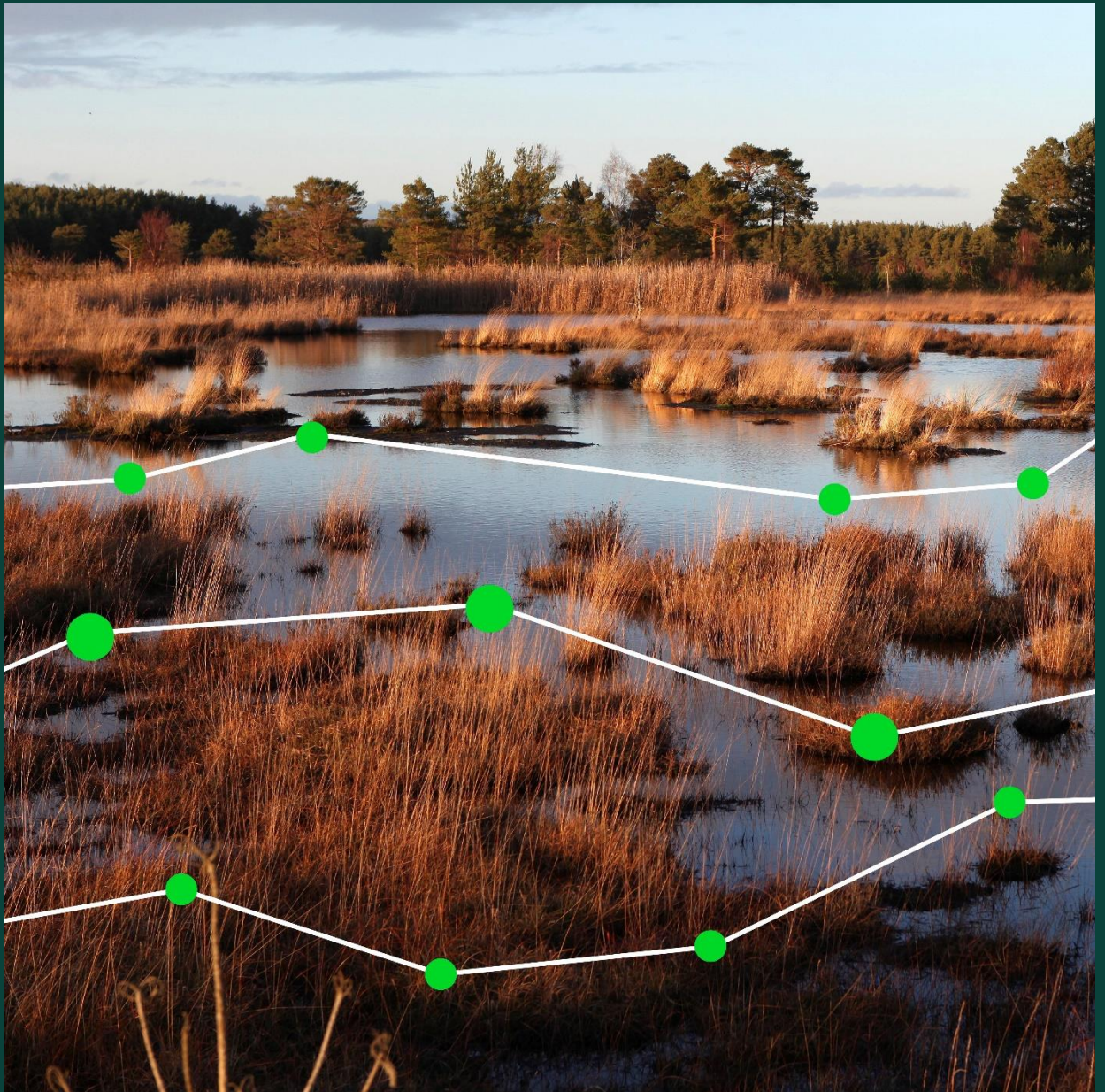


Nature Returns: Field survey methodology for comparative assessment of carbon and biodiversity.

May 2024



nature
returns

A partnership of government departments, charities and organisations working together to build the evidence for nature-based solutions to climate change and biodiversity loss.



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Introduction

This booklet is a guide to the methods that the Natural England Climate Change team are carrying out at the six pilot sites across the UK as part of Nature Returns project. These methods will produce data for baseline assessments at each of the pilot sites before changes in land-use or habitat creation takes place. The carbon stock, sequestration rate and biodiversity of each habitat will be measured through a varied range of methods including soil coring, vegetation surveys, gas flux measurements, woodland surveys and 3D scanning of scrub and hedgerow. Combining all these data alongside other monitoring efforts will enable us to build a detailed individual understanding of each pilot site. Repeated measurements and surveys at these sites will allow us to assess the net carbon losses or gains as well as changes in biodiversity over time as these pilot sites undergo land-use change and habitat creation. These methods are also being used in existing habitats of different ages, on pilot sites and elsewhere, to assess the build-up of carbon and changing gas fluxes in retrospect.

1. Plot Selection and Sampling Design

1.1. Summary

This project involves sampling across a range of different habitats at each of the pilot sites and it is important that the samples taken are representative of these habitats. For relatively large land parcels with homogeneous vegetation, plots are randomly allocated (see section 1.2). Where land parcels contain a range of different habitats within one area, referred to as a mosaic habitat, a variation of this sampling approach is taken (see section 1.3). We aim to allocate soil and vegetation plots adjacent to each other to ensure comparability. Greenhouse gas measurements are more complex and require more replicates, repeated frequently, to build a better picture of sequestration rates (see section 1.4). In woodland habitats, there is more flexibility in the number of locations to take account of variability in the structure of the woodland (see section 1.5).

1.2. Selecting plots in large, homogeneous habitats

For each field or other predetermined section of land, five random GPS locations are selected in advance using QGIS (QGIS Desktop 3.36.1), leaving a 10 m buffer at the parcel boundary to minimise any potential edge effects from adjacent sites or areas of



Figure 1. Example of random plot selection for soil coring and vegetation surveys, made with QGIS.

compaction (e.g. gateways) and a minimum distance of 10 m between plots (Figure 1 and 2). If on arrival at a location there is an obvious anomaly, such as a path, the location is changed to 10 m from the feature and a new GPS location recorded. Plot markers are installed at the centre of each plot to help locate the plot for future field surveys. For soil surveys, cores are taken in triplicate within each of the 5 subplots, resulting in 15 cores taken for each field (Figure 2). By using this approach, we can account for both field scale and plot scale variability (Rowe and others, 2016).

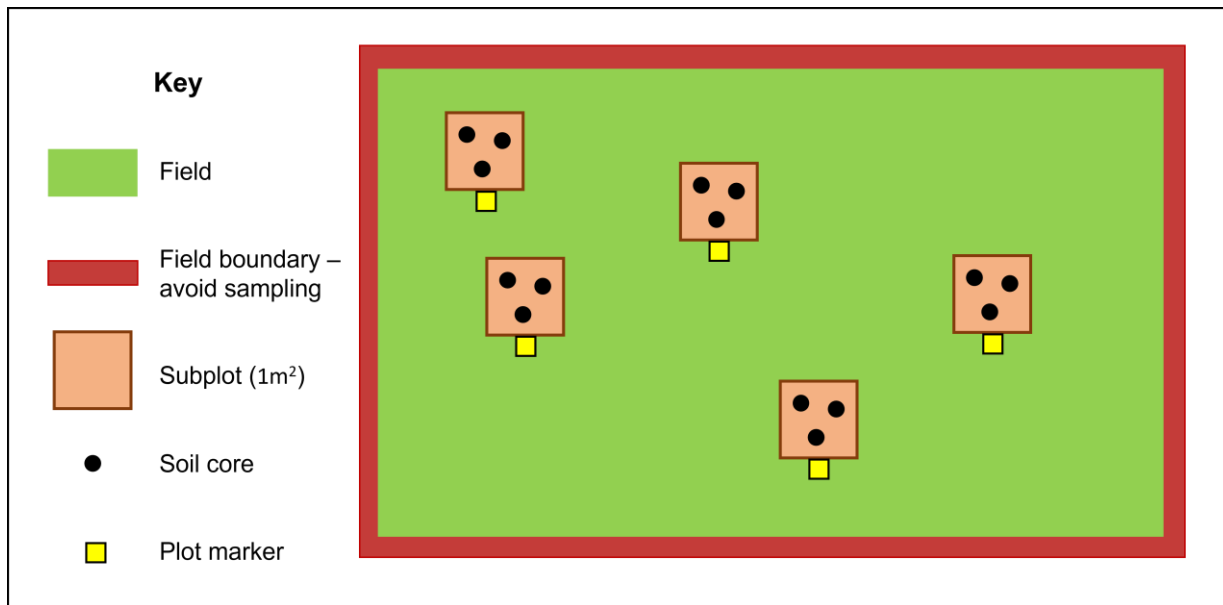


Figure 2. Example of subplots for soil core locations randomly distributed in field with field boundary. Soil cores are taken from the 1 m² located directly north of the plot marker. A vegetation plot would also normally be located next to the soil cores, 2 m south of the plot marker.

1.3. Selecting plots in large, heterogeneous habitats

Some sites contain a range of different habitats within one area; this is known as a mosaic habitat. For example, grassland and scrub may form a mosaic. When sampling across a large mosaic habitat it is important that the samples taken are representative of all the different types of habitats present. Taking a truly randomised approach, as described in section 1.2, would not provide adequate representation. We therefore conduct a stratified randomised sampling approach where habitat mosaics are present to account for their 'patchy' nature, whereas a transect will be used where a gradient between different habitats is present for example in a floodplain mosaic. The type of sampling applied is dependent on the individual site and habitat.

1.3.1. Habitat Mosaics

QGIS is used to draw polygons round each habitat type within a given heterogeneous site (Figure 3). Five randomly located plots are generated within each habitat type through the QGIS geoprocessing tool 'random points within polygons'. The number of points is specified inside polygon features (habitat type). After sampling, an estimate of

the percentage area for each of the different habitats within the mosaic area are calculated within QGIS using the 'measure area tool' to allow us to scale up the carbon stock calculations and biodiversity assessments.



Figure 3. Left: Map of Thornhill, Derbyshire Wildlife Trust, with a mix of different habitats including grassland, scrub and woodland. Polygons are drawn round the different habitats in QGIS. Right: Map of the same area showing the land parcels attributed to the different habitats identified on the left and 5 random plots are generated within each parcel, made with QGIS.

1.3.2. Habitat Gradients

QGIS is used to draw stratified transects using polygons across a habitat gradient (floodplain mosaic for example), which are divided up into habitat type within the transect boundaries. These are identified using GPS points where habitats transition along a transect from an initial site visit, as well as using aerial imagery and the National Vegetation Classification survey of the area. A 10 m buffer around the entire polygon boundary and around each respective transect line is applied using the QGIS 'Buffer' tool.

Five randomly located plots for both soil and vegetation are generated within the stratified transect using the QGIS geoprocessing tool 'random points within polygons'. The total area per habitat type per transect is calculated within QGIS. The number of plots are randomly generated and representative to the overall size of each habitat within a transect.

The number of transects to survey are dependent on the size of the area and the heterogenous habitat. For example, in Figure 4A and Figure 4B, three transects are plotted across a large area with a seasonal fluctuating gradient. The location and direction of the transect angles are perpendicular to the location of the water body to

ensure the full habitat gradient can be surveyed (Rothero and others, 2016). Figure 4A shows an example gradient across grassland to fen, to water body, to fen and then finally grassland.

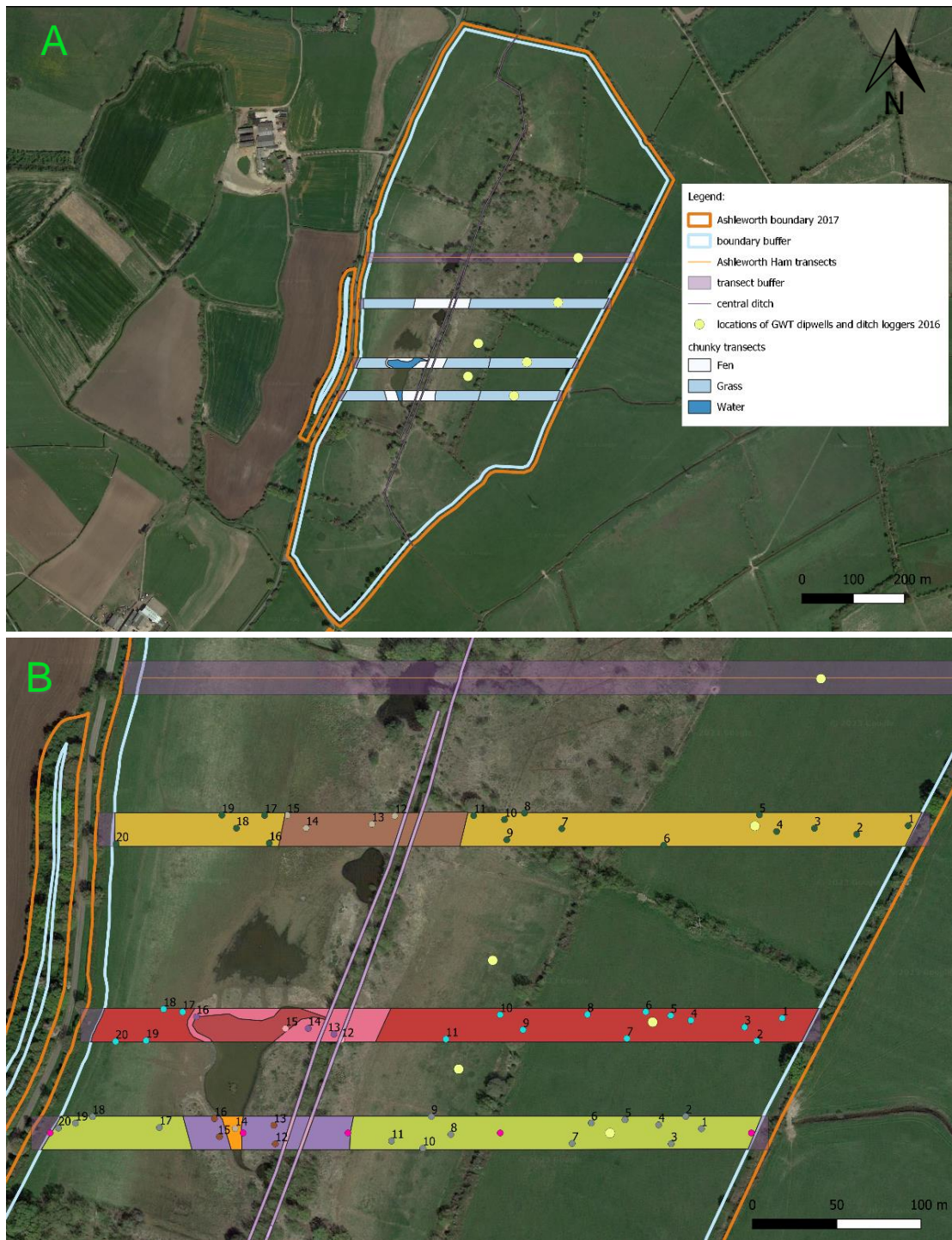


Figure 4. A: Map of stratified transects per habitat type for Ashleworth Ham Nature Reserve, Gloucestershire, Gloucestershire Wildlife Trust (GWT). The areas coloured white, light blue and dark blue indicate the different habitat types along a transect gradient. The buffer zone 10 m each side of the transect line is shown in purple. B: Map of the same area with 20 randomly generated plots according to habitat type per transect for gas flux analysis. The colour of the bottom three stratified transect are according to the habitat type fen, grass, and water as in map A. The pink points on the bottom transect are GPS points where the habitat transition was recorded from the initial site visit. Both: Polygons and plots are generated in QGIS; the light green points show the location of Gloucestershire Wildlife Trust old dip-wells; the orange polygon lines are the overall boundary of the reserve and the blue polygon lines are the 10 m buffer zone inwards.

1.4. Selecting Plots for Gas Flux Analysis

1.4.1. Spatial Approach

Research shows that the spatial variability in gas fluxes can be very high, even in a homogeneous habitat, and therefore require a higher number of replicates than when surveying for carbon stocks or biodiversity (Subke and others, 2021). In homogenous habitats, such as grasslands, a minimum of 20 randomly allocated replicates across the site are selected, this approach both helps to eliminate spatial bias and informs more powerful statistical analysis. In heterogenous habitats, we use the polygons and transects described in sections 1.3.1 and 1.3.2 respectively and allocate a minimum of 20 replicates within each polygon. Sampling points are allocated using the QGIS geoprocessing tool: 'random points within polygons'. At each plot, one measurement is taken with the soil respiration and the clear canopy chamber.

1.4.2. Temporal Approach

Diurnal and seasonal influences must also be considered when surveying environmental gas fluxes (Pumpanen and others, 2010). When working across multiple sites, sampling cannot be carried out as regularly as more concentrated, single site studies. To capture as much seasonal variation as possible, a minimum of four surveys are undertaken throughout the year, ideally at around 3-month intervals. Measurements are carried out throughout daylight hours, excluding an hour post-sunrise and pre-set. This allows data to be collected from a broad range of environmental conditions, specifically the lower light and/or temperatures experienced in winter and outside of peak daylight hours, which are often excluded from studies. The sampling methodology as described in 1.4.1 allows us to sample at high volume and factor in these influences during statistical analysis.

1.5. Selecting plots in Woodlands

Woodland plots are mapped using QGIS based on pre-existing site information and GPS coordinates. The size and uniformity of the woodland parcel determines the number of plots surveyed (Table 1). According to the Woodland Carbon Code (WCC) Assessment Protocol (Jenkins and others, 2018), a stratum/woodland parcel would be considered 'uniform' if it has ALL these features:

- Planted within 3 years and are of similar height (e.g., no more than 4m height difference) AND
- Single species AND
- Planting positions are fairly evenly distributed AND
- Diameter at breast height (DBH) range is 'normal'.

A stratum/woodland would be considered 'variable' if it has at least one of these features:

- Several species planted in an intimate mixture OR

- The spacing of the planting positions is not uniform but varies across the stratum
OR
- From year 15 onwards, more than 3 years/ 4 m height difference across the stratum or the DBH range is unusually wide.

Table 1. Number of plots required within a stratum/woodland parcel depending on parcel area (ha) and the uniformity of the stratum/woodland. Source: Forestry Commission WCC: Carbon Assessment (v2.0) (Jenkins and others, 2018).

Area of parcel (ha)	Uniform woodland	Variable woodland
<0.5	4	6
0.5 – 2.0	6	8
2.0 – 10.0	8	12
>10.0	10	16

The aim is to have a plot size that contains 7 to 20 trees of DBH (diameter at breast height = 1.3 m) \geq 7 cm. Our default plot size has an 8 m radius which gives a plot size of 0.02 ha. The plot size can be changed, on first inspection of the woodland, depending on density of trees. However, the same plot size should be maintained across the stratum/woodland parcel.

Random plots within each stratum/woodland parcel are mapped in QGIS. A 10 m buffer from the edge of the parcel is applied to ensure the whole plot is inside the stratum/woodland. A minimum distance of 17 m between points is applied to avoid overlaps.

1.5.1. Associated vegetation and soil surveys in woodlands

To ensure that the woodland surveys are comparable with the soil and vegetation sampling, these take place at the same location. To do this, five of the woodland plots are randomly selected using a random number generator.

At the selected plots, the 2 x 2 m quadrat is placed 2 m south of the centre (marked with a plot marker) of the woodland plot for vegetation surveying. Soil surveys are taken within a 1 x 1 m area directly north of the centre of the woodland plot (Figure 5). The soil and vegetation surveys are conducted, in the same way as described in sections 2.3 and 3.3 respectively.

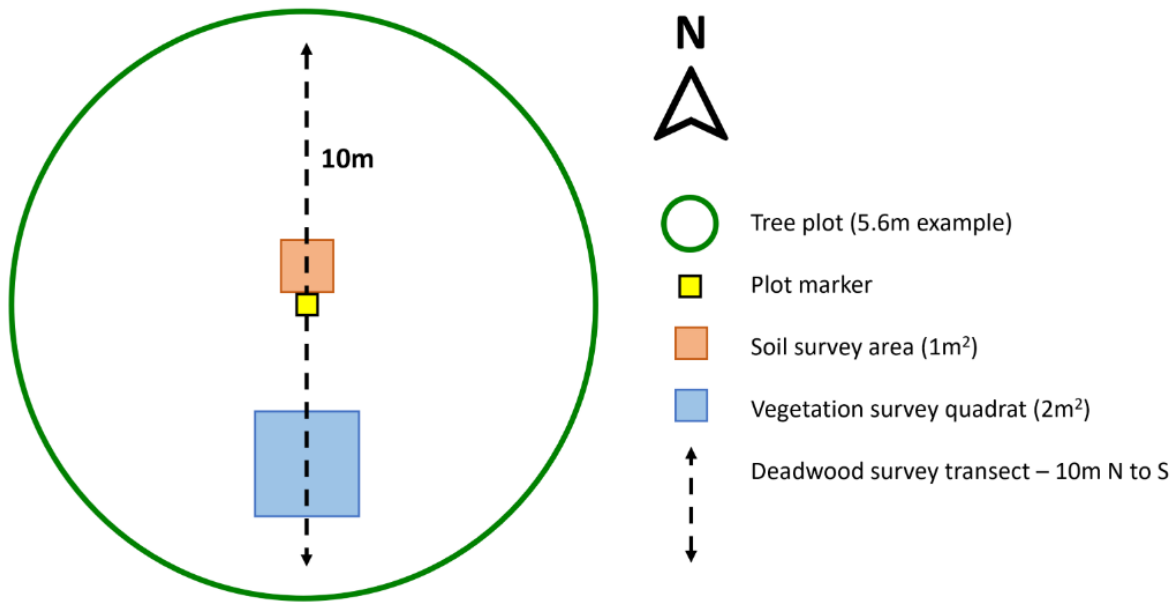


Figure 5. A woodland plot at which a tree survey, deadwood survey, vegetation survey and soil survey takes place. Within the tree survey plot, a vegetation quadrat is placed 2 m south of the centre, a soil survey is taken directly north of the plot centre and a 10 m transect is placed through the centre of the plot, orientated N to S, to survey lying deadwood.

2. Soil sampling for carbon stock assessment

2.1. Summary

Soils can store significant amounts of carbon, over timescales ranging from days to millennia and vary widely both within and between habitats. The carbon content of soil also varies considerably with depth, often declining in organic carbon as the soil vertical depth increases, and is influenced by factors including plant root depth, water infiltration, soil macrofauna and graziers (Laskar and others, 2021; Wang and others, 2022). Current and past management practices also directly influence the distribution of carbon within a soil profile. For example, ploughing, often to depths of up to 30 cm, can cause losses of stored carbon, as well as redistributing crop residues, and therefore carbon, to the sub-surface (Lorenz & Lal, 2005; Harrison and others, 2011; Yang and others, 2017). In semi-natural habitats or habitats with minimal intervention, 'recent' carbon tends to accumulate in the top 0-10 cm (Li and others, 2007). Therefore, soil depth is an important factor to consider when collecting soil for carbon stock assessments (Vanden Bygaart and others, 2011). Collecting only the topsoil could lead to overestimations in carbon stock estimates.

To facilitate a robust baseline assessment, and to provide comparison across different habitats, we have taken a standardised approach to soil sampling. Across all of our habitats, we core to a depth of 30 cm, in line with the default depth outlined in IPCC guidance (IPCC, 2003).

2.2. Equipment for Soil Sampling

The soil corer that is used is an Eijkelkamp split tube sampler, diameter 4.8 cm (Eijkelkamp Agrisearch Equipment BV, Giesbeek, The Netherlands) (Figure 6) (Elias and others, 2023). The corer is designed to split in two to promote minimal disturbance when handling the sample. The soil coring equipment includes a transparent liner, which is inserted into the corer in a rolled up lengthways position, resting on the small metal lip inside the corer. The corer is put back together and secured with the locking pin and is hammered into the ground using a wooden mallet with a nylon head. When the soil core has been collected, the corer is taken apart and the liner (with soil core inside) is laid out flat for processing. If needed, the corer/liner is washed or wiped between each sample to avoid cross-contamination.



Figure 6. Assembly of the soil corer. Left to right: The transparent liner is inserted into one half of the corer; the corer is slotted back together with the liner inside and is fixed with the locking pin. The coring location is identified, and sample collection is ready. Photo credit: Celina Jennings

We collect the following additional field data, to later assess the relationships between field conditions and soil carbon:

- Soil moisture, using a Delta-T ML3 Theta Probe and HH2 reader.
- Soil temperature, using an Arctic Hayes Compact Digital Thermometer.
- Soil pH, using a Mettler Toledo Seven2Go™ Pro pH/Ion Meter paired with an InLab Expert Go-ISM Sensor. This is carried out in the laboratory using a subsample collected from the field. See section 2.3.1 for more information.

2.3. Field Data Collection

In dry conditions all field data is recorded using pre-designed surveys in ArcGIS Survey123 (esri). However, in wet conditions, all field data is recorded in field notebooks using pre-set templates and are backed up using Survey123. On arrival at the first plot, key features such as topography, exposure and climatic conditions are noted. Within each plot area, five soil moisture and temperature readings are taken (Figure 7). A subsample of fresh soil is collected from in situ within 10 cm of the surface for the determination of pH back in the laboratory (see section 2.3.1).



Figure 7. Example of a plot marker and the soil temperature and moisture probes. Photo credit: Chris Parkes

At each of the 5 plots, 3 replicate soil cores are collected. The soil cores are taken at random within a 1 m² area north of the plot marker. The corer is driven into the ground by hand until it stands by itself. A mallet is used to knock the corer into the ground up to 30 cm (Figure 8) or the maximum depth if the soil is shallower than this. The corer is then pulled from the ground carefully, ensuring that all of the soil sample remains within the corer (particular care is taken in overly wet soil and overly dry soil, where the sample can fall out of the bottom of the corer on extraction).



Figure 8. Soil corer being hammered into the ground to a target depth of 30 cm. Photo credit: Tamsin Lockwood

The corer is taken apart and measurements of the hole depth and total soil core length are taken to account for any compaction or under-coring. A photograph of each core is taken for records (Figure 9). The core is measured and split into two subsamples from 0-15 cm and 15-30 cm using a knife. The soil samples from the 3 cores taken in each plot are bulked together in 2 labelled sample bags – one for the upper 0-15 cm and the other for the lower 15-30 cm (Figure 10). This method is repeated at each of the plots.

2.3.1. Soil analysis

The bulked soil samples are sent to NRM laboratories (Cawood Scientific), where analysis is carried out to measure total carbon, organic carbon, nitrogen, bulk density and soil texture classification.

Soil pH is measured by field team members in the laboratory. Stones, roots, and vegetation are removed and 10 cm³ of soil is suspended in 25 ml deionized water. The pH of the suspension is then determined using a Seven2Go pro pH/Ion Meter.



Figure 9: An extracted soil core with the intact core measured. Photo credit: Becky Davess



Figure 10. Example of the soil core split into the top 0 to 15 cm and bottom 15 to 30 cm before putting into sample bags. Photo credit: Becky Davess

3. Vegetation species identification and biodiversity assessment

3.1. Summary

We are in a joint nature and climate change emergency. Ecosystem function and resilience is under threat with the rapid changing environmental conditions caused by climate change (Bellard and others, 2012). Efforts to mitigate biodiversity loss can be achieved through nature-based solutions such as habitat creation and restoration, which in turn can remove and lock up greenhouse gas emissions from the atmosphere (Habibullah and others, 2022). However, the relationship between carbon and biodiversity across a range of habitats is not well understood. In some cases, it may be that habitat restoration enhances carbon stocks as well as increasing biodiversity, in other cases, high carbon may not necessarily mean high biodiversity.

We are therefore exploring the relationships between carbon and biodiversity in habitats with key evidence gaps. To do this, we are baselining vegetation and carbon assessments before work begins and look to return over a time period to monitor the changes in both. It is important to consider how the relationship between biodiversity and carbon can be used to guide conservation practises and maximise their potential where appropriate.

This section focuses on a standardised method (Rodwell, 2006) to assess vegetation and plant diversity alongside soil carbon (see section 2.3). Pilot partners are surveying other elements of biodiversity and we look to combine this with our findings where the information is available.

3.2. Equipment for Vegetation Surveying

Transects are measured out using tape measures and marked using quadrats. In addition, several published resources are used to aid identification in situ as follows:

- Grasses: A Guide to Their Structure, Identification, Uses and Distribution in the British Isles, 1992 – C.E. Hubbard, revised by J.C.E Hubbard
- The Wild Flower Key: How to identify wild flowers, trees and shrubs in Britain and Ireland, 2006 – Francis Rose revised and updated by Clare O'Reilly
- Grasses: A Guide to Identification Using Vegetative Characters (AIDGAP), 2022 – Hilary Wallace
- A Field Guide to Grasses, Sedges and Rushes, 2016 – Dominic Price
- Vegetative Key to the British Flora, 2009 – E.J Clement and J Poland.

3.3. Field Data Collection

The pre-allocated plots are identified using a GPS device. The quadrat is placed 2 m south of the plot marker (as described in section 1.2 and 1.3), adjacent to, but at a safe distance away from soil coring operations. A plot description is recorded including location, slope, aspect, general features and any information on management. In addition, a photograph of the plot is taken, with a whiteboard at the bottom of the plot with information about location, time and date. A 4 m² (2 X 2 m) quadrat is marked out in which to undertake the vegetation survey (Figure 11).



Figure 11. Left – quadrat on species-rich grassland. Right – quadrat on woodland ground flora. Photo credit: Celina Jennings

The surveyor stands on the outside of the quadrat to avoid disturbance of the vegetation within the area being surveyed. The following characteristics are observed and recorded:

- An estimate of the percentage cover of the vegetation structure classes is taken in preparation for invertebrate proxy (see section 3.3.1). Total percentage cover may exceed 100%.
- The presence, number and extent of any ant hills, animal burrows, dung and rocks.
- The percentage cover of ground cover types (bare, moss, litter, dead wood).
- The percentage cover of all vascular plant species present within the quadrat. Any overhanging material from plants not rooted in the quadrat is included as the aim is to get species richness and diversity information. Total cover may exceed 100%, where there are several layers of vegetation.
- Where the species ID is uncertain, pseudo species names are assigned. Photographs and notes are taken (including whole plant, detail of stem, leaves, buds, flowers and fruits) and percentage cover recorded.

3.3.1. Invertebrate proxy

A further dimension to the vegetation survey is the invertebrate proxy. We are recording a 3D element of structural complexity in the vegetation, as a complement to the ground-cover element provided by the species ID and percentage cover data.

The invertebrate proxy gives an indication of how varied the vegetation structure is, with resulting potential for use by invertebrates, and records percentage cover of four height classes of the vegetation in a plot; classes are lower than 10 cm, 10-50 cm, 50-100 cm, and taller than 100 cm (Figure 12; Table 2).

Getting an idea of how useful a habitat might be to invertebrates has the potential to inform us of how much that habitat might support other taxonomic groups such as birds and mammals, and so help develop a broader understanding of diversity in that landscape.

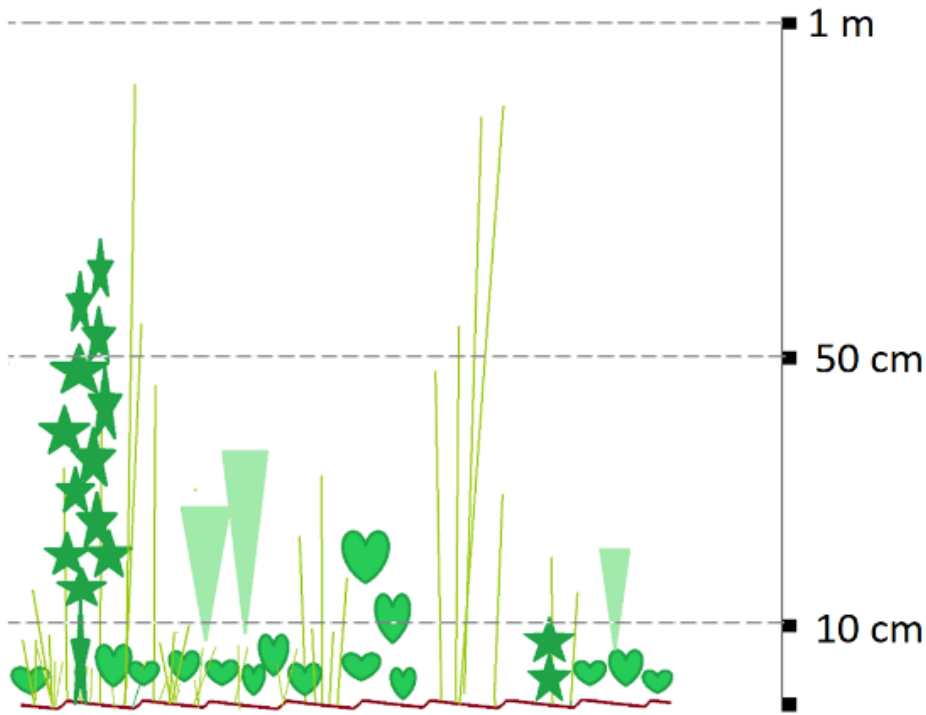


Figure 12. Schematic of invertebrate proxy height classes.

Table 2. Vegetation height classes given as a comparison of height in cm and where the vegetation would approximately align to on the body. Given variations in height, surveyors should familiarise themselves with height bands before estimating on surveys.

Vegetation height	Vegetation height class
≤10 cm	Approximately ankle height
10 – 50 cm	Knee height
50 – 100 cm	Hip height
>100 cm	Above hip height

3.3.2. National Trust Sites

On sites owned or managed by the National Trust, further information is gathered relating to the wider vegetation structure within a 10 m radius of the 2 x 2 m quadrat, to provide consistency with surveys already carried out by the National Trust. Additional information includes:

- % bare ground within 10 m radius
- Mean number of flowers in 1 m²
- % cover shortgrass (<5 cm)
- % cover medium grass (5 to 30 cm)
- % cover long grass (over 30 cm)
- % cover tall herbs (over 30 cm)
- % cover rushes
- % cover bracken
- % cover large sedges, rushes or reeds
- % cover low scrub (below 50 cm)
- % cover medium scrub (0.5 to 1.5 m)
- % cover established scrub (taller than 1.5 m)

4. Carbon dioxide and methane flux

4.1. Summary

As active systems, soils can act as carbon sources or sinks, emitting or sequestering carbon, with soil respiration representing one of the largest terrestrial carbon fluxes (Lei and others, 2021). They are affected by natural variations in the environment, such as temperature and soil moisture and in undisturbed 'natural' systems these fluxes often balance out over time (Zhou and others, 2016). However, land use change and human activity can change rates of greenhouse gas (GHG) emissions or uptake (Huang and others, 2024). Carbon dioxide and methane account for the main GHG fluxes in most habitats and there is a lack of evidence and understanding as to the behaviour of GHGs in different scenarios (Bond-Lamberty & Thomson, 2010; McDaniel and others, 2019). GHG flux work in the Nature Returns project seeks to understand the behaviours of carbon dioxide and methane on land undergoing change and establish baseline flow rates for key habitat evidence gaps.

4.2. Equipment for Measuring Gas Flux

Ground level carbon dioxide and methane fluxes are measured using portable, closed chamber systems. Carbon dioxide is measured using a PP Systems EGM-5 Gas Analyser. The system is used with two chambers: the SRC-2 Soil Respiration Chamber and CPY-5 Net Canopy Chamber (Figure 13). The transparent chamber (CPY-5 Net Canopy Chamber) allows plants to photosynthesise and therefore measures the net flux of carbon to or from the area of the chamber at that time. The opaque chamber (SRC-2 Soil Respiration Chamber) can be used on bare soil to calculate soil respiration.

In addition, methane and carbon dioxide can be measured simultaneously using a LiCOR LI-7810 Trace Gas Analyser (Figure 14), using an opaque chamber to record fluctuations from the soil. The analysers use different forms of spectroscopy to measure the change in gas concentrations within the chamber over a set time (60 seconds) or until a maximum concentration is reached. This allows a snapshot of the gas emissions/ sequestration from that area, at that time.



Figure 13. Left: PP Systems EGM-5 Gas Analyser and SRC-2 Soil Respiration Chamber. Right: PP Systems SRC-2 Soil Respiration Chamber and CPY-5 Net Canopy Chamber. Photo credit: Celina Jennings



Figure 14. Licor-7810 trace gas analyser for measuring methane. Photo credit: Celina Jennings

4.3. Field Data Collection

On arrival at site, key features such as topography and exposure are recorded along with environmental factors such as temperature, windspeed and recent rainfall. When carrying out surveys, ground disturbance prior to and during measurements are avoided as much as possible to reduce its influence on results. This is particularly important in saturated sites as pressure on the ground can cause spikes in readings as gas is redistributed. Ideally in these sites, ground would be accessed from an established walkway. Where this is not possible, stand as far from the reading point as possible, on firm ground.

Collars have not been used throughout these surveys. This allows flexibility in survey times, as collars need to be installed a minimum of 12 hours prior to sampling and allows for the inclusion of more spatial variation by the re-randomising of plot locations. It also removes possible influences on biological processes from the installation of a foreign structure, e.g. potential influence of shading on photosynthesis and therefore canopy flux. However, the use of chambers directly on soil surface could lead to increase leakage at base of chamber. Therefore, particular care should be taken to ensure chamber is as well fit to the surface as possible, wind sheltered as much as possible, and any clearly non-linear respiration results repeated (Zaman and others, 2021). Both analysers are used alongside a soil probe which is inserted into the ground before measurement process. This records soil moisture and temperature. Gas flux data will also be integrated with soils data derived from soil surveys in section 2.3.

If two EGMs are available, these can be run simultaneously. If one is available, the clear canopy chamber should be used first, followed by the opaque soil respiration chamber, allowing the reading to be taken from the same location. Whichever set up is used, it is important to record this to allow correct comparison of results.

When using the EGM canopy chamber, vegetation is gathered into the chamber, ensuring the edges are flush with the ground. If the vegetation volume is larger than the chamber, only measurements from the SRC-2 Soil Respiration Chamber can be taken. If vegetation is taller than the chamber but the volume will fit, it can be gathered into the chamber with flowers removed as necessary. Any changes to the vegetation structure before reading is however be recorded, i.e. by noting approximate vegetation height. When using the EGM or LiCOR opaque chambers, vegetation is removed prior to analysis. This is done by cutting vegetation at soil height, causing as little disturbance to soil as possible.

Both systems provide step-by-step instructions for carrying out measurements, either through connection to a smart phone (LiCOR) or on-screen instructions. Both systems have integrated memory to record live process data. Survey123 is also used to provide a back-up to some of this data by recording final process figures, as well as notes on habitat and environment.

5. Carbon stock assessment for trees

5.1. Summary

Woodlands are an important carbon sink and will play a crucial role in meeting UK Net Zero targets by 2050. Typically, newly planted native broadleaf woodlands sequester carbon at a higher rate than other semi-natural habitats, slowing up to and beyond 100 years (Gregg and others, 2021). As woodlands age, they become significant carbon stores, both within the tree itself and belowground in soils (Gregg and others, 2021). However, this is highly variable between woodland type, soil type and management history (Poulton and others, 2003; Bellamy and others, 2005; Benham and others, 2012; Ashwood and others, 2019).

In our comparative assessment, we aim to explore the relationships between above-ground carbon stock in trees, including deadwood, with below-ground carbon stock in forest soil and plant diversity assessments (see section 1.5). In doing so, we will be able to compare these relationships to the other habitats being studied. We aim to provide further comparisons between woodland carbon and carbon stored in hedgerow and scrub, which are currently under development (Appendix 1 – Hedgerows and Appendix 2 – Carbon stock assessment for scrub and hedgerow using LiDAR).

This section focuses on trees within woodlands of primarily native broadleaf species. A method for measuring trees outside of woodlands (such as for wood pasture and traditional orchards) is currently in development. More information can be found in Appendix 3 – Trees outside of woodlands.

5.2. Equipment for Measuring Carbon Stock in Trees

We use the Haglöf Vertex (V5) and Transponder (T3) to calculate the height of each tree within a plot. The diameter at breast height (DBH) of each tree within the plot is measured using a diameter tape or tree callipers. To mark the centre of the plot, we use a monopod with a 360° adapter (Figure 15). During heavy rain, the Haglöf kit may not work as efficiently, therefore we carry out an alternative height recording method using a clinometer to measure tree height.

In dry conditions all field data is recorded using pre-designed surveys in ArcGIS Survey123. However, in wet conditions, all field data are recorded in field notebooks and is later backed up.

Several published resources are used to aid tree identification in situ as follows:

- Winter Trees: A Photographic Guide to Common Trees and Shrubs, FSC publications, 2013 - Dominic Price and Leif Bersweden
- A Guide to the Identification of Deciduous Broad-Leaved Trees and Shrubs in Winter, FSC publications, 2000 - Andrew May and Jonathan Panter

- The Field Key to Winter Twigs A Guide to Native and Planted Deciduous Trees, Shrubs and Woody Climbers (Xylophytes) Found in the British Isles, 2020 - John Poland



Figure 15. Tree methods equipment: (1) Vertex V5, (2) Transponder T3, (3) Monopod, (4) 360° Picture credit: Haglöf Sweden, 2020.

5.3. Field Data Collection

A GPS is used to navigate to each plot using the coordinates generated during plot selection (see section 1.5). The centre of each plot is marked using the monopod (Figure 15) and the time, temperature, weather and topography are recorded. A plot marker is added to the centre of the plot so the plot can be easily located in the future and a photograph is also taken from the centre of the plot.

Prior to measuring tree height, both the Haglöf V5 and T3 are turned on to give time to reach ambient temperature. The T3 is calibrated to 10 m using the tape measure and is placed on the monopod at the centre of the plot using the 360° adapter (Figure 15). The V5 is used to measure the distance of trees to the centre of the plot in order to determine which trees are within the 8m radius plot. Each tree in the plot is marked with a number using chalk.

The diameter at breast height (DBH) of each tree within the plot is measured. All stems with a DBH ≥ 2 cm are identified to species level where possible (Figure 16).



Figure 16. Measuring the diameter at breast height (DBH) of a tree with a diameter tape. Photo credit: Tamsin Lockwood

For trees with multiple stems below 1.3 m, the DBH of all stems ≥ 2 cm are measured (Figure 17). In the field notes, trees with multiple stems are labelled as “MS” to indicate a multi-stemmed tree and each stem assigned a letter from a-z. Leaning tree DBH is measured at 1.3 m along the lower side of the trunk, closest to the ground (Figure 18). When using Survey123, there is an option to indicate the angle at which the tree is growing. When field notebooks are being used, leaning stems are indicated with an “L” and horizontal stems are indicated with a “H”.

The height of each tree is measured using the T3 and the V5 (Figure 19). The T3 is placed at breast height on each tree. From a distance of at least 1 tree height away and where the top of the tree is visible, the V5 is used to measure the timber height (point where the tree becomes approximately <7 cm diameter) and the top height (height of the top of the crown). For trees less than 7 cm DBH, only the top height is taken.

Where trees have a slight lean, the height of the tree is measured with the lean to the right or the left, not with lean towards or away. Extra height measurements can be taken to increase accuracy. Ideally, each tree is measured from opposite sides, perpendicular to the lean and an average taken. Where trees have an obvious lean to one side, the leaning tree method is used (Figure 20).

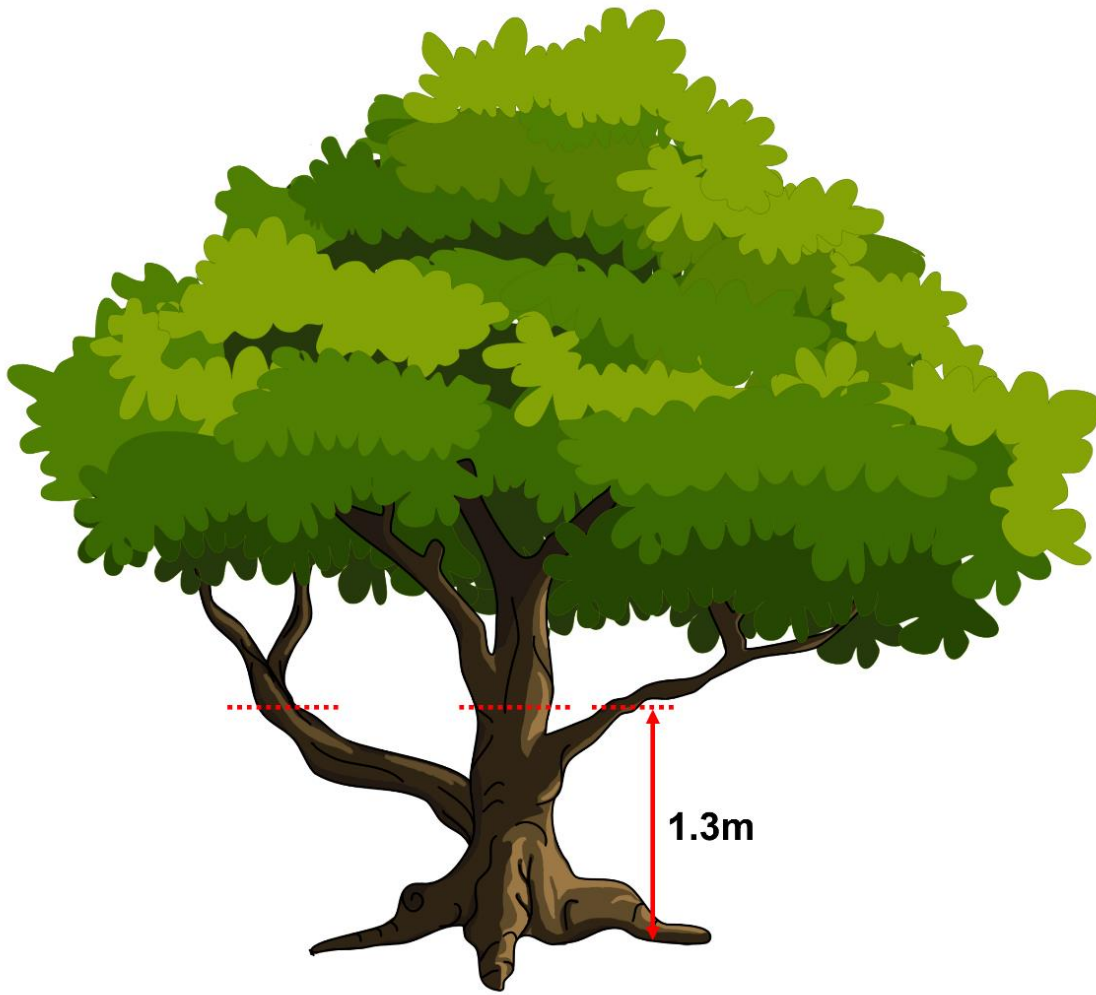


Figure 17. Measuring DBH of a multi-stemmed tree, 1.3 m up from the base of the root stock.

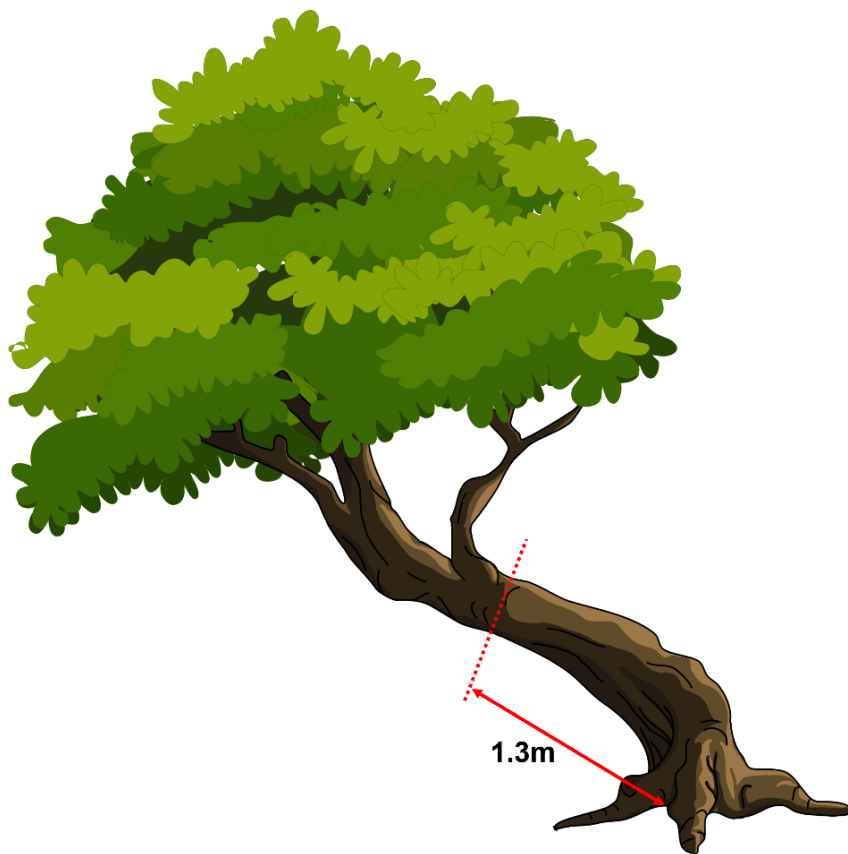


Figure 18. Measuring DBH of a leaning tree, 1.3 m along the lower side of the trunk closest to the ground.

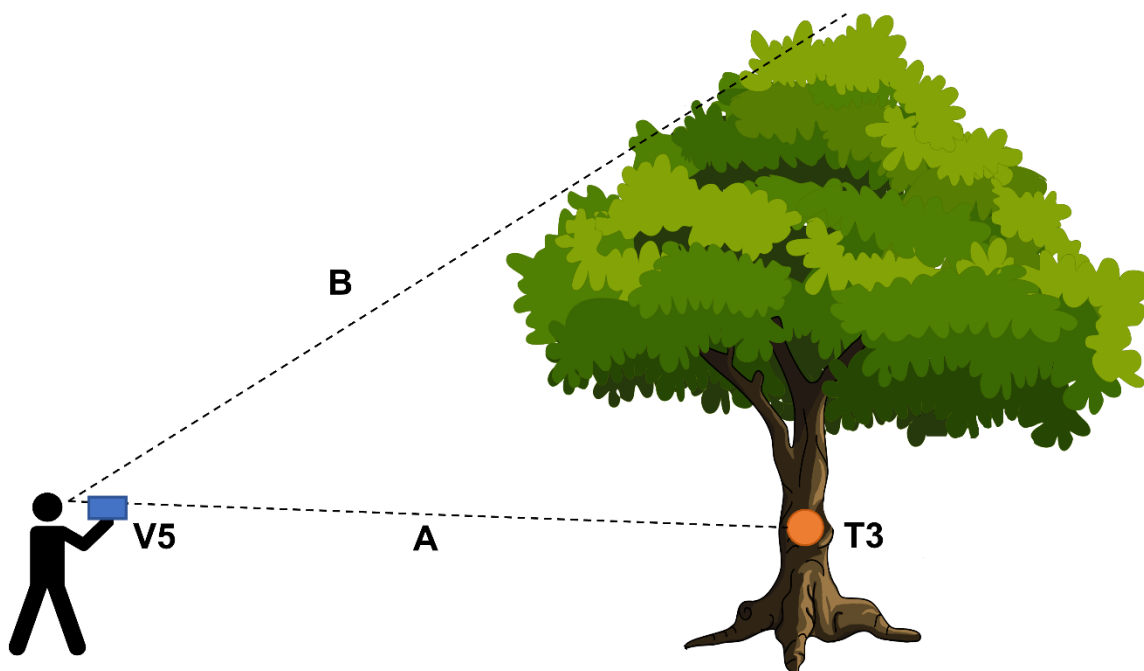


Figure 19. Taking tree height measurement using the Haglöf Vertex 5 (V5) and the Transponder (T3). A is the distance at least one tree height away where the top of the tree is visible B.

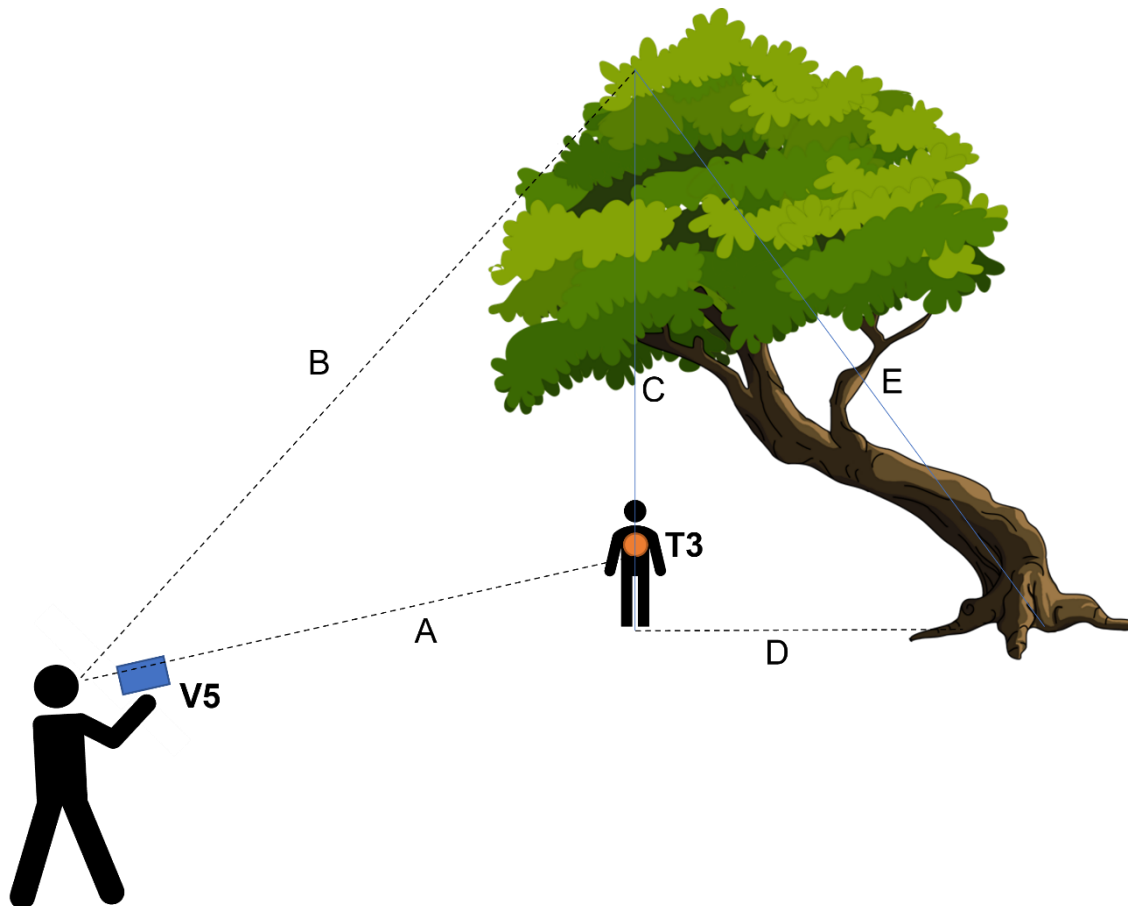


Figure 20. Taking measurements of an obviously leaning tree. One person stands directly underneath the top of the tree holding the Haglöf T3 at breast height (1.3 m). Another person uses the V5, which takes measurements for A and B, to calculate the distance from the point directly under the top of the tree up to the tree top (C). A tape measure is then used to measure the distance from the point underneath the top of the tree to the base of the tree (D). The measurements for C and D can then be used to calculate the height of the tree (E) using Pythagoras ($C^2+D^2=E^2$).

5.3.1. Recording Deadwood

Standing deadwood is measured in the same way as living stems. It is labelled as “SD” in the field notes to indicate standing deadwood and notes made on whether it is snapped or whole. The decay class is also assessed from 1 to 5, as described in Rondeux and others, 2012.

Lying deadwood is assessed using the line-intercept method used by the National Forest Inventory (NFI) (Rondeux and others, 2012). At each tree plot a 10 m transect is laid out, running 5 m north and 5 m south of the plot centre (Figure 21).

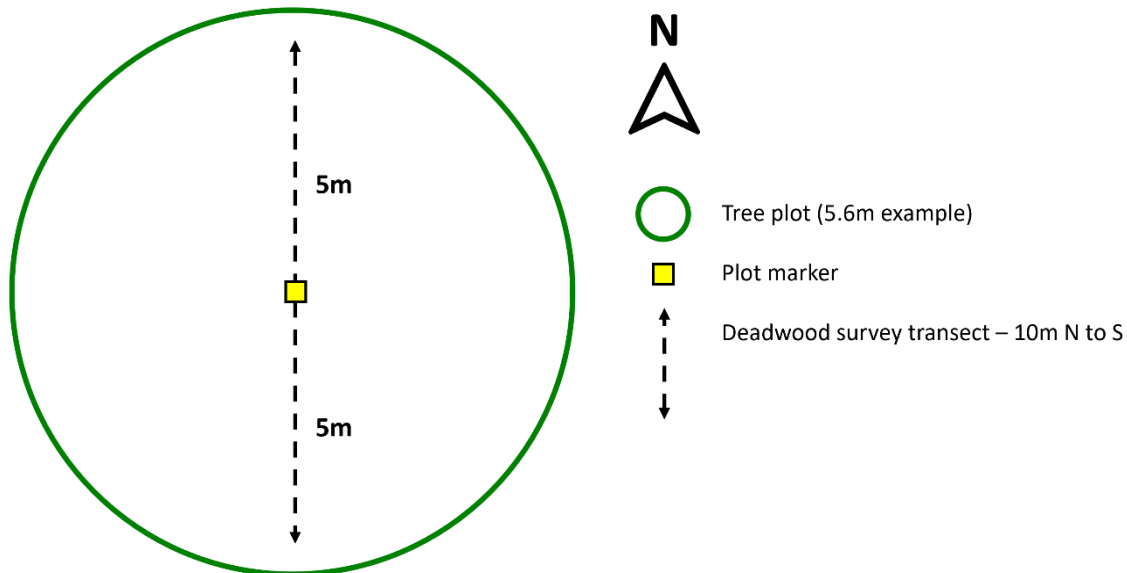


Figure 21. Set up of line transect within each tree survey plot for measuring deadwood.

All the fallen deadwood pieces that have a diameter ≥ 7 cm where they cross the transect are counted. The diameter is measured using the tree callipers for extra precision. Three diameter measurements are taken: the point where the deadwood crosses the transect, the smallest end of the log and the largest end of the log. The length of each recorded deadwood is recorded, and a decay class assigned (Rondeux and Others, 2012).

5.3.2. Tree carbon stock calculations

Project partners from Royal Botanical Gardens Kew are using ground-based LiDAR to quantify tree volume and therefore carbon stock (see Appendix 2 – Carbon stock assessment for scrub and hedgerow using LiDAR for a description of LiDAR). The carbon stock calculated from LiDAR is being compared to carbon stocks calculated from field measurements and different allometric equations. The calculations used to quantify carbon stock in the trees surveyed by the Nature Returns field team at pilot sites will be informed by the findings by the research team at Kew.

References

- Ashwood, F., Watts, K., Park, K., Fuentes-Montemayor, E., Benham, S. and Vanguelova, E.I. (2019) 'Woodland restoration on agricultural land: long-term impacts on soil quality' *Restoration Ecology*, 27(6), pp. 1381–1392. doi.org/10.1111/rec.13003.
- Axe, M.S., Grange, I.D. and Conway, J.S. (2017) 'Carbon storage in hedge biomass—A case study of actively managed hedges in England', *Agriculture, Ecosystems & Environment*, 250, pp. 81–88. doi.org/10.1016/j.agee.2017.08.008.
- Bellamy, P.H., Loveland, P.J., Bradley, R.I., Lark, R.M. and Kirk, G.J.D. (2005) 'Carbon losses from all soils across England and Wales 1978–2003', *Nature*, 437(7056), pp. 245–248. doi.org/10.1038/nature04038.
- Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W. and Courchamp, F. (2012) 'Impacts of climate change on the future of biodiversity' *Ecology Letters*, 15(4), pp. 365–377. doi.org/10.1111/j.1461-0248.2011.01736.x.
- Benham, S.E., Vanguelova, E.I. and Pitman, R.M. (2012) 'Short and long term changes in carbon, nitrogen and acidity in the forest soils under oak at the Alice Holt Environmental Change Network site' *Science of The Total Environment*, 421–422, pp. 82–93. doi.org/10.1016/j.scitotenv.2012.02.004.
- Biffi, S., Chapman, P.J., Grayson, R.P. and Ziv, G. (2023) 'Planting hedgerows: Biomass carbon sequestration and contribution towards net-zero targets', *Science of The Total Environment*, 892, p. 164482. doi.org/10.1016/j.scitotenv.2023.164482.
- Black, K., Lanigan, G., Ward, M., Kavanagh, I., hUallacháin, D.Ó. and Sullivan, L.O. (2023) 'Biomass carbon stocks and stock changes in managed hedgerows', *Science of The Total Environment*, 871, p. 162073. doi.org/10.1016/j.scitotenv.2023.162073.
- Bond-Lamberty, B. and Thomson, A. 2010 'A global database of soil respiration data', *Biogeosciences*, 7(6), pp. 1915–1926. doi.org/10.5194/bg-7-1915-2010.
- Calders, K., Newnham, G., Burt, A., Murphy, S., Raunonen, P., Herold, M., Culvenor, D., Avitabile, V., Disney, M., Armston, J. and Kaasalainen, M. 2015 'Nondestructive estimates of above-ground biomass using terrestrial laser scanning', *Methods in Ecology and Evolution*, 6(2), pp. 198–208. doi.org/10.1111/2041-210X.12301.
- Dubayah, R.O. and Drake, J.B. 2000 'Lidar Remote Sensing for Forestry', *Journal of Forestry*, 98(6), pp. 44–46. doi.org/10.1093/jof/98.6.44.
- Elias, D.M.O., Mason, K.E., Howell, K., Mitschunas, N., Hulmes, L., Hulmes, S., Lebron, I., Pywell, R.F. and McNamara, N.P. 2023 'The potential to increase grassland soil C stocks by extending reseeding intervals is dependent on soil texture and depth', *Journal of Environmental Management*, 334. doi.org/10.1016/j.jenvman.2023.117465.
- Gregg, R., Elias, J., Alonso, I., Crosher, I., Muto, P. and Morecroft, M. 2021 Carbon storage and sequestration by habitat: a review of the evidence (second edition), *Natural England Research Report NERR094*. Natural England, York.
- Habibullah, M.S., Din, B.H., Tan, S.-H. and Zahid, H. 2022 'Impact of climate change on biodiversity loss: global evidence.', *Environmental science and pollution research international*, 29(1), pp. 1073–1086. doi.org/10.1007/s11356-021-15702-8.
- Harrison, R.B., Footen, P.W. and Strahm, B.D. 2011 'Deep Soil Horizons: Contribution and Importance to Soil Carbon Pools and in Assessing Whole-Ecosystem Response to Management and Global Change', *Forest Science*, 57(1), pp. 67–76. doi.org/10.1093/forestscience/57.1.67.
- Huang, N., Wang, Li, Song, X.-P., Black, T.A., Jassal, R.S., Myneni, R.B., Wu, C.,

- Wang, Lei, Song, W., Ji, D., Yu, S. and Niu, Z. (2024) 'Spatial and temporal variations in global soil respiration and their relationships with climate and land cover', *Science Advances*, 6(41), p. eabb8508. doi.org/10.1126/sciadv.abb8508.
- IPCC (Intergovernmental Panel on Climate Change) (2003) Good Practice Guidance for Land Use, *Land-Use Change and Forestry*. Edited by J. Penman et al. Japan: Institute for Global Environmental Strategies IGES. www.ipcc-nggip.iges.or.jp/.
- Jenkins, T., Mackie, E., Matthews, R., Miller, G., Randle, T. and White, M. (2018) *FC Woodland Carbon Code Assessment Protocol (v2.0)*, Forestry Commission. www.woodlandcarboncode.org.uk/standard-and-guidance/2-project-governance/2-5-monitoring.
- Laskar, S.Y., Sileshi, G.W., Pathak, K., Debnath, N., Nath, A.J., Laskar, K.Y., Singnar, P. and Das, A.K. (2021) 'Variations in soil organic carbon content with chronosequence, soil depth and aggregate size under shifting cultivation', *Science of The Total Environment*, 762, p. 143114. doi.org/https://doi.org/10.1016/j.scitotenv.2020.143114.
- Lei, J., Guo, X., Zeng, Y., Zhou, J., Gao, Q. and Yang, Y. (2021) 'Temporal changes in global soil respiration since 1987', *Nature Communications*, 12(1), p. 403. doi.org/10.1038/s41467-020-20616-z.
- Li, H., Han, X., Wang, F., Qiao, Y. and Xing, B. (2007) 'Impact of Soil Management on Organic Carbon Content and Aggregate Stability', *Communications in Soil Science and Plant Analysis*, 38(13–14), pp. 1673–1690. doi.org/10.1080/00103620701435456.
- Lorenz, K. and Lal, R.B.T. (2005) 'The Depth Distribution of Soil Organic Carbon in Relation to Land Use and Management and the Potential of Carbon Sequestration in Subsoil Horizons', in *Advances in Agronomy*. Academic Press, pp. 35–66. doi.org/10.1016/S0065-2113(05)88002-2.
- Maskell, L.C., Norton, L.R., Smart, S.M., Scott, R., Carey, P.D., Murphy, J., Chamberlain, P.M., Wood, C.M., Bunce, R.G.H. and Barr, C.J. (2008) 'CS Technical Report No.2/07: Vegetation Plots Handbook v1.0'. Centre for Ecology and Hydrology (Natural Environment Research Council). Available at: www.ceh.ac.uk/our-science/projects/cs-technical-reports (Accessed: 13.05.2024).
- McDaniel, M.D., Saha, D., Dumont, M.G., Hernández, M. and Adams, M.A. (2019) 'The Effect of Land-Use Change on Soil CH₄ and N₂O Fluxes: A Global Meta-Analysis', *Ecosystems*, 22(6), pp. 1424–1443. doi.org/10.1007/s10021-019-00347-z.
- Poulton, P.R., Pye, E., Hargreaves, P.R. and Jenkinson, D.S. (2003) 'Accumulation of carbon and nitrogen by old arable land reverting to woodland', *Global Change Biology*, 9(6), pp. 942–955. doi.org/10.1046/j.1365-2486.2003.00633.x.
- Pumpanen, J., Bernard, L. and Kutsch, W.L. (2010) 'Field measurements of soil respiration: Principles and constraints, potentials and limitations of different methods', *Soil Carbon Dynamics - an Integrated Methodology*, 16-33 (2009) [Preprint]. doi.org/10.1017/CBO9780511711794.003.
- Rodwell, J.S. (2006) *National Vegetation Classification: Users' Handbook*. JNCC, Peterborough. hub.jncc.gov.uk/assets/a407ebfc-2859-49cf-9710-1bde9c8e28c7.
- Rondeux, J., Bertini, R., Bastrup-Birk, A., Corona, P., Latte, N., McRoberts, R.E., Ståhl, G., Winter, S. and Chirici, G. (2012) 'Assessing Deadwood Using Harmonized National Forest Inventory Data', *Forest Science*, 58(3), pp. 269–283. doi.org/10.5849/forsci.10-057.
- Rothero, E., Lake, S. and Gowing, D. eds. (2016) *Floodplain Meadows – Beauty and Utility. A Technical Handbook*. Milton Keynes: Floodplain Meadow Partnership, Open

University, UK. Available at:

[www.floodplainmeadows.org.uk/sites/default/files/Floodplain Meadows - Beauty and Utility A Technical Handbook.pdf](http://www.floodplainmeadows.org.uk/sites/default/files/Floodplain%20Meadows%20-%20Beauty%20and%20Utility%20A%20Technical%20Handbook.pdf).

Roussel, J.-R., Auty, D., Coops, N.C., Tompalski, P., Goodbody, T.R.H., Meador, A.S., Bourdon, J.-F., de Boissieu, F. and Achim, A. (2020) 'lidR: An R package for analysis of Airborne Laser Scanning (ALS) data', *Remote Sensing of Environment*, 251, p. 112061. doi.org/10.1016/j.rse.2020.112061.

Roussel, J.-R. and Auty, D. (2024) *Airborne LiDAR Data Manipulation and Visualization for Forestry Applications, R package version 4.1.1*. Available at: <https://cran.r-project.org/package=lidR> (Accessed: 10 May 2024).

Rowe, R.L., Keith, A.M., Elias, D., Dondini, M., Smith, P., Oxley, J. and McNamara, N.P. (2016) 'Initial soil C and land-use history determine soil C sequestration under perennial bioenergy crops', *GCB Bioenergy*, 8(6), pp. 1046–1060. doi.org/10.1111/gcbb.12311.

Subke, J.-A., Kutzbach, L. and Risk, D. (2021) 'Soil Chamber Measurements BT - Springer Handbook of Atmospheric Measurements', in T. Foken (ed.). Cham: Springer International Publishing, pp. 1603–1624. doi.org/10.1007/978-3-030-52171-4_60.

VandenBygaart, A.J., Bremer, E., McConkey, B.G., Ellert, B.H., Janzen, H.H., Angers, D.A., Carter, M.R., Drury, C.F., Lafond, G.P. and McKenzie, R.H. (2011) 'Impact of Sampling Depth on Differences in Soil Carbon Stocks in Long-Term Agroecosystem Experiments', *Soil Science Society of America Journal*, 75(1), pp. 226–234. doi.org/10.2136/sssaj2010.0099.

Wang, L., Li, Z., Wang, D., Liao, S., Nie, X. and Liu, Y. (2022) 'Factors controlling soil organic carbon with depth at the basin scale', *CATENA*, 217, p. 106478. doi.org/10.1016/j.catena.2022.106478.

Yang, Y., Wu, J., Zhang, J., Pan, X., Wang, Y. and He, F. (2017) 'Effect of tillage method on soil water infiltration, organic carbon content and structure', *Chinese Journal of Eco-Agriculture*, 25(2), pp. 258–266. doi.org/10.13930/j.cnki.cjea.160720.

Zaman, M., Kleineidam, K., Bakken, L., Berendt, J., Bracken, C., Butterbach-Bahl, K., Cai, Z., Chang, S.X., Clough, T., Dawar, K., Ding, W.X., Dörsch, P., dos Reis Martins, M., Eckhardt, C., Fiedler, S., Frosch, T., Goopy, J., Görres, C.-M., Gupta, A., Henjes, S., Hofmann, M.E.G., Horn, M.A., Jahangir, M.M.R., Jansen-Willems, A., Lenhart, K., Heng, L., Lewicka-Szczebak, D., Lucic, G., Merbold, L., Mohn, J., Molstad, L., Moser, G., Murphy, P., Sanz-Cobena, A., Šimek, M., Urquiaga, S., Well, R., Wrage-Mönnig, N., Zaman, S., Zhang, J. and Müller, C (2021) 'Climate-Smart Agriculture Practices for Mitigating Greenhouse Gas Emissions BT - Measuring Emission of Agricultural Greenhouse Gases and Developing Mitigation Options using Nuclear and Related Techniques: Applications of Nuclear Techniques for GHGs', in Mohammad Zaman, Lee Heng, and Christoph Müller (eds). Cham: Springer International Publishing, pp. 303–328. doi.org/10.1007/978-3-030-55396-8_8.

Zhou, L., Zhou, X., Shao, J., Nie, Y., He, Y., Jiang, L., Wu, Z. and Hosseini Bai, S. (2016) 'Interactive effects of global change factors on soil respiration and its components: a meta-analysis', *Global Change Biology*, 22(9), pp. 3157–3169. doi.org/10.1111/gcb.13253.

Appendices

The following appendices demonstrate where methods are currently under development. We anticipate that future versions of this methodology booklet will expand upon these for inclusion in the main text.

Appendix 1 – Hedgerows

Hedgerows are woody features of British agriculture, consisting mainly of shrubs and small trees, that provide numerous functions including demarcation of field boundaries, shelter for livestock, and retention of soil and water (flood mitigation). They also provide significant benefits to biodiversity, providing connective habitat for woodland fauna and flora, both above and belowground.

The potential for hedgerows to store carbon is unclear but has received preliminary investigation (Axe and others, 2017; Biffi and others, 2023; Black and others, 2023). Unlike natural habitats, hedgerows are managed through a shaping regimen of growth and cutting which may result in significant carbon storage capacity. The following method for soil, vegetation, and above-ground carbon are in early stages of development and look to improve knowledge of hedgerow services.

Appendix 1.1. Soil

Field Data Collection

The hedgerow soil survey method focuses on soil carbon from under the hedgerow and into the adjacent field. Three linear transects are used to capture the soil gradient with a minimum of 10 m buffer distance from each transect (Figure 22). Along each transect there are three intervals: 0 m (under the hedge), 3 m (directly away from the hedge) and 9 m (directly away from the hedge and the furthest point in the adjacent field). The GPS coordinates are recorded. This soil survey method follows the protocol under section 2.3). At each interval, three soil core samples are taken to depths of 30 cm or the maximum depth if the soil is shallower than this. At each interval, five soil moisture and soil temperature readings are recorded and one pH sample: mixing the soil from the three coring holes. Data is recorded in ArcGIS Survey123 templates.

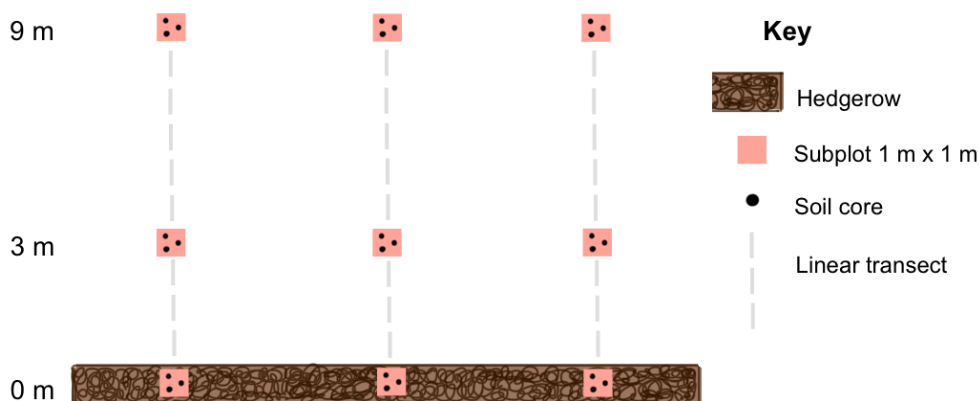


Figure 22. Example of transect soil sampling at a hedgerow with intervals 0, 3 and 9 m.

Appendix 1.2. Vegetation

The vegetation survey method for hedgerow understory vegetation is based on that used by the Countryside Survey method for hedgerow understorey recording (H-plots in Maskell and others, 2008). In order to equate the survey effort employed in open-habitat areas, quadrats at the hedge base are 4 x 1 m rather than 2 x 2 m.

Field Data Collection

A quadrat of 4 x 1 m is randomly located along the hedgerow, and GPS co-ordinates recorded at the most south westerly end (such that returning surveyors will place repeat quadrats to the north/east of the recorded co-ordinates). At-hedge quadrats should be aligned along the hedgerow's long axis and extend 1 m out from the centreline of the hedge (Figure 23). Quadrats along the transect from the hedgerow into the adjacent land should revert to being 2 x 2 m rather than 4 x 1 m.

Land-use context immediately either side of the hedge should be noted alongside any evidence of previous management. The plot should be photographed, making a note of the time and direction it was photographed from.

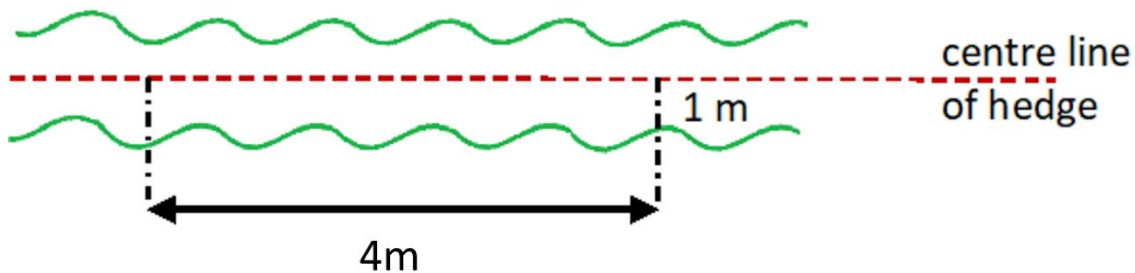


Figure 23. Diagram of transect set-up along the hedgerow with a 4 x 1 m quadrat indicated.

Data Recorded

- An estimate of the percentage cover of the vegetation structure classes for the invertebrate proxy is taken (for more information see section 3.3.1 Invertebrate Proxy below). Total % cover may exceed 100%.
- The presence, number and extent of any ant hills, animal burrows, dung and rocks.
- The percentage cover of ground cover types (bare, moss, litter, dead wood).
- The percentage cover of all vascular plant species present within the quadrat. Any overhanging material from plants not rooted in the quadrat is included as the aim is to get species richness and diversity information. Total cover may be >100%, where there are several layers of vegetation.
- Where the species ID is uncertain, pseudo species names are assigned. Photographs and notes taken (including whole plant, detail of stem, leaves, buds, flowers and fruits) and percentage cover recorded.
- The height and width of the hedgerow at each end of the quadrat is measured and the side of the hedge the quadrat lies on, e.g., N, S, E, W, is noted.
- For any trees within the hedge, a DBH (diameter at breast height = 1.3 m) is measured, with note of tree species and estimation of total height (Jenkins and others, 2018).

Appendix 2 – Carbon stock assessment for scrub and hedgerow using LiDAR

Nature Returns is collaborating with experts from Royal Botanic Gardens Kew to develop a method for scrub and hedgerow carbon assessment.

LiDAR (Light Detection and Ranging) is a remote sensing method which enables measuring features in the landscape in 3D and has become widely used for volumetric estimates of tree structure in woodlands (Calders and others, 2015). The method uses laser pulses of light to build up 3D information of the object being scanned (Dubayah & Drake, 2000). In this context, we are testing the use of a mobile, handheld LiDAR on scrub and hedgerows, to produce more accurate estimates of the volume of wood in scrub and hedgerows to calculate carbon stocks. This is not possible otherwise without destructive sampling and is a major evidence gap.

The aim of the methods described below is to develop a non-destructive model for scrub and hedgerow carbon assessment, linking LiDAR measures of volume with destructive measures of biomass at the pilot sites. To date, fieldwork has been carried out to establish a methodology for sampling with both LiDAR and destructive methods. This calibration will allow us to calculate a carbon stock estimate from the LiDAR volume alone.

Appendix 2.1. Scrub carbon assessment

Field Data Collection – LiDAR Survey of Scrubland

This study used a Faro ZEB-Horizon 3D for laser scanning of scrub and hedgerow vegetation. A mobile laser scanner is advantageous because it is easy to use across different and challenging terrain. Operation of LiDAR scanning is limited because it cannot be operated in adverse conditions, such as rain and wind. The ZEB-Horizon batteries are charged ahead of going into the field, 1 battery per 30-minute scan.

For scrub assessment, nine 50 cm X 50 cm square quadrats are marked using two 1 m rulers and four poles are placed at each corner (Figure 24). A neon pole is placed in one corner for visibility when processing. Three quadrats mark small-sized scrub, three quadrats mark medium-sized scrub and three quadrats mark large-sized scrub. All species are recorded within the quadrats e.g. Blackthorn and dogwood.

Pictures are taken of the area at different angles and a map of the nine quadrats drawn to help with processing. Details of which quadrats are small, medium and large-sized scrub is included (Figure 25).

The ZEB-Horizon 3D laser scanner requires time to calibrate before use (Figure 26). To scan the scrub with the ZEB-Horizon, one person walks around the quadrats in a circular motion and the surrounding areas, ensuring scan consists in closed loops which is necessary for the Simultaneous Localization and Mapping (SLAM) algorithm, moving the hand-held scanner obtain multiple view angles (Figure 27). To avoid noise in the LiDAR data, the operator needs to ensure that vegetation is not disturbed as they pass. A scan of 20 minutes is sufficient, and the scanner can be passed between colleagues during survey.



Figure 24. 50 X 50 cm quadrat marked up round the scrub. Location: Coombe Hill National Trust, Buckinghamshire. Photo credit: Tamsin Lockwood



Figure 25. Multiple quadrat sites with varying sized scrub. Location: Aston Rowant National Nature Reserve. Photo credit: Becky Davess



Figure 26. The Faro ZEB-Horizon 3D laser scanner. Photo credit: Becky Davess



Figure 27. Walking around the scrub in continuous closed loops for approximately 20 minutes holding the ZEB-Horizon 3D laser scanner. Location: Coombe Hill National Trust, Buckinghamshire. Photo credit: Mandy Cooper

Field Data Collection – Destructive Scrubland Sampling

In this study, destructive sampling of scrub made use of planned scrub clearance at two National Trust sites/national reserves.

Wet biomass samples of the woody material in the 50 cm x 50 cm quadrats are collected and mass is measured using hand scales with materials in tonne bags. 50-gram samples of wood are taken for every 500 grams of wet mass and dried in an oven at 80 °C until dry mass values are stable. A variety of width samples are used to account for variation in wood densities. To obtain the carbon stock, the dry biomass is halved.

Appendix 2.2. Hedgerow vegetation biomass carbon assessment

Field Data Collection – Hedgerow LiDAR Survey

A minimum of five plots are randomly selected along a hedgerow starting from one end and walking along. Two poles are placed at each plot a minimum of 20 cm apart (Figure 28). The Faro-Horizon 3D laser scanner needs time to calibrate before use (Figure 26). It is important to not capture anything but the hedgerow in the scan, so the scan pathway is cleared before starting, including any tall or creeping ground vegetation.



Figure 28. Ten 20 cm sample plots randomly selected along a hedgerow to be scanned. Location: Small Dean Farm Buckinghamshire. Photo credit: Becky Davess

Starting from the end of the hedgerow, the scan is carried out by walking in a wave-like motion towards and away from the hedgerow with the laser always facing towards the hedgerow. When scanning the poles, the laser is carefully placed in front of them to ensure the hedgerow has been scanned with the poles not included. Once the last set of poles have been scanned, we loop back walking in a wave-like motion. This wave-like motion includes moving further away and the laser to be held higher and lower to include different angles of the hedgerow (Figure 29).

Once one side of the hedge is scanned and the end of the edge is reached, the laser scanner is passed to a colleague ensuring the laser is facing the hedge. The scan is repeated on the other side of the hedgerow. When the scan is complete, it is important to return to the starting point where the laser was turned on (exact point which can be

marked or selected on the carrying case). These processes are repeated after biomass sampling so that points representing the removed vegetation can be identified.

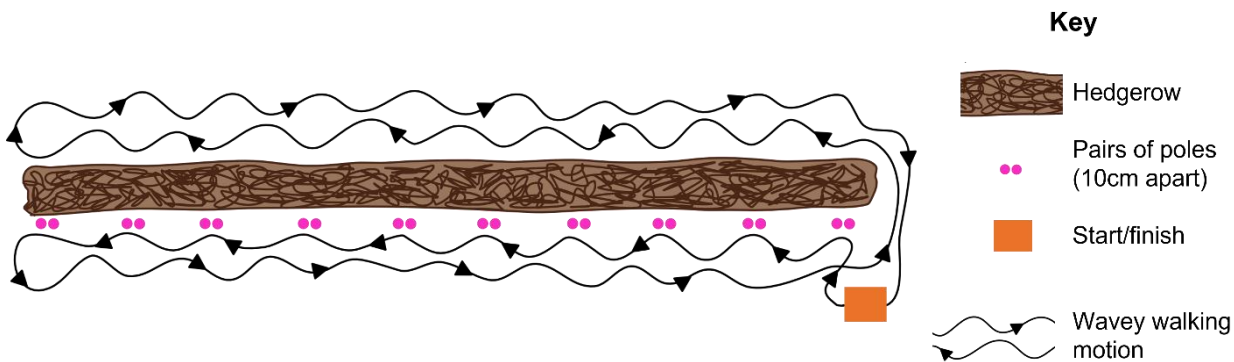


Figure 29. Diagram showing the wave-like walking motion used to scan both sides of the hedgerow.

Field Data Collection – Hedgerow Biomass Sampling

Hedgerows are destructively sampled during the winter months, out of bird nesting season. At each set of poles, the hedge is removed between the poles to half the depth of the hedge ~ 0.5 -1 m. Any woody material within this is collected and weighed using a tonne bag and a handheld scale. The bags are weighed before sampling and the weight is subtracted from the total weight.

To obtain the dried biomass from the hedge samples and the carbon stock, the same method is applied as in Appendix 2.1. Scrub carbon assessment

Appendix 2.3. LiDAR processing

The data is uploaded and processed in Faro Connect software (Faro 2024, version 2024.2). Preliminary data cleaning is performed to filter outliers and noisy points, reduce the surface noise and apply colouring techniques. Once initial processing is completed, point clouds are exported to CloudCompare software (CloudCompare 2.6.2, 2023) and are used to classify ground and vegetation points and calculate point heights above the ground. Points representative of the sampled vegetation are then identified and clipped from the main point clouds for further analysis in R Statistical Software (R version 4.2.2., R core team, 2022). Point clouds of each sampled section of scrubland or hedge are modelled to voxels using the lidR package (Roussel and others, 2020; Roussel & Auty, 2024) and volumes consisting of vegetation are calculated from a voxel size of 1 cm.

Appendix 3 – Trees outside of woodlands

Methods for quantifying carbon stock in trees outside of woodland are currently under review. Research and conversations to date with experts at Royal Botanical Gardens Kew has resulted in this suggested method:

For wood pasture and traditional orchards, aerial imagery could be used to assess the number of trees in the field/parcel. Where there are ≤ 100 trees, all trees with stems ≥ 2 cm DBH would be measured. When the number of trees exceeds 100, aerial imagery in QGIS will be used to assign each tree a number and then a random number generator will be used to select 100 random trees. For each tree measured, a GPS coordinate will be recorded, and the tree identified to species level where possible. DBH will be measured using diameter tape and the height recorded using the Haglöf V5 and T3 (as described in section 5.3). Both timber height (point where tree becomes approx. < 7 cm in diameter) and top height (height to the topmost branch) will be recorded.

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