist of ten habitats most important for safeguarding of existing carbon stores and increasing the net sequestration of atmospheric carbon by habitats, including measures to reduce habitat-based carbon emissions.

The study is founded on the Priority Habitats Inventory (PHI) which has some inaccuracies and older classifications and does not necessarily have detailed data on all priority habitats in all areas of the country due to lack of survey effort. Natural England’s Nature Returns project is a four-year programme running from 2023 to 2026, which is helping to fill the data gaps in the carbon data

It is appreciated that this study has limitations arising from the fact that it is based on a rapid literature review and has not involved any field measurements, and assignment of

typical carbon storage values has been internally tested, rather than externally peer-reviewed.

Nevertheless, accepting these limitations, the study enables the quantification of carbon in habitats and landscapes at an England-wide scale. This means it can form the basis of priority-setting for future research and work programmes for Natural England's Nature Net Zero workstream.

Parts 2 to 4 of the Nature Net Zero research (listed in the introduction to this study) use the data and priorities identified in this report, by:

- Assessing habitat carbon vulnerability and /or sensitivity to climate change (Part 2)
- Identifying scenarios for habitat network enhancement and/or de-fragmentation that would bring benefits to both carbon storage and biodiversity (Part 3)
- Analysis of what types of landscapes would enable ecosystem and carbon restoration (Part 3)
- Recommendations regarding Nature Net Zero pathways to expand carbon in nature (Part 3)
- Analysis of trade-offs between different land-uses and where integrated delivery could deliver habitat carbon and biodiversity enhancement (Part 4)

Commented [FH1]: As per intro - we rolled pt 5 into pt 3

In respect of the outputs specific to Part 1, recommendations for future refinement are:

- Peer review and validation of the typical carbon storage estimates and the adjustment to consider the contribution of peat.
- Ongoing research and literature to fill knowledge gaps, especially in respect of carbon flux (sequestration and emissions) associated with different habitats as this will inform upland management and woodland establishment investment decisions.
- Update of the national PHI dataset, in particular the inclusion of wood pasture and parkland.
- Refinement of the PHI to stratify the deciduous woodland grouping into its component woodland types and assign carbon storage and sequestration values to each.
- Updates to reflect the replacement of Coastal floodplain and grazing marsh with the latest Floodplain wetland mosaic dataset.

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Acronyms and Abbreviations

C – Carbon

CFGM – Coastal floodplain and grazing marsh

CO2 – Carbon dioxide

CO_2e – Carbon dioxide equivalent

PHI – Priority Habitat Inventory

SOM – Soil organic matter

SOC – Soil Organic Carbon

g – gram

t – tonnes

ha – hectare

cm – centimetre

m – metre

m^3 – cubic metre

y – year

< – less than

> – greater than

ONS – Office for National Statistics

FC – Forestry Commission

FR - Forest Research

BAP – Biodiversity Action Plan

NNR –National Nature Reserve

WCC – Woodland Carbon Code

WPP – Wood Pasture and Parkland

Appendices

See Part 1 – Appendices 1 to 5 in separate document

These 25 tables split by different themes and information, that go into more granular detail than in the report above. These are designed to help certain work areas and give clearer information to help other sectors understand their carbon implications in their work, so helping them deliver in a more integrated way by joining up Nature and Net Zero recovery work.

Appendix 1: Baseline Habitats and their Relationship with Peat

Appendix 2: Carbon Storage and Sequestration in Habitats

Appendix 3: Habitat Carbon in Ecologically Designated Sites

Appendix 4: Habitat Carbon in Landscape Designations

Appendix 5: Habitat Carbon in National Character Areas

Supplementary excel files

These spreadsheets collect the underlying data from the GIS processing work in 4 different geographical geographies. They are intended to be used by different sectors, that will want to understand the evidence and analysis process in more detail. In helping to understand the implication on future climate and biodiversity targets such as 30x30 and CBD & Net Zero pathways.

1. Habitats, Carbon Storage and Sequestration
2. Habitat and Carbon in Ecologically Protected Sites
3. Habitats and Carbon in Landscapes Designations
4. Habitats and Carbon in National Character Areas

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