Appendix 4

Optimum Shelter Belts

How to Guide

Monitoring the carbon benefits of your Optimum Shelter Belt:

Above and below ground carbon

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Introduction

Shelterbelts are rows of trees or shrubs that reduce the force of the wind. They can reduce soil erosion, increase crop yields and protect livestock from heat and cold. They beautify the landscape and also support climate change mitigation. Within the farming and land use sector, tree planting is considered to make a vital contribution to climate change mitigation. The Net Zero Strategy (UK Government, 2021) aspires to increase forestry cover from 13% to 17% by 2050 by planting 30,000 ha or more of woodland each year from 2025. Towards that target, the England Trees Action Plan (ETAP) 2021-24 seeks planting rates of 7500 ha annually by March 2025. Trees outside woodlands are also important. The ETAP speaks of agroforestry playing 'an important role in delivering more trees on farms and in our landscape, improving climate resilience and encouraging more wildlife and biodiversity in our farming systems'.

This how to guide supports the standardised monitoring of the climate mitigation benefits of establishing OSBs at 20 sites, focussing on the carbon sequestered into the biomass of the shelterbelt vegetation. It is hoped that the results will be of great interest to landowners and many categories of professionals.

General approach

The main carbon pools associated with OSBs are the biomass within the stems, branches and roots of the shrubs and trees composing the shelterbelt, and the carbon stored in the soil under and around the shelterbelt. This protocol focuses on the biomass carbon and accompanies the protocol for the soil carbon. The biomass carbon draws on work by ORC modelling the carbon sequestration potential of agroforestry systems as well as recent research into carbon storage and sequestration in hedgerows (Axe et al 2017, Levin et al 2020, Biffi et al 2023, Black et al 2023).

As with the biodiversity protocols, this carbon protocol recognises the varying level of interest and knowledge of those undertaking the monitoring, addressing this by providing a tiered approach (Table 1). In all three methods it is important to be aware of the distinction between above ground biomass (AGB) and below ground biomass (BGB) and the conversion by standard ratio equations to above and below ground carbon (AGC and BGC). The units of AGC are either tons carbon or carbon-dioxide equivalent (CO_2e) expressed as a total or per hectare.

1. Tier 1 represents the most straightforward method using the Woodland Carbon Code calculator. It provides a prediction of carbon being sequestered and stored based on tree species, densities, and growth of the OSB over time. This method is based on the advanced modelling of trees of different yield classes by Forest Research. However, it is most applicable

for trees growing in woodland blocks rather than lines and bands in open countryside, hence may not be so accurate for OSBs.

2. Tier 2 is also based on the Woodland Carbon Code but in this case follows an allometric modelling approach requiring a set of measurements of a sample of trees. It follows the Woodland Carbon Code Carbon Assessment Protocol (v2.0) (FC, 2018).
3. Tier 3 also follows an allometric modelling protocol, in this case developed by ORC under an Agroforestry Carbon Code scoping project. It involves measuring dimensions of individual trees and using standard equations to convert these measurements into biomass/carbon estimates which are scaled up to the OSB as a whole.

Table 1: Biomass carbon tiers of modelling or measurement.

Indicator	**Modelling/Measurement level**		
	Tier 1	**Tier 2**	**Tier 3**
Above and below ground carbon (AGC and BGC)	Woodland Carbon Code calculator (predictive estimate)	Allometric approach based on WCC Carbon Assessment Protocol	Allometric approach based on ORC modelling developed for agroforestry

Protocols

Tier 1

Woodland Carbon Code calculation. This protocol uses the WCC calculator to predict net carbon sequestration of, in this case, the shelterbelt, having taken into account any relevant establishment and thinning activities. Using the Standard Project Carbon Calculator (Excel WorkSheet 1) the tree data that are required comprises, for each tree species, the planting spacing and yield class (obtained from the Ecological Site Classification tool) as well as the total area (being the same for each species and calculated as the length of the OSB in metres multiplied by the width (assumed 5 m), and whether there will be any thinning for each of the species. (Note, the WCC calculator does not contain all tree species in its drop-down menu selection; the most appropriate grouping of trees relevant to each species has to be selected.) The emissions budget is calculated on the basis of input data on number of saplings (to calculate indirect emissions from the tree nursery), ground preparation, any tree protection (fencing and/or use of tree guards) and use of herbicide. The cumulative net carbon sequestration values are then presented as tCO_2e values for 5-year time steps (column CJ).

Equipment/resources: Full guidance on the Woodland Carbon Code is provided at: https://woodlandcarboncode.org.uk/. The carbon calculator described above can be found and downloaded by navigating to Carbon Tools>Carbon Prediction Tools.

Tier 2

Allometric modelling based on WCC Carbon Assessment Protocol. The FC Woodland Carbon Code: Carbon Assessment Protocol (v2.0) outlines a range of recommended procedures for undertaking a comprehensive carbon assessment of the living tree biomass, above- and below-ground, within an area of woodland. It is based on standard tree mensuration techniques. For the purposes of the OSB carbon monitoring, the plot-based approach is suggested, involving establishing plots along the OSB and taking the following basic mensuration assessments (see figure below):

- All trees are counted and classified for species and possibly characteristics such as competitive status and canopy position.
- A systematic sample of the trees in the plot are measured for diameter at breast height (dbh). (In many situations all trees in the plot will be measured.)
- A smaller systematic sample of the trees in the plot are measured for total height and other variables: total height, crown width and depth, diameter at different points on the stem.

Thereafter, computation of basic mensurational results for the OSB as a whole (numbers of trees, basal area, quadratic mean dbh, stem volume, top height and/or mean height) is undertaken, followed by estimation of tree and stand biomass (for root, stem, branch, foliage) through reference to standard allometric relationships. Tree and stand carbon is estimated from biomass by reference to standard values for carbon content (typically 0.5 – see Matthews, 1993).

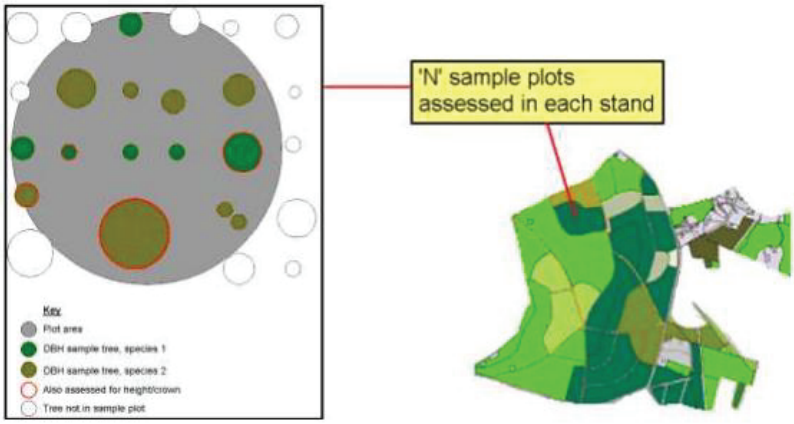

Figure 1.4 Illustration of basic principles of a plot-based survey for estimation of carbon stocks in a small forest estate. An example of assessments taken in a circular-shaped plot is shown.

For an OSB, square rather than circular plots are recommended. There should be at least three plots of 5 x 5 m at fixed intervals, spanning most of the length of the shelter belt.

Equipment/resources: Further details are available from the Assessment Protocol available from the WCC website: https://woodlandcarboncode.org.uk/. Equipment requirements include diameter measuring tape, optionally a measuring pole, and clinometer for top height measurements of tall trees.

Tier 3

Allometric modelling based on ORC Protocol. This protocol involves tree growth and allometric modelling, estimating tree biomass and carbon from individual tree to field and system level. As described below, it is a predictive modelling method (i.e. comparable to Tier 1) that relies on growth models derived from mature trees in the landscape rather than the OSB itself. As the shelterbelt matures, measurements taken of trees within the OSB itself turns this into a monitoring method.

The approach is based on documented tree growth relationships and tree allometries:

- Tree growth: the relationship between age and tree girth (measured as diameter at breast height, 1.3 m, DBH)
- Tree allometry: the relationship between DBH and above ground biomass.

Whilst tree growth rates will be specific to tree species and site characteristics, we propose that for tree allometry a generic regression equation is robust enough to work across a range of species. That of Bunce (1968) is proposed (Eq 1) although other candidate equations are being explored. Bunce's equation derives from the sampling of five deciduous broadleaved tree species in Cumbria and – like some other equations - uses tree girth rather than height, considered to be a more stable character, especially in an agroforestry context. The Bunce equation has been compared with other equations with little difference in the predictions obtained; it is considered robust across a wide range of species (see e.g. Robertson et al. (2012)).

Eq 1: Allometric equation of Bunce (1968).

Regression equation	**Definitions**
Bunce (1968), mixed deciduous trees $\log_e y = a + b\,(\log_e x)$	y = tree dry weight, kg, (trunk + branches), x = tree girth at 1.3 m. a = -5.445, b = 2.507

The steps in the approach involve:

1. Generating a tree growth model for the same or similar species (see description below) used in the OSB.
2. Applying the Bunce (1968) regression to estimate, from the tree growth models, AGB accumulation over the project period on a tree-by-tree basis
3. Estimating root biomass from published above/below ground allometric assumptions. Here we propose using the mean root to shoot ratio for temperate broadleaf forest/plantation (0.326, CI ± 0.070907, n = 7, (IPCC, 2000)).
4. Converting tree dry mass to carbon and CO2e estimates using the carbon content ratio of 0.5, as applied in the Woodland Carbon Code calculator. This compares with the conversion standard of 0.48 recognised by the IPCC for broad-leaved trees growing in temperate climates (Aalde et al., 2006).
5. Calculating OSB-level totals for the project period as the average stored C and CO2e values over the project period, taking into account any thinning and harvesting management operations.

<u>Generating a tree growth model</u>

Models of tree growth for woodland and urban environments are well advanced but scant for trees outside woodlands in the UK. To be able to account for different growing conditions (edaphic, climatic) around the UK, we are therefore proposing a scheme relying initially on making new project-specific tree measurements. This approach has the dual purpose of creating a tree growth model specific to the environmental conditions of the project concerned whilst, over time, contributing to the development of a database of measurements that – with sufficient coverage of species and geography – will avoid the need for further mensuration in the case of future projects. The following two steps are involved:

1. The farmer is encouraged to gather tree diameter measurements from target trees of known approximate age within the vicinity of the OSB project. The location should be as near as possible to the project site (say, within 5 km and ideally 1.5 km) such that the environmental conditions (climate and soil conditions) are as similar as possible to the OSB site. Distances of measured trees to the project site will be recorded as one indicator of model confidence.

The current MS Excel spreadsheet implementation allows applicants to enter (for each tree species they will plant) diameter at breast height (dbh, 1.3 m) for a target number of 10 trees per age category for a range of different ages. At least three ages/development stages will be needed, with a minimum of three years and including trees at maturity. While very old trees may be of minimal relevance to carbon crediting of new plantations, we will allow applicants to enter details of trees of up to 150 years age as this allows quantification of carbon accumulation asymptote in the model described below.

2. The tree measurements are used to parameterise a simple tree growth model. Much research work has been done to quantify DBH-age relationships in urban trees and we use this work as a model for agroforestry systems as trees tend to occur in lower densities than forests in both systems. We use the formula dbh=B0 (1-e(B1)(Age))B2 to describe the dbh-age relationship here. This model has been successfully fitted to numerous urban tree species from 0 to around 40 years across multiple US cities (McPherson and Simpson, 1999), however initial experimentation with the formula suggests it has stable behavior beyond this range, tends to asymptote, and likely represents dbh-age relationships beyond this range. The model additionally is mildly sinusoidal, describing the accelerating tendency of carbon accumulation during early-year growth. Many additional models have been suggested in the urban tree literature (see refs in (Peper et al., 2014)) but most are complex (typically high order polynomials) and have unpredictable behaviour beyond the data range. Parameters B0 B1 and B2 in the formal are optimised in our spreadsheet implementation to available data using machine learning implementation in the Excel Solver add-on which is initiated using a button that starts a recorded macro.

Equipment/resources: Tape measure, Data entry sheet with detailed instructions for tree measurements, Excel calculator tool. The data entry sheet and calculator are available from agroforestry@organicresearchcentre.com.